Water requirement of cement, W_{180} – A practical test method

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ABSTRACT

Water requirement of cement is a very important factor affecting the quality of concrete. In spite of its importance the water requirement of cement is difficult to measure, only few test methods are available. In the present paper, a practical test method is presented. The water requirement can be measured simply and reliably. With the method also the effects of the admixtures and additives on the water requirement can be analysed.

Key words: water requirement, cement, consistency, workability, quality.

1. INTRODUCTION

In cement production, the quality of cement is mainly controlled with help of compressive strength development of cement. The quality variation of cement clinker is normally compensated by grinding the clinker in different fineness or using different amounts of mineral additives in cement. However, this easily leads to variation in water requirement of cement. And in concrete production, the water requirement of cement is a very important factor, often even more important than the compressive strength. Variation in the water requirement causes variation on the final quality of concrete in several ways; mechanical properties, durability properties and surface quality of concrete can be affected by the water requirement.

In spite of its importance for concrete production the water requirement of cement is not very well known. In cement factory, the water requirement is normally checked in the setting time test (Vicat), but the method (Standard consistency) /1/ is rather insensitive. The Standard consistency test is primarily made to adjust the consistency of cement paste suitable for the setting test, not to analyse the water requirement of cement. Also, the test is made using pure cement paste without admixtures. In concrete factory, the water requirement is very seldom determined, because suitable test methods are not commonly known. The test method for such purpose should be practical, reliable and fast to carry out. In addition, the test method should reflect the workability of concrete used in the particular production. In the present paper, a test method is presented.

2. PRINCIPLE OF THE METHOD

The principle of the test method is to determine the water-cement ratio of cement mortar, which gives a certain, easily measurable consistency. The principle is very similar as used in DIN 1060 /2/ for determination of water requirement of building limes.

In the present method cement mortar is used instead of cement paste or concrete. Cement mortar better simulates the real situation compared to cement paste. The composition of mortar can be varied according to the particular concrete product; the mortar can contain admixtures and/or additives. Thus, also the compatibility of cement and admixtures can be effectively analysed. Effects of aggregate on test results are minimised by using standardised sand. Cement mortar tests gives more accurate test results compared to tests made using concrete. The smaller amounts of the materials allow more precise control of the material quality. Also a larger number of tests can be performed with mortar tests.

The consistency of mortar is determined using the mortar flow table (Figure 1). The equipment is used for determination of the consistency of mortar in a German Standard /3/. In the present method, the tests are carried out using different water-cement ratios so that the water-cement ratio giving a flow of 180 mm can be interpolated. The interpolated water-cement ratio reflects the water requirement of mortar. When the method is used to analyse the water requirement of cement, the interpolated water-cement ratio can be called: *Water requirement of cement* (W_{180}). However, the value is dependent on the composition of mortar (sand, admixtures) and, therefore, the value can be used only for comparison purposes.

Figure 1 - Mortar flow table.

3. MATERIALS AND TEST PROCEDURE

Test mortar consists of cement, additives (optional), admixtures (optional), sand and water. The composition of mortar can be varied, but in the normal case a weight ratio of 1.5 between sand and cement (+ additives) is used. The ratio of 1.5 corresponds to a concrete mix having a relatively high cement content. In some cases (e.g. lean mixes), a higher ratio would better correspond to the real situation. For example for cement content of 300 kg/m^3 or below, a sand-cement ratio near 2 would be more correct. The ratio (= 3) used for the determination of strength of cement is normally too high for this purpose. A low ratio is preferred because with high ratios the quality of aggregate may have a significant effect on test results. Two different types of sand can be used:

a) Standard sand, EN 196-1 /4/
b) Laboratory sand;
dried, glacial / fluvial sand, combined of minimum three sieved fractions.

If the test results need to be fully comparable with other results, the standard sand has to be used. If the test method is used for indicating variation in water requirement or for compatibility between cement and superplasticizer, laboratory sand can be used. Then, the test results are dependent on the quality of sand and are not fully comparable with the results made by using different sands. The combined grading of the laboratory sand shall fulfil the requirements presented in Table 1.

