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DELAYED BEHAVIOUR OF CONCRETE: INFLUENCE OF ADDITIONS AND AGGREGATE CHARACTERISTICS IN RELATION TO MOISTURE VARIATIONS

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ABSTRACT

The delayed behaviour of concrete depends essentially on the nature of its two phases: paste and aggregates. The presence or absence of mineral additions as well as the nature of aggregates play an important part in the modification of concrete properties.

This paper studies therefore, the effect of phases on the shrinkage and creep strains of concrete in relation to moisture variations. For the study of the role of cement paste the measurements of the delayed deformations were carried out on mortars with or without additions. As for the aggregates, their role was studied through moisture distribution in two-phase models using gammametry, a method based upon absorption of gamma radiation.

The most important conclusion drawn from this study is that the delayed behaviour of concrete depends not only on the physico-chemical evolution of cement paste but also on the microstructural characteristics of aggregates.

Introduction

Portland cement concrete is a composite material and thus heterogeneous. The properties of aggregates in spite of their very small variation with time, take part, along with the physico-chemical evolution of the cement paste in the modification of concrete behaviour.

In fact, on the one hand, the presence or absence of mineral additions in the cement paste modifies the moisture variations which control the shrinkage and creep strains. On the other hand, some aggregates, due to their mineral character as well as their more or less developed porous structure, act as a source of water for the surrounding cement paste. This exchange of moisture between the cement paste and aggregates is the reason behind the moisture variations and consequently large dimensional changes.

In order to improve our understanding of this phenomenon, the influence of cement paste has first been analysed by measuring creep and shrinkage strains in mortar samples composed of binders. The first contains only cement and the others 80% cement and 20% siliceous or

TABLE 1
Mortar Compositions

Composition	cement (kg/m^3)	additions (kg/m^3)	A/(C + A)	S/(C + A)	W/(C + A)	f_{c28} (MPa)	E_{28} (GPa)
MCPA	450	0	0	3	0,53	49,5	44
MAC	360	90	0,2	3	0,53	35	36
MASi	360	90	0,2	3	0,53	42	39

calcareous additions. Secondly, the influence of aggregates has been studied by quantifying the moisture variations in two-phase specimens during drying and with sustained loading, with the help of gammametry.

Materials and Experimental Methods

Materials. Table 1 gives the composition of three mortars used for the study of the effect of paste on the delayed behaviour. The ratio: water/(cement + additions), W/(C + A), is the same for all the mortar compositions because the aim of this study is principally to observe the variation in the water content.

Table 2 gives the measurement of the fresh mortar characteristics: workability, density, air content.

With:
- C: cement
- A: additions
- S: sand
- W: water
- MCPA: mortar with 450 kg/m^3 of cement
- MAC: mortar with 360 kg/m^3 of cement and 90 kg/m^3 of calcareous additions
- MASi: mortar with 360 kg/m^3 of cement and 90 kg/m^3 of siliceous additions

For the measurement of shrinkage and creep strains, the prismatic specimens (4 × 4 × 16 cm) are kept in a room at 20°C either with a 50% relative humidity or in conditions of self-desiccation with no moisture exchange with the environment.

In order to analyse the effect of the nature of aggregates on creep and shrinkage strains, two-phase specimens have been made. These are cubic and made up of prismatic aggregates

TABLE 2
Characteristics of Fresh Mortar

Composition	workability (s)	density	air content (%)
MCPA	7 ± 1	2,240	4,2
MAC	6 ± 1	2,210	3,9
MASi	6 ± 1	2,194	3,7

