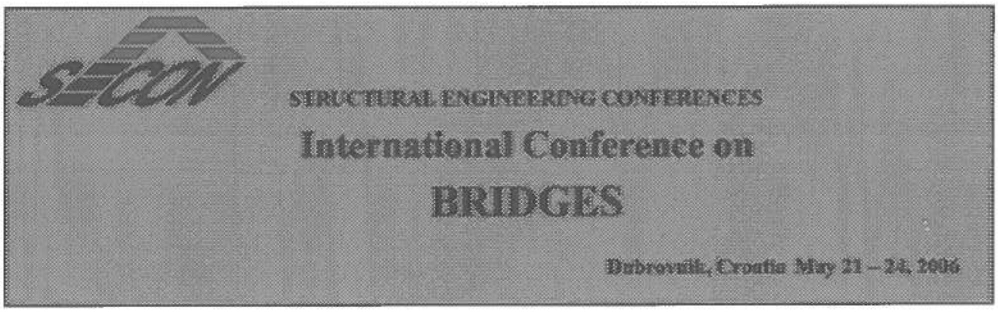
Pros and cons for European Standards and Guidelines concerning grout performance in post-tensioned structures



PROS AND CONS FOR EUROPEAN STANDARDS AND GUIDELINES CONCERNING GROUT PERFORMANCE IN POST-TENSIONED STRUCTURES

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Abstract: *In the case of prestressed tendons in concrete structures, grouts are pressed into the space between the steel and the surrounding material. This space must be fully filled by the grout without any voids, which is ensuring durability of post-tensioned structures. The test methods and requirements prescribed in European standards (EN 445:1996, EN 447:1996, prEN 447:2004) and in the fib-guideline:2002 for grouts for prestressing tendonds, are described in this paper, followed by a discussion with regard to their advantages and/or disadvantages. While these standards and fib-guideline give general guidance and define test procedures, there is no guidance given on grout formulation.*

1. INTRODUCTION

In the case of prestressed tendons, grouts are pressed into the space between the steel and the surrounding material (duct). This space should be fully filled by the grout and free of voids. Furthermore, in the case of prestressing tendons the thickness of the concrete cover and the quality of the concrete must be good enough to ensure that during the service life of the structure steel corrosion can not be initiated due to the ingress of aggressive agents. The integrity of the grout must be suited to form a good physical barrier against aggressive substances. Unfortunately, practical experience has shown that ducts are often not completely filled with the grout and contain voids. The problems are equal in the case of anchors. However, if the grout contains voids and ducts are not fully filled, corrosion can not be excluded as water often finds a way into ducts and can initiate corrosion even in the absence of aggressive agents, but the risk of damage is much higher if chlorides are present. The situation can be improved by upgrading the rheology of grouts so that the grout flows easier into the ducts reducing the risk of appearance of voids.

While European Standards EN 445 and 447 "Grout for prestressing tendons" as well as the *fib*-guideline "Grouting of tendons in prestressed concrete" give general guidance and define test procedures, there is no guidance given on grout formulation. Therefore investigations have been started with the overall goal to develop rules for grout formulation. These investigations are part of the European COST Materials Action 534 "New Materials and Systems for prestressed Concrete Structures" and are carried out in a direct cooperation between three institutes from Austria, Croatia and Scotland. As a consequence of research work on grouts and their performance, the critical overview of existing European standards and guidelines is given in this paper.

2. REQUIREMENTS AND PRESCRIBED TEST METHODS

Prescribed test methods for testing grout's quality for prestressed tendons are given in National standards, which are accepted European standards, in countries involved in this project. Descriptions and requirements of test methods given in EN 445:1996, EN 447:1996, prEN 447:2004 and in the *fib*-guideline, are presented in this paper, followed by a discussion with regard to their advantages and/or disadvantages.

2.1 Flowability

Flowability of the grout is most important property concerning the execution of the grouting procedure, since the grout should be easy pumpable and should fully fill the space between tendons and duct. Concerning the rheological behaviour of the grout there are three methods: flow cone method, immersion test and grout spread method (Table 1), and they all give single point values. From the scientific point of view this seems to be insufficient but might be good enough for control reasons. Contrary to the EN 447:1996 which is still in force, the prEN447:2004 and the *fib*-guideline do not contain requirements with regard to fluidity of the grout at the end of injection period. It is mentioned in prEN447 that "fluidity of the grout during the injection period shall be sufficiently high for it to be pumped effectively and adequately to fill the sheath, but sufficiently low to expel the air and any water in the sheath". Fluidity might change until all of the grout mixture is used up which usually takes longer than 30 minutes. Requirements on fluidity at the end of use of one grout mixture are essential from the authors' point of view.

