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ASSESSMENT OF THE "RHEOPLASTICITY" OF CONCRETES

Mario Collepardi
Department of Science Materials
University of Ancona
Ancona, Italy

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ABSTRACT

In the present paper it is proposed to evaluate the rheological behaviour and the plasticity of fresh concrete by means of the determination of a so-called "rheoplasticity" index defined as $RPI = 1/\int BdS$ or $RPI' = 1/B'$, where B is the bleeding capacity, S is the slump, and B' is the bleeding capacity of very flowable concrete (S = 20 cm). Since concretes with high value of RPI or RPI' can be obtained only with relatively low water/cement ratio and by using certain highly fluidifying additives, the properties of these hardened concrete are in general very good.

Nel presente lavoro si propone di valutare il comportamento reologico e la plasticità del calcestruzzo fresco determinando il cosiddetto indice di "reoplasticità" definito come $RPI = 1/\int BdS$ o $RPI' = 1/B'$, dove B è la capacità di bleeding, S è lo slump, e B' è la capacità di bleeding del calcestruzzo quando è molto fluido (S = 20 cm). Poichè i calcestruzzi con un alto valore di RPI o di RPI' possono essere ottenuti solo con rapporti acqua/cemento relativamente bassi e mediante l'impiego di certi additivi fluidificanti, anche le proprietà allo stato indurito di questi calcestruzzi sono in generale molto buone.

Introduction

It is well known that a reduction in the water/cement (w/c) ratio causes an improvement in all the properties of the hardened concrete. In fact, a decrease of the w/c ratio will lead to higher strength, reduced capillary porosity, increased impermeability, higher resistance to chemical attack and to cycles of freezing and thawing and finally, to reduced shrinkage. Unfortunately, reducing the water/cement ratio also reduces the workability of the fresh concrete to a point where under certain values of w/c ratio, it is no longer possible in practice to place the concrete and obtain all the good qualities mentioned above. This fact has prevented the full utilization of the potential which characterises concrete as a material, and has, as a consequence, forever stimulated the search for new fluidifying additives, and for new systems of compaction.

Recently, specially in Europe and Japan, new additives with high fluidifying powers have appeared on the market, which should lead to an exceptional improvement in the characteristics of concrete precisely because their use now makes it possible to obtain a very flowable concrete (slumps 15-25 cm) with low w/c ratios, of the order of 0.40-0.45.

It must not be forgotten, however, that to evaluate the workability of a concrete, not only should flowability be taken into account but also plasticity and resistance to segregation of aggregates.

Usually, in the evaluation of workability, this second aspect is neglected, perhaps because of the difficulty of measuring quantitatively the tendency towards segregation. A rapid and simple evaluation of this latter characteristic can be effected by measuring the amount of bleeding, provided that care is taken to prevent both evaporation and the absorption and/or loss of water due to the form-work and unsaturated aggregates(1).The combination of a measurement of the rheological properties, for example slump measurement using Abram's cone, with a measurement of the bleeding, could form the basis of a more valid indication of the characteristics of the fresh concrete. This becomes more important than it was in the past, due to the introduction of the new additives mentioned above, some of which exhibit considerable segregation of aggregates and bleeding phenomena together with their high fluidifying properties.

The scope of the present article is to propose a method for the simple and rapid assessment of the rheological properties of flowability and plasticity of concrete by means of the definition and determination of a "rheoplasticity" index. A high "rheoplasticity" index (RPI) indicates the concrete, apart from being fluid and easily placed, is also plastic, cohesive, resistant to segregation, and presents relatively low bleeding. Such a concrete will be more homogeneous and the project engineer may rely on a high quality material not only because of the higher strength due to the lower w/c ratio, but also because the quality remains more constant in different parts of the structure. Furthermore, in a concrete with little or no bleeding there is no accumulation of water under aggregates and reinforcing bars so that the adhesion between the cement paste and the other elements of the mix becomes stronger.

Calculation of the "Rheoplasticity" Index

The method consists of preparing a series of concretes which differ one from the other only in terms of their w/c ratio values. All other parameters regarding the composition of the concrete (types of cement, aggregates and additive, aggregates/cement ratio and percentage of additive) remain constant. When the test batches have been properly mixed, a series of measurement of slump and bleeding are made on the concretes.

The values of bleeding are plotted on a graph as functions of the slump readings, as is schematically illustrated in Fig. 1.

The points of the curve represent concretes with w/c ratio values increasing as slump increases.