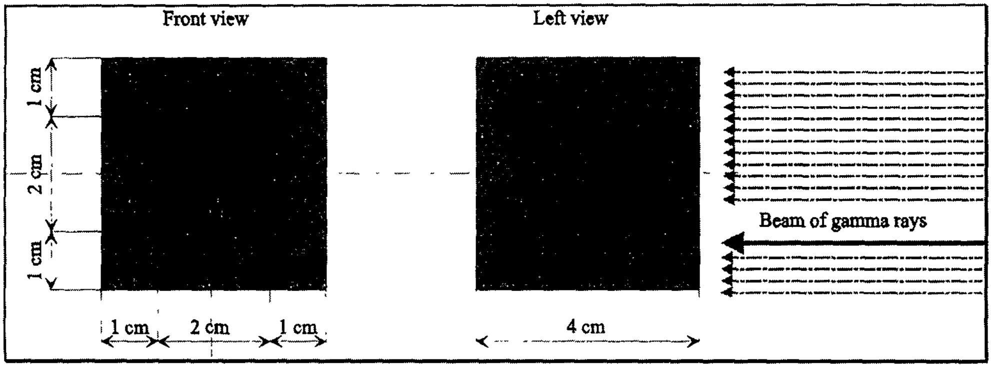

FIG. 1.
Cubic specimens used for gammametry.

2 × 2 × 4 cm surrounded by pure cement paste (W/C = 0.38) (Fig. 1). The optimal specimen stiffness, 4 cm, is inferred from (1) study. Two types of aggregates are tested: calcareous and siliceous aggregates. Their characteristics are given in Table 3.

The results presented here are uniquely for the specimens kept in desiccation at 20°C and 50% RH.

Experimental Methods. In the study of the effect of paste on the delayed behaviour for each mix composition three specimens without loading were tested for the dimensional variation measurement and three more in loaded conditions for the measurement of creep strain. This procedure was carried out for each mode of curing. The loading, carried out at 3 days, represented 40% of the crushing strength measured at the same age (3).

On the two lateral parallel sides of each specimen, where the top and bottom had already been rectified, two induction gauges were fixed which measured the average strain under sustained loading. The base length for these measurements was 10 cm.

A measurement device received the information from the gauges and displayed the displacements of the rod in hundredths of a millimetre.

Shrinkage specimens subjected to desiccation were weighed to quantify the influence of the moisture movement on deformations.

In the study of the effect of aggregate on delayed behaviour, the spatial distribution of water content and its evolution with time was determined experimentally by the method of gamma radiation absorption.

The gammametry, also called gammadensimetry measured the local evolution of moisture

TABLE 3
Aggregate Characteristics (1)

Aggregate	calcareous	siliceous
Crushing strength (MPa)	177 ± 11%	373 ± 5%
modulus of elasticity (MPa)	43700 ± 10%	102000 ± 5%
Density	2.78 ± 0.01	2.94 ± 0.01

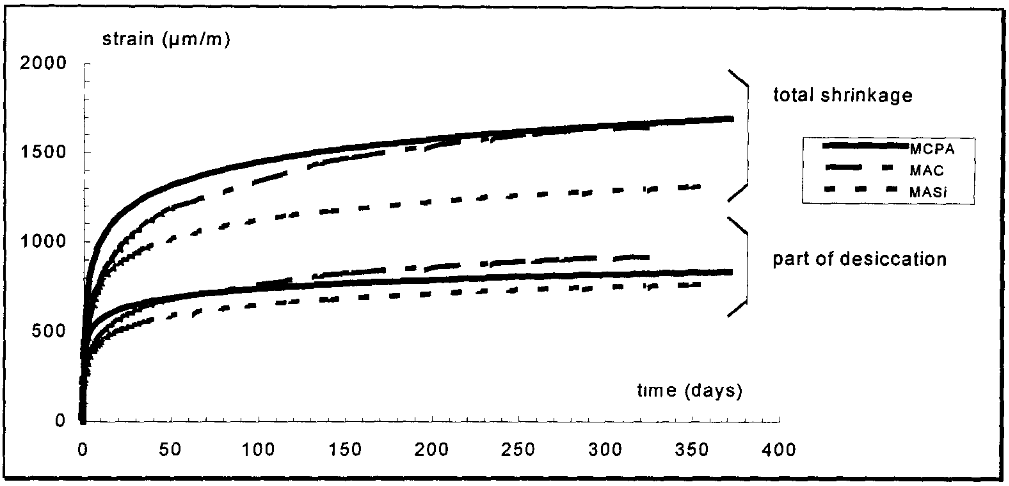

FIG. 2.
Comparison of total shrinkage strains.

content related to the variation of mass density of the material which induced a variation in the attenuation of the gamma beam (4). The method is regular and non-destructive.