Table 1 - Requirements for the grading of the laboratory sand.

Sieve size [mm]	Passing [%]
0.125	2 ± 2
0.5	35 ± 3
1	70 ± 3
2	98 ± 2

Principally, also the normal production sand (e.g. 0-2 mm or 0-4 mm) can be used. Then the test would perfectly reflect the real situation. However, the properties of sand vary and this causes additional variation to the test results. Especially, the quality variation of the finest particles (< 0.125 mm) may affect the results. Consequently, use of standard or laboratory sand is recommended.

In the case of standard sand, 900 g cement and 1350 g sand is used. A bag of standard sand contains 1350 g and a sand-cement ratio of 1.5 gives a suitable composition of mortar. If the sand-cement ratio differs from 1.5, the content of cement has to be corrected. In the case of laboratory sand, the amounts of cement and aggregate can be freely selected; e.g. 500 g cement and 750 g give an adequate amount of mortar.

The mortar flow table consists of conical mould and flow table. Two different types of mortar flow table are available:

a) ASTM flow table /5, 6/
b) DIN flow table /2/

In the case of the ASTM flow table, the mould has the following dimensions: $Ø_{bottom}$ = 101.6 mm, $Ø_{top}$ = 69.9 mm and h = 50.8 mm. The diameter of the table is: $Ø_{table}$ = 254 mm and the height of drop: h_{drop} = 12.7 mm. In the case of the DIN flow table, the respective dimensions are: $Ø_{bottom}$ = 100 mm, $Ø_{top}$ = 70 mm, h = 60 mm, $Ø_{table}$ = 300 mm and h_{drop} = 10 mm. In the present paper, the ASTM flow table is always used. The mixer is described in the standard /4/. The temperature of the materials, equipment and laboratory has to be 20 ± 2 °C and the relative humidity of air 60 - 80%.

Cement (+ additive) and sand is first dry-mixed for about 15 s. Water (+ admixture) is added and the mixture is mixed for 30 s using the first gear. The mixer is stopped and the bowl and blade are cleaned using a rubber spatula and the mixing is continued using the second gear. The total mixing time (after adding the water) is 3 min. Superplasticizer can be added delayed e.g. 1 min after the initial water. Then, the cleaning is carried out just before adding the superplasticizer.

Immediately after mixing the specimen is moulded on the flow table. The flow mould is filled and compacted in two levels. The compaction shall be just sufficient to ensure uniform filling of the mould. The mould is removed and the dropping of table is started at 45 s after the ending of mixing. The flow table is dropped 15 times during 15 s. The spread (total diameter) is measured in 3 or 4 directions (depending on the type of table) and the average value is calculated. The test is repeated until the water-cement ratio (or water-binder ratio when additives are used) giving a spread of 180 mm can be interpolated. The water-cement ratio is varied by altering the water content, the contents of other constituents are not changed. The two nearest water-cement ratios around the water requirement value (step: 0.01) shall be tested. The principle is illustrated in Figure 2. When admixture is used, it is recommended that the water content of admixture (normally app. 60%) is taken into account when calculating the water-cement ratio.

Figure 2 also shows the effect of water-cement ratio / superplasticizer dosage on the slope; without admixture the slope is typically about 5 mm / 0.01 in water-cement ratio. With superplasticizer the slope is clearly higher.