The "rheoplasticity" index (RPI) can be defined as:

$$RPI = 1/\int_{S=2}^{S=22} B\,dS \qquad [1]$$

where B is the bleeding, S is the slump, and the limits of the integral 2 and 22 cm, correspond to the values of slump measured by the Abram's cone, under and over which the readings are not repetitive, and lose their significance.

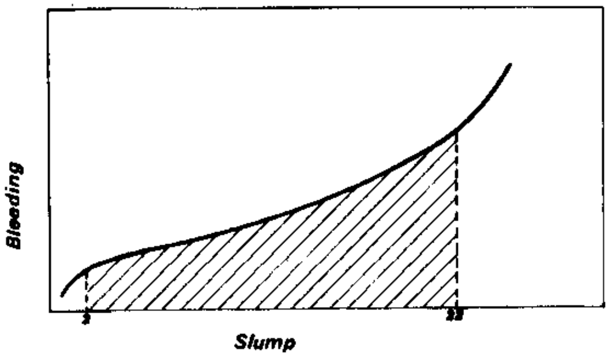

FIG. 1
Bleeding in function of slump.

In fact, slump measurements under 2 cm can hardly be considered repetitive, while values of slump over 20-25 cm cannot in practice be obtained if it is considered that, even with the most flowable concrete, on lifting the cone there always remains a "pancake" of a certain thickness.

The value of the integral which appears in equation [1] can easily be calculated by measuring the area between the curve of Fig. 1 and the abscissa, being, obviously, smaller the higher becomes the flowability and the lower become the segregation of aggregates and bleeding of the fresh concrete.

Experimental

All the procedures for the preparation of the concretes and the measuring of the slump and the bleeding, were carried out in a climatised room thermostatically controlled at 20°C± with relative humidity at 65%. The materials used (Portland cement, aggregates, water and additive) were maintained for at least three days under the same hydrothermic condition, before being used.

By using a pan mixer with vertical axis, three types of concrete mix were prepared each having a nominal cement content of 300, 350, and 400 Kg/m^3. The w/c ratio of each mix was made to vary so that the slump, measured immediately after a 2 min mixing of the batch, would vary from 2 cm to 25 cm, approximately.

A Portland cement type I ASTM, a sand having a maximum diameter of 5 mm and a fineness modulus of approximately 2, and a gravel having a maximum diameter of 15 mm, were used. The sand/gravel weight ratio was 2/3.

The tests were carried out with and without additives which were chosen from those available commercially; additive No. 1 is a fluidifier of traditional type based on hydroxycarboxilic acids, additives No. 2 and 3 superfluidifiers based on synthetic polymers. The additive dosages in relation to the weight of cement were 0.2%, 3% and 3% respectively for additives No. 1, 2 and 3. The slump measurement was taken immediately after the batch was discharged from the mixer.

The bleeding was measured according to the method described to the UNI Italian Standards (2), that is by means of a pipette, drawing off the resultant bleed water at intervals of 10 min. during the period of the first 60 min. and successively at intervals of 30 min. for the period of time remaining until the initial set commences, when no further bleed water is produced. The test cylinder (25 cm diameter, height 27 cm) was kept sealed between one reading and the other to prevent the evaporation of water.

The ratio of volume (in cm^3) of the exuded water to the section (in cm^2) of

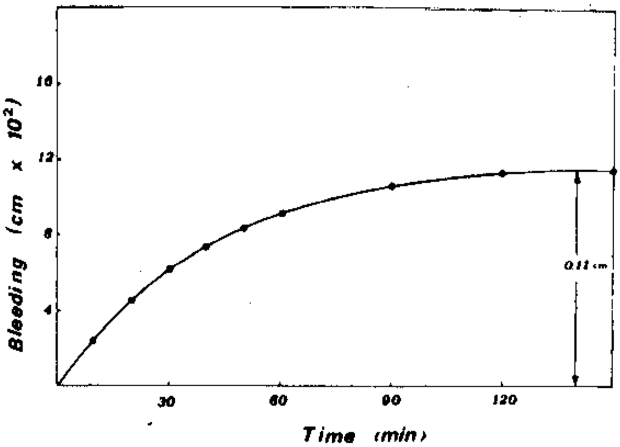

FIG. 2
Bleeding in function of time.

the test cylinder was then plotted as a function of the time, as is schematically represented in Fig. 2. The velocity of bleeding, in cm/sec, is constant for a period of time which depends on the characteristics of the concrete, and then diminishes to zero at the moment when the cement commences its set (1). At this point, the total volume of exuded water per unit of surface area, referred to concrete thickness (25 cm) inside the test cylinder, indicates the so-called bleeding capacity (1). The latter was plotted as a function of the slump in graphs similar to Fig. 1, for the calculation of the "rheoplasticity" index. By taking into account that the bleeding capacity is an adimensional property and the slump is measured in cm (or inch), the integral of equation (1) is measured in cm (or inch) and RPI in cm^{-1} (or $inch^{-1}$).