The gamma ray beam passed through the material at various points in a direction perpendicular to its axes. The measurement device gave the number of interactions, N, corresponding to the number of gamma photons having crossed the specimen. This was itself inversely proportional to the density of the material which was a function of the solid phase and the quantity of the water present in the pores. So, for a constant solid matrix, an increase in N corresponds to a decrease in the quantity of water present in the material.

Moisture content variations of the two-phase specimens have been studied throughout the duration of the drying period and for those under sustained loading starting from the age of 1 day.

The gammametric measurements on the specimens intended to be loaded were taken just before loading and then immediately after the first loading. Afterwards, during sustained loading, the specimens were unloaded at predefined periods (3, 7, 14, 28, 90 and 180 days) before measurements.

Results and Discussion

Influence of Paste. The evolution of total shrinkage strain is presented in Figure 2. A reduction of around 23% is brought about by the presence of siliceous additions compared to that in the mortars without additions, while the calcareous additions only reduce those strains by 4%. A possible interpretation of this result is that the mortars with siliceous additions contain larger pores than those in mortars with only cement or with calcareous additions. Consequently, the capillary tension is weaker and hence the shrinkage strains are reduced. This reduction may be due to the difference in superficial crack density (5).

Escadeillas (6) found that the deformations of mortars with calcareous fillers were slightly

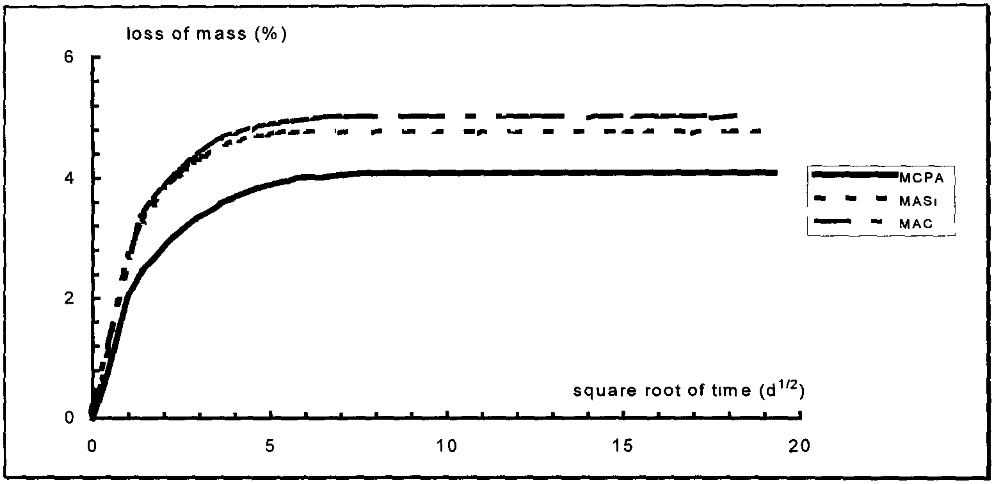

FIG. 3.
Comparison of loss of mass.

lower than those of mortars without fillers. Our results on additions compared to their fillers are not contradictory because in their case the filler content was much higher (20 to 30%).

The same figure shows the evolutions of drying shrinkage, being the difference between the total and basic shrinkage, carried out on mortar specimens without exchange of moisture with the environment.

The result of the sensitivity of drying shrinkage to the additions signifies their insignificant influence on the deformations of mortars with additions. The difference between the deformations remains small and is of the order of 20%.

Apparently, this difference in behaviour between mortars with calcareous and siliceous additions lies in the basic shrinkage. In fact, it can be supposed, as in the case of the fillers (7), that calcareous additions possess a strong water retention power. This water contributes to the formation of a greater amount of hydration products. As the hydration progresses, pore sizes become smaller and smaller and capillary tension becomes more and more significant, thus producing in the mortar in which they are incorporated, a greater amount of basic shrinkage compared to mortars with siliceous additions.

The specimens are weighed regularly in order to evaluate the influence of the presence of additions on mass variations during the hardening period. Figure 3 shows the average of the evolution of the quantity of water evaporated as a function of the square root of time for different mortar specimens kept in desiccation.

The loss of water varies with the use of additions. It is increased by 15% for the MASi and 20% for the MAC. These mortars, being less rich in cement, give rise to larger evaporations. The study of Escadeillas (6) also showed that mortars with fillers presented a larger water loss than those without fillers.