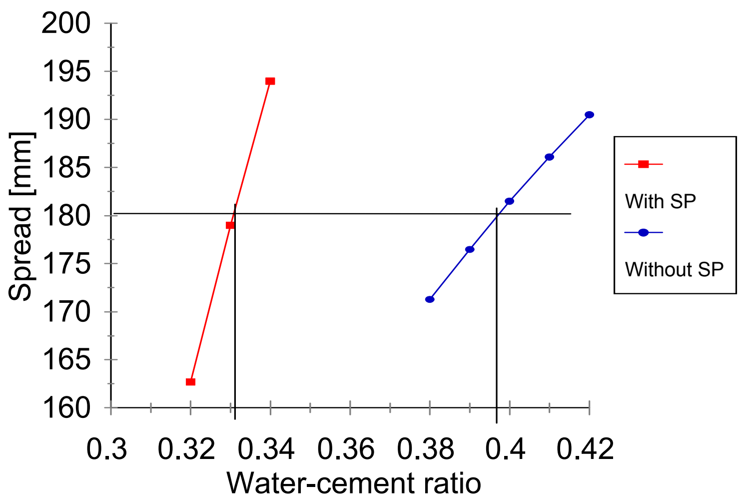

Figure 2 - Principle of water requirement test. Tests have been made with and without superplasticizer. The calculated water requirement values are: 0.331 and 0.397. Napthalene-type superplasticizer, 4% SP (25% solution) by weight of cement, very rapid hardening cement (CEM II A 52.5 R).

4. REPEATABILITY AND REPRODUCIBILITY OF THE METHOD

The errors of repeatability can be caused by the following factors:

1. Variation in the mixing procedure

2. Variation in the filling / removing the flow mould

Especially when a superplasticizer is used attention should be paid on the mixing procedure. As commonly known the addition time of superplasticizer significantly affects the rheological properties of cement paste. Therefore, a fixed addition time of superplasticizer has to be used.

If the consistency of mortar is low, a proper filling of the mould can be difficult. However, with a consistency giving a spread near 180 mm this is not normally a problem. In the case of high superplasticizer dosages, cement mortar may adhere on the walls of the mould and, thus, affect the test results.

Repeating the whole test six times tested the repeatability of the method. The test series were made both without and with superplasticizer. The results have been collected in Table 2. Generally, a very good repeatability was achieved. For example using two parallel tests, the confidence limits of the average would be ±0.0028 in both cases. Even with a single test the repeatability is good (error typically max. ±0.004 without SP and ±0.007 with SP). Based on the results, it is recommended that the results are given by using three significant numbers (three decimals) when at least two parallel tests have been carried out. In the case of single test, the accuracy of 0.005 is recommended.

Table 2 - Repeatability of water requirement test. Results of six parallel tests have been presented. Tests have been made without and with superplasticizer. Naphthalene-type superplasticizer, 4% SP (25% solution) by weight of cement, very rapid hardening cement (CEM II A 52.5 R).

	Water requirement of cement				
	Average	Standard deviation	Coefficient of variation	Minimum	Maximum
Without SP	0.429	0.0020	0.47%	0.427	0.431
With SP	0.332	0.0020	0.60%	0.330	0.337

In addition to the factors causing repeatability errors, the errors of reproducibility can be caused by the following factors:

1. Variation in the quality of sand
2. Variation in testing temperature
3. Variation caused by test equipment and operator

The water requirement of sand directly affects the measured water requirement value. Two very different types of sand (for example well-rounded glacial sand and crushed sand) may give over 0.05 difference in the measured water requirement value. However, between glacial / fluvial sands the difference is much smaller. The reference sand EN 196-1 is very well rounded, quartz rich fluvial sand and thus gives a low water requirement value. In Table 3, the standard sand and laboratory sand has been compared. The standard sand was produced by Normensand Gmbh, Germany and the laboratory sand by Optiroc Oy, Finland. The laboratory sand consists of three fractions (0.1-0.6, 0.5-1.2 and 1-2 mm). The sand is glacofluvial, granitic aggregate.

According to the tests, the laboratory sand gives rather similar water requirement values compared to the standard sand. When no superplasticizer was used, the laboratory sand gave slightly higher water requirement values. This is obviously due to the more rounded particle shape of the standard sand. Also the content and quality of the finest particles (< 125 μm) may be different between the aggregate types. When a superplasticizer was used, the difference was negligible. The role of the cement paste is probably so dominant that small differences in the quality of sand do not significantly affect the test results. If a higher sand-cement ratio is aimed at also the effect of the quality of sand might be larger.

Table 3 - Effect of the aggregate type on the results of water requirement tests. Tests have been made without and with superplasticizer. Naphthalene-type superplasticizer, 4% SP (25% solution) by weight of cement, very rapid hardening cement (CEM II A 52.5 R). Averages of two parallel tests have been presented.