Some of these concrete were cured at 20°C with relative humidity at 65% and then the compressive strength at 28 days was measured.

Results and Discussion

Fig. 3 shows the bleeding capacity (B) in function of slump (S), for concretes without additive. The values of area corresponding to the integral in equation [1], and those of the RPI, are shown in Table 1. It can be observed that an increase in the cement content reduces the value of the integral and increases, therefore, the value of the RPI.

Fig. 4 shows the behaviour of two concretes with the same cement content of 350 Kg/m^3, one of which has been treated with the traditional type of fluidifying additive No. 1 (Fig. 4a) and the other with the superfluidifying additive No. 2 (Fig. 4b).

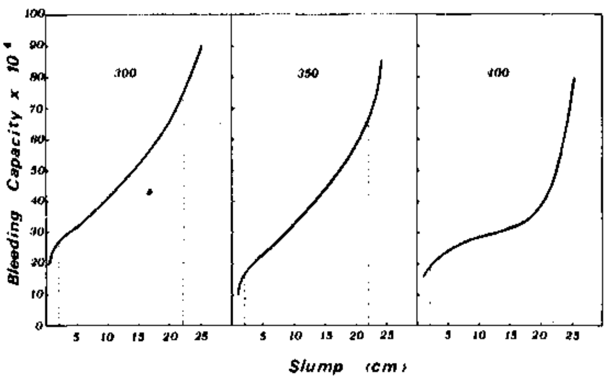

FIG. 3
Bleeding capacity versus slump for plain concretes with a cement content of 300, 350 and 400 Kg/m^3.

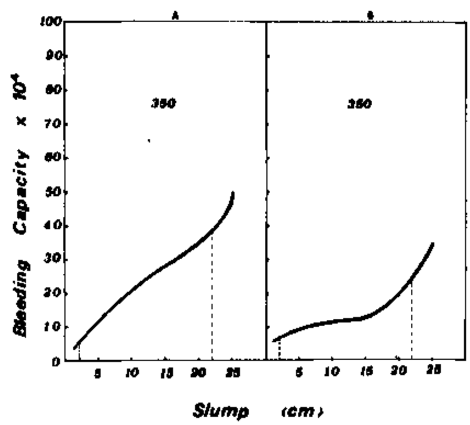

FIG. 4
Bleeding capacity versus slump for concretes containing the admixture No. 1 (A) and No. 2 (B), cement content = 350 Kg/m^3.

Table 1

Effect of Some Additives on the Rheoplasticity of the Concrete

Cement Content (Kg/m^3)	Additive No.	$\int BdS$ (cm)	RPI (cm^{-1})	E
300	-	0.094	10.64	1.00
350	-	0.076	13.16	1.00
400	-	0.060	16.67	1.00
350	1	0.046	21.74	1.65
350	2	0.027	37.04	2.81
300	3	0.023	43.47	4.09
350	3	0.016	62.51	4.75
400	3	0.000	∞	∞

For the same cement content, the RPI of the concrete containing the first additive (21.74 cm^{-1}) is slightly higher than that of the concrete without additive (RPI = 13.16 cm^{-1}). A greater increase in the RPI is obtained by using the second additive (RPI = 37.04 cm^{-1}).

The last column of Table 1 indicates the ratio of the PRI of a concrete containing additive to that of the same concrete without additive. The ratio, which could be defined as the "rheoplastic" effect (E), is a measure of the efficiency of an additive to increase the flowability of a concrete without, at the same time, causing excessive segregation. The values of E are 1.65 and 2.81 for additives No. 1 and 2 respectively. From this point of view, additive No. 3 is decidedly better than the previous ones. Fig. 5 shows the bleeding capacity in function of the slump, for three concrete mixes each containing additive No. 3. It can be seen that the area corresponding to the integral decreases with an increase in the cement content, and it becomes zero in the richer mix (400 Kg/m^3). This indicates that the RPI of this concrete is practically infinite. This means that there is no segregation although the slump is very high (for example 22 cm) and the concrete is self-levelling. The value of the "rheoplastic" effect for additive No. 2 is 4.09, 4.75 and infinite for concretes with cement contents of 300,350 and 400 Kg/m^3 respectively. The RPI values for these concrete are 43.51, 62.51 and infinite respectively.