The creep strains are represented by the difference between the total strains under sustained loading and those of shrinkage. Total deformations measured in the specimens kept in desiccation are shown in Figure 4. Deformations of the mortars without additions and with calcareous additions are practically the same and less than those with siliceous additions.

Figure 5 gives details of the total creep and of that stemming from desiccation (drying

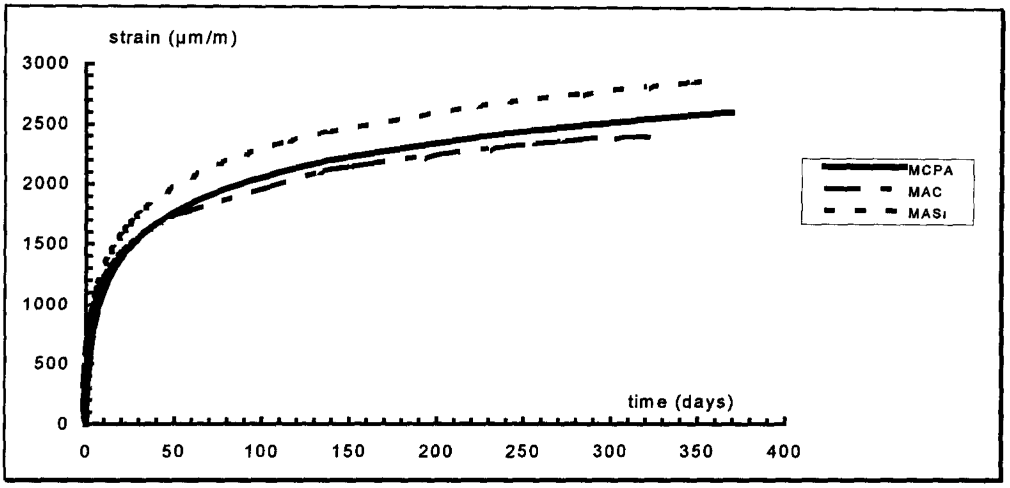

FIG. 4.
Comparison of total strains.

creep) which is calculated as the difference between total creep and basic creep. The total creep represents the difference between the total deformations during the sustained loading and the total shrinkage in the specimens kept in desiccation. Basic creep is the difference between total deformation and shrinkage measured in the specimen in self-desiccation.

As explained above, shrinkage strains may decrease soon after the appearance of superficial cracks (5) particularly in mortar with siliceous additions. On the surface however the superposition of a sustained loading on the tensile stresses of desiccation can prevent cracking and induce an increase in drying creep.

Creep deviation for the mortars incorporating the additions from the control mortar

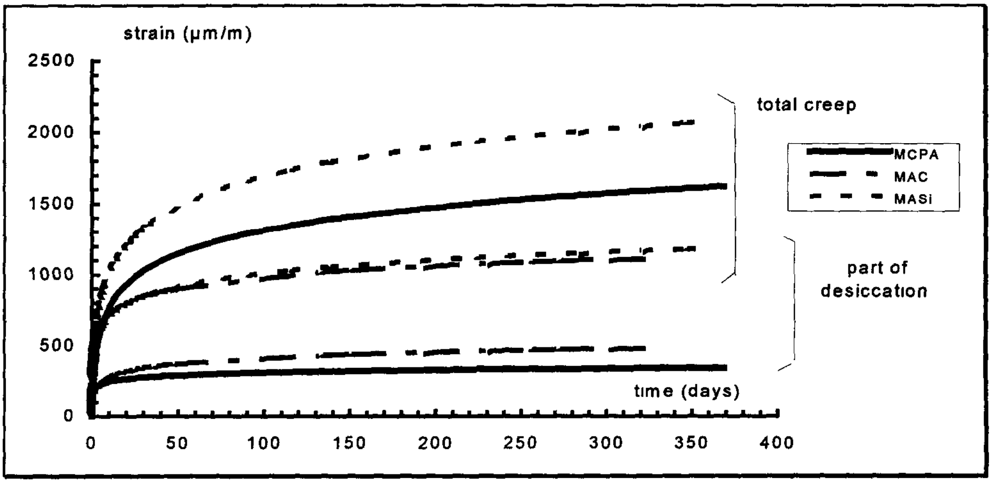

FIG. 5.
Comparison of creep strains.