Type of aggregate	Water requirement			
	Without SP		With SP	
	average	range	average	Range
Standard sand	0.417	0.005	0.338	0.001
Laboratory sand	0.426	0.001	0.337	0.001

Temperature has a significant effect on the early consistency of cement mortar. Compared to concrete, the effect of temperature is bigger because of the higher cement content. Therefore, the operating temperature has to be controlled (acceptable temperature range: 18 - 22 °C) .

The method is rather insensitive to variation in the test equipment or operators. However, different types of flow table give slightly different results. Therefore, the type of flow table has always to be mentioned. If the results of two laboratories need to be fully comparable, reproducibility tests have to be carried out.

5. LIMITATIONS OF THE METHOD

The consistency of mortar giving a spread of 180 mm can be considered as equivalent to the consistency of concrete typically used in the prefabricated production (slump approximately 150 mm). Therefore, the method is not necessarily very suitable if the water requirement of cement for no-slump or self compacting concrete is analysed. For example, the effect of superplasticizer may depend on the consistency of mortar / concrete.

In two-point system of cementitious material rheology, the consistency is divided into yield stress and plastic viscosity. The present test method can be considered as a one-point method because it mainly measures the yield stress (it is also slightly affected by the plastic viscosity). From the test methods for consistency of concrete, the German flow table measures the similar rheological properties as the present method. Compared to mortar / concrete viscometer the method gives rather incomplete information. In order to get more accurate information from rheological properties, mortar / concrete viscometer should be used. However, viscometer tests may be too difficult and time-consuming in factory environment.

6. EXAMPLES

In the following, the water requirements of different types of cement have been presented (Table 4). As can be seen from Figure 3 the fineness is a very important factor affecting the water requirement, but the fineness alone cannot explain the differences between the cement types. Also, the effect of superplasticizer dosage on the water requirement has been illustrated (Figure 4). In Figure 5, use of water requirement test in the quality control of cement has been demonstrated. Eight different lots of cement have been tested in a concrete factory.

Table 4 - Water requirement of different types of cement. Tests have been made without and with superplasticizer. Naphthalene-type-superplasticizer, 4% SP (25% solution) by weight of cement. Results of single test have been presented. The cements were produced by Finncement, Finland except the white cement, which was produced by Aalborg Portland, Denmark.

Cement type	Description	Composition [%] (C_3S, C_2S, C_3A, C_4AF)	Fineness Blaine [m^2/kg]	Water requirement	
				Without SP	With SP
CEM II A 42.5 R	Rapid hardening cement	62, 11, 8.5, 8.5 [1]	450	0.393	0.323
CEM II A 52.5 R	Very rapid hardening cement	62, 11, 8.5, 8.5 [1]	540	0.422	0.349
CEM I 42.5 SR	Sulphate-resistant portland cement	70, 10, 1.0, 13	340	0.350	0.290
CEM I 52.5 R	White portland cement	70, 19, 4.5, 1.0	385	0.345	0.305 [2]

[1] = composition of clinker, typical values given by the producer
[2] = melamine-type superplasticizer, 0.8% dry SP by weight of cement.

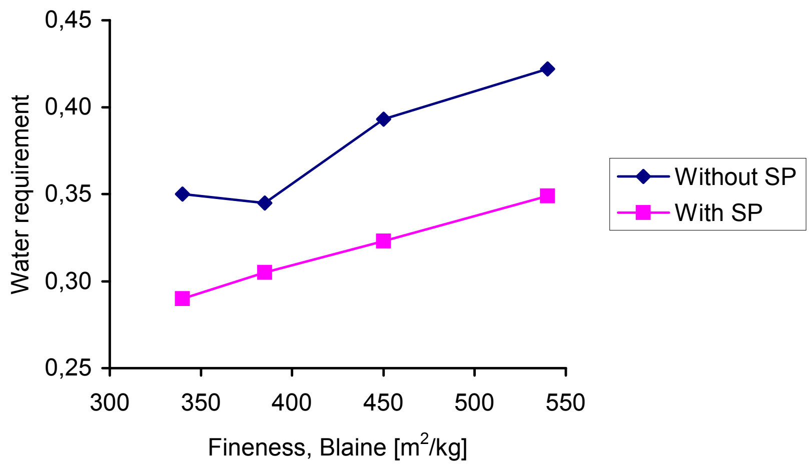

Figure 3 – Effect of fineness of cement on the water requirement. The cements are the same as presented in Table 4.