From a practical point of view it is more interesting to examine the behaviour of very flowable concretes when the slump is, for example, higher than 18 cm (or about 7 inches), which is the maximum value suggested for normal flowable concretes (3,4). By comparing the curves of Fig. 3 with that of Fig. 5, one can deduce that the differences in the RPI values are substantially due to the differences in the bleeding capacity of very flowable concretes and only to a lower extent to that of stiff concretes. In other words the "rheoplasticity" index (RPI')

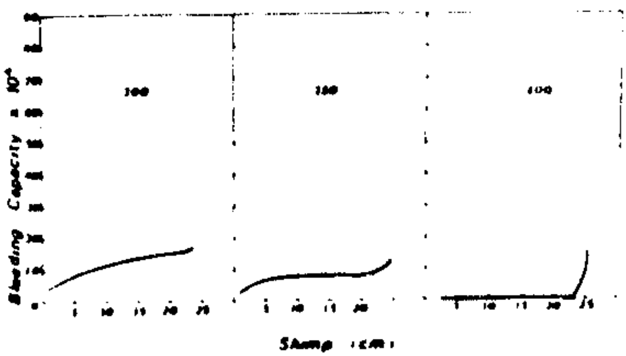

FIG. 5

Bleeding capacity versus slump for concretes containing the admixture No. 3 and with a cement content of 300, 350 and 400 Kg/m^3.

of a concrete could be more rapidly and easily evaluated only by determining the reciprocal of the bleeding capacity of a very flowable concrete having a certain value of slump, for example, 20 cm. One could tentatively define as "rheoplastic" a concrete when the slump is, for example, higher than 20 cm (or 8 inches) and the bleeding capacity is, for example, lower than 2.10^{-3}. This would mean that the RPI' of a "rheoplastic" concrete is at least 500. Since these results can be obtained only if the water/cement is relatively low, all the properties of a "rheoplastic" concrete are very good not only in the fresh state, but also in the hardened one.

Table 2 shows the values of the "rheoplasticity" index expressed as RPI' = 1/B', where B' is the bleeding capacity of a very flowable concrete with a slump of 20 cm. In the same Table the w/c ratio and the 28 days compressive strength are shown. The results indicate that high values of RPI' correspond to good properties of the hardened concrete, as it is demonstrated by the low w/c ratio and high compressive strength. Other properties concerning shrinkage, porosity, durability, etc., are also improved in "rheoplastic" concrete, that is when RPI is higher than 40 cm^{-1} or RPI' is higher than 500.

Table 2

"Rheoplasticity" Index RPI' of Very Flowable Concretes (Slump = 20 ± 1 cm) with and without Fluidifying Additives.

Cement Content (Kg/m^3)	Additive No.	RPI' (1/B')	w/c	Compressive Strength (Kg/cm^2)
300	-	150	0.70	245
400	-	260	0.61	365
350	-	170	0.65	310
350	1	290	0.58	340
350	2	500	0.51	410
350	3	1250	0.45	455
300	3	600	0.48	390
400	3	∞	0.40	520

Conclusion

An increase in the flowability of concrete, obtained by using additives with high fluidifying power, is generally accompanied by an increase in the segregation of the aggregates and an increase of bleeding. As is well known, this can cause serious inconveniences such as heterogeneity of the structure, reduction of the bond of the cement paste to the aggregates or reinforcing steel, and an overall decline of the properties of the hardened concrete.

In the present paper it is proposed to estimate the rheological behaviour and the plasticity of fresh concrete by means of the determination of a so-called "rheoplasticity" index, defined as:

$$RPI = 1/\int_{S=2}^{S=22} B dS \text{ or } RPI' = 1/B'$$

where B is the bleeding capacity and S is the slump, and where B' is the bleeding capacity of a very flowable concrete (S = 20 cm). High values of RPI correspond to very flowable and, at the same time, non-segregating concretes.

The "rheoplasticity" of a concrete depends not only on the content of cement, the type and the amount of additive, as is shown in this work, but also on the type of aggregates, the mixing system and obviously the room temperature. However "rheoplastic" concretes, for example with RPI higher than 40 cm^{-1} or RPI' higher than 500 can be obtained only by using particular additives. Since in practice, these values of RPI or RPI' can be obtained only with w/c ratio relatively low, also other properties concerning the hardened "rheoplastic" concrete such as strength, shrinkage, durability, etc., are in general very good.

It is proposed, furthermore, to define the "rheoplastic" effect of an additive as the ratio between the RPI of the concrete containing the additive and that of the same concrete without additive.

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