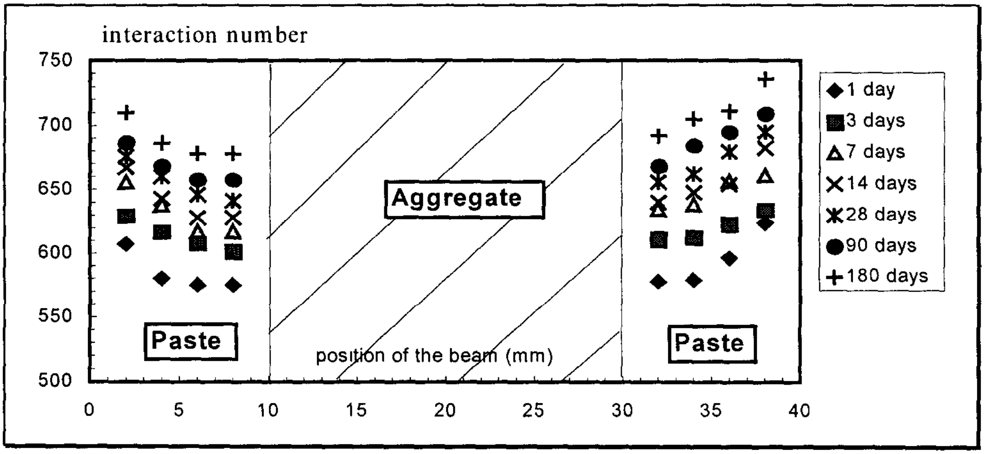

FIG. 6.
Distribution of attenuations measured on unloaded two-phase specimen with a siliceous aggregate.

specimens can be explained by the fact that they have a smaller elastic modulus (Table 1) and thus are more compliant. Moreover, the increase in evaporation in loading conditions is more pronounced in mortars using additions (especially for the mortars with siliceous additions), without doubt due to the fact that their porous structure is much more developed (8).

Influence of Aggregates. Figure 6 and 7 show the crude profiles of the number of interactions per minute 'N'. These curves show the evolution of the drying phenomenon in space and time. In fact, for a given point, N increases with time and as the extremities of the specimen are approached.

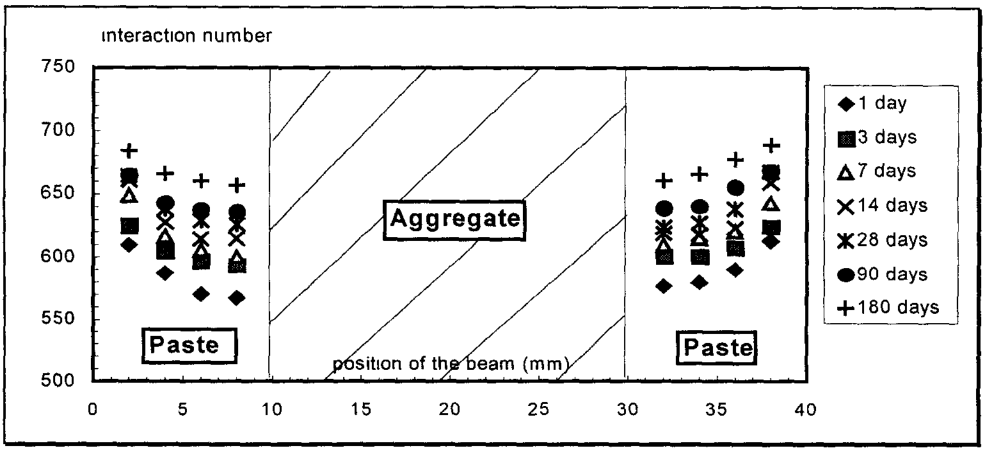

FIG. 7.
Distribution of attenuations measured on unloaded two-phase specimen with a calcareous aggregate.