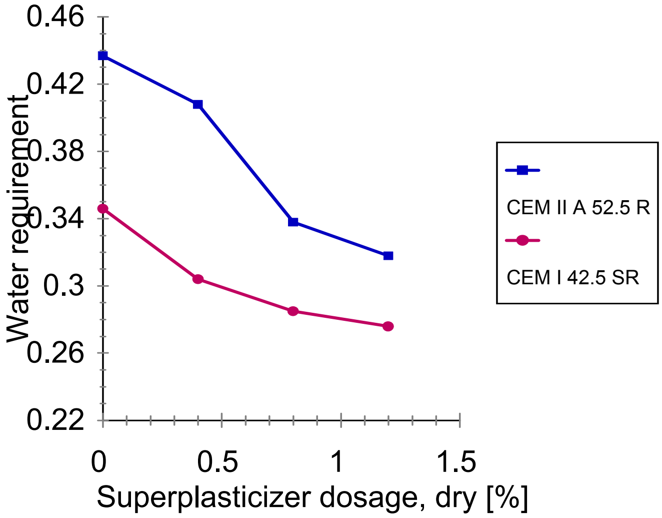

Figure 4 –
Effect of superplasticizer dosage on the water requirement. Naphthalene-type superplasticizer, very rapid hardening cement (CEM II A 52.5 R) and sulphate-resistant portland cement (CEM I 42.5 SR). Results of single test have been presented.

As demonstrated in Figure 5, the method effectively reveals the variation in the compatibility of cement and superplasticizing admixture. The methods made for pure cement paste without admixtures (e.g. standard consistency) may not reflect very well the real situation where also admixtures are used. In Figure 5, for example, the cement lot which had the lowest water requirement without superplasticizer gave the second highest water requirement with superplasticizer.

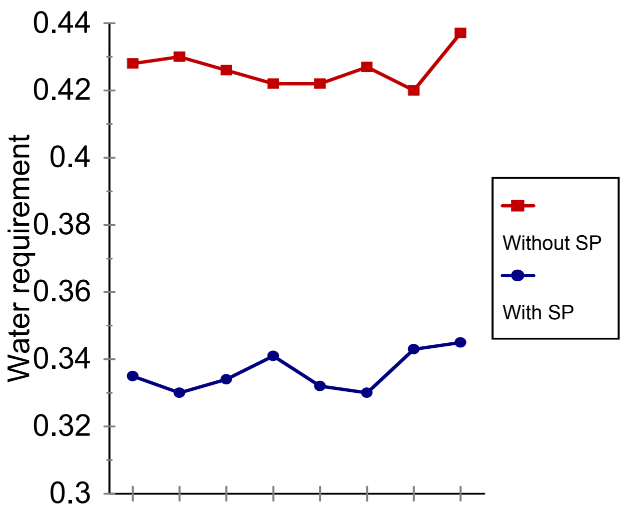

Figure 5 –

Use of water requirement test in the quality control of cement. Eight different lots of cement have been tested. Tests have been made without and with superplasticizer. Naphthalene-type superplasticizer, 4% SP (25% solution) by weight of cement, very rapid hardening cement (CEM II A 52.5 R). Results of single test have been presented.

7. CONCLUSIONS

The proposed test method for determination of water requirement of cement has proved to be applicable for testing of cement and plasticizing admixtures as well as quality control of cement. The test is relatively rapid to carry out (takes 0.5 - 1 h) and the test results are well reproducible. Based on the repeatability tests two parallel tests normally give an adequate accuracy.

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