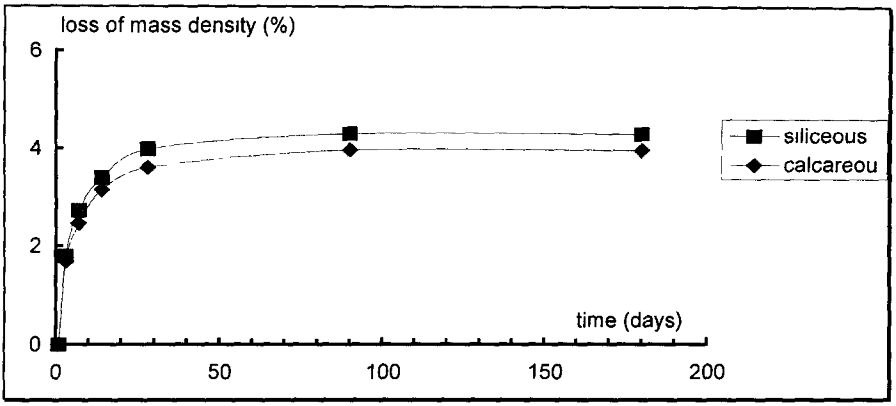

FIG. 8.
Comparison of loss of mass density calculated by gammametry of two-phase specimens with calcareous and siliceous aggregates.

Comparison of Figures 6 and 7 shows the influence of the nature of aggregate. In the case of the siliceous aggregate, N is slightly higher than in the case of calcareous one. This explains a smaller density which can be due to a more intense drying.

Figure 8 shows the evolution of the decrease of mass density deduced from the gammametric measurements. Figure 9 shows the evolution of mass loss determined by weighing. The two sets of results correlate well.

The difference in the density of the paste surrounding the two types of aggregate is, according to us, due to the difference in microstructure of the paste caused by the aggregates. As a matter of fact, as the paste is in contact with a porous aggregate such as calcareous aggregate, a fraction of water contained in the paste is absorbed. This creates the capillary forces in the paste. As the hydration process continues, the capillary pore sizes become smaller and they take back water from the aggregate. The calcareous aggregate, in this way,

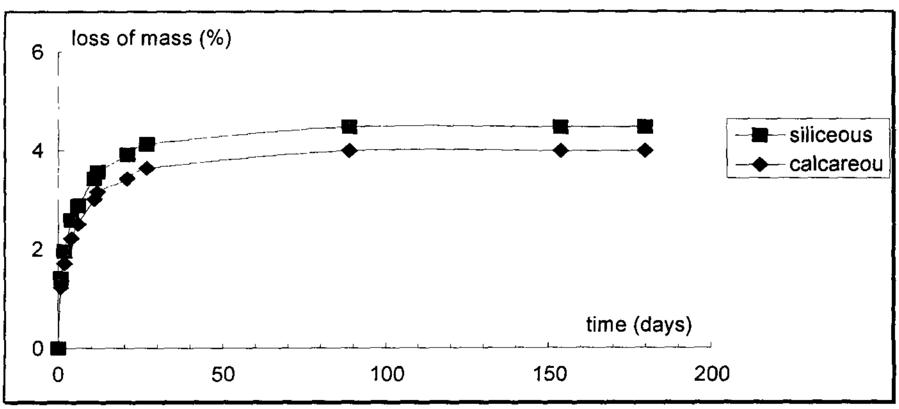

FIG. 9.
Comparison of loss of mass measured by weighing of two-phase specimens with calcareous and siliceous aggregates.

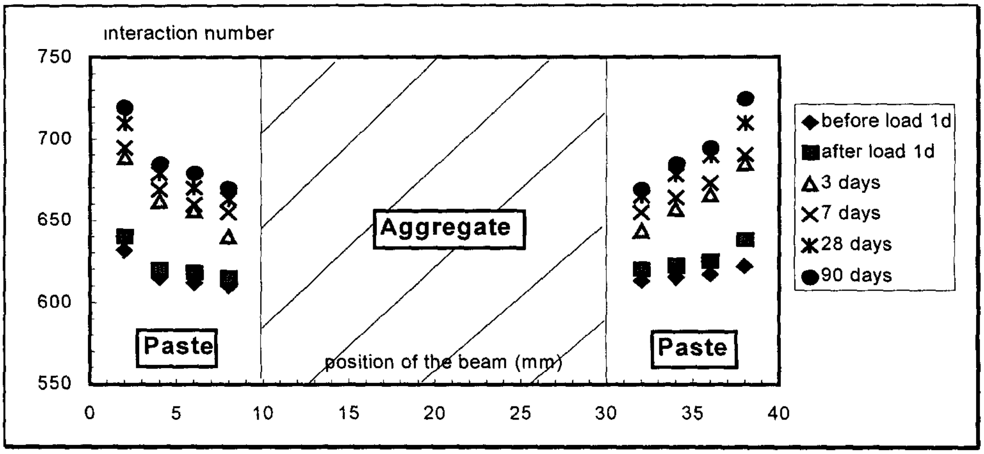

FIG. 10.
Distribution of attenuations measured on loaded two-phase specimen.

plays the role of a water source decreasing the intensity of attenuations of gamma rays measured in the paste around the aggregate. The process of water evaporation is slowed down with respect to the paste in contact with a dense aggregate such as siliceous aggregate.

Compared to the siliceous aggregate, limestone is more porous and was investigated by measuring total porosity. This was 2% for siliceous aggregate and 5.3% for calcareous aggregate.

The study of the effect of loading on the hydric behaviour was carried out only for one type of two-phase specimen, the one containing the calcareous aggregate. The profiles of the number of interactions N are noticeably similar to those presented before (Fig. 10).

The evolution of variations of mass density are the same for the two loaded and unloaded specimens (Fig. 11) and no effect of loading appears on the variations. Creep can thus be said not to be directly related to additional water movements.

Conclusion

This study confirms the effect of the nature of mortar constituents on the delayed behaviour of concrete and concludes as follows:

- Mortars where cement is partially replaced by additions, show less shrinkage deformations than those in control mortars. Calcareous additions have very much smaller influence (−4%) compared to the siliceous additions (−23%).
- Under sustained loading, the total delayed deformations which the mortars in desiccation undergo, vary due to the presence of additions. They are increased for the mortar with siliceous additions while those of mortars without additions and with calcareous additions are practically the same. This establishes the usefulness of calcareous additions in reducing deformations.
- The nature of aggregates plays an important role in modifying the properties of paste in contact with them. In fact, due to the greater porosity of calcareous compared to the

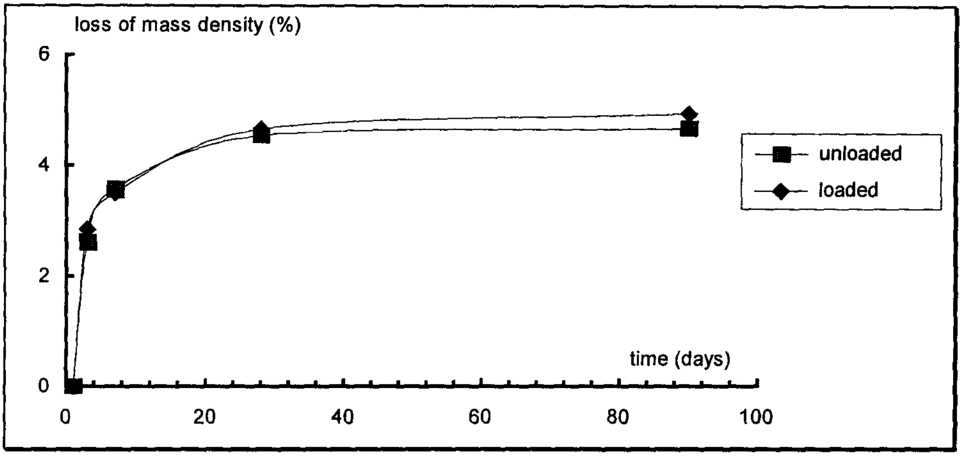

FIG. 11.
Comparison of loss of mass density of two-phase unloaded and loaded specimens, calculated by gammametry.

siliceous aggregates, the former play the role of a water reservoir. They absorb water from the paste which is returned to the paste as the hydration process progresses. This exchange of water between the paste and aggregates brings about the hydric variations which cause dimensional changes in the paste. Loading has no effect on the variations of hydric distributions and it seems difficult, therefore, to link creep phenomenon to water movements.

- Measurements taken locally by gammametry correspond closely to overall results obtained by weighing.

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