For fluidity determination according EN 445:1996 flow cone test method may be used, where grout is poured in the cone (1,7 litre of volume), and then the time until 1 litre of grout flows out is measured. The time is measured immediately after all ingredients have been mixed and after 30 minutes of mixing, and it should be less than 25 seconds according EN 447:1996. Phases during measuring fluidity according EN 445 is shown on figure 1.

Table 1. Test methods and requirements for flowability

Grout property	**Test method**	**Requirements**		
		EN 447 (1996)	**prEN 447 (2004)**	***fib*-guideline (2002)**
Flowability / fluidity	Cone method (EN 445 1996)	after mixing: ≤ 25 s	equal to *fib*-guideline	after mixing (t_0): ≤ 25 s
		after 30 min or at the end of injection period: ≤ 25 s (50 s)*)	equal to *fib*-guideline	after 30 min (t_{30}) or at the time specified by the manufacturer: 1,2 $t_0 \geq t_{30} \geq 0{,}8\ t_0$ and $t_{30} \leq 25$ s
		at duct outlet time: ≥ 10 s		
	Immersion test (EN 445 1996)	after mixing: ≥ 30 s	---	---
		after 30 min or at the end of injection period: ≤ 80 s (200 s) *)	---	---
		at duct outlet time: ≥ 30 s	---	---
	Grout spread method (slump)	---	after mixing (a_0): ≥ 140 mm; 30 min after mixing (a_{30}) or at the time specified by the manufacturer: 1,2 $a_0 \geq a_{30} \geq 0{,}8\ a_0$ and $a_{30} \leq 140$ mm	---

*) For grouts prepared in some mixers which have a high shear mixing action, the upper limits given may be increased to 200 s for the immersion test and to 50 s for the cone test. The mixture and these limits shall be subject to the approval of the competent authority

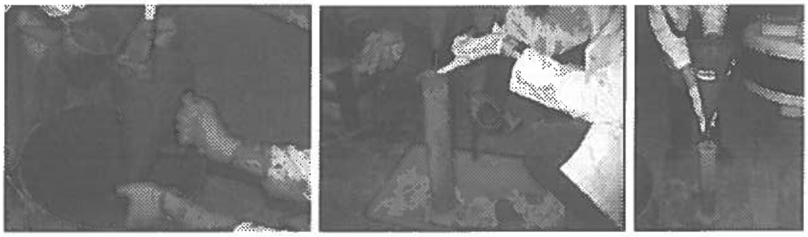

Figure 1. Procedures during measuring grout fluidity according to EN 445:1996

2.2. Bleeding, sedimentation and setting time

In practice usually much more water is mixed with the cement, than it is needed for hydration process. The average water cement ration is 0.40 to 0.45, but with the addition of superplasticizers it can be significantly lowered, down to 0.30. The consequences of excess water are bleeding and sedimentation, which are main reason for causing problems with durability of tendons.
Overview of prescribed methods and requirements are given in table 2.

Table 2. Test methods and requirements for bleeding, sedimentation and setting time

Grout property	**Test method**	**Requirements**		
		EN 447 (1996)	**prEN 447 (2004)**	***fib*-guideline (2002)**
Bleeding	Wick-induced test or Inclined tube test	---	equal to *fib*-guideline	after 3 hours of rest: ≤0,3% of the initial volume
	(EN 445:1996) Glass cylinder (∅ 25 mm; filling height 250 mm or ∅ 50 mm; filling- height 100 mm	<2 vol% after 3 h	---	---
Sedimen-tation	Grout density between top and bottom (grout filled in a PVC tube; 5 m long, ∅ 80 mm)	---	equal to *fib*-guideline	after 3 hours: ≤5%
Setting time	EN 196-3	---	beginning: >3 h	beginning >3 h
			ending: <24 h	---

2.2.1 Bleeding

Compared to the test described in EN 445:1996, bleeding tests according to *fib*-guideline and prEN 445:2004 are much more difficult to carry out. According to the EN 445:1996 a simple glass cylinder is needed into which the grout is poured (∅ 25 mm or ∅ 50 mm – filling height 250 mm or 200 mm, respectively). Bleeding is determined by measuring the

volume (height) of the water layer above the grout after 3 hours of resting, as shown on figure 2. However, as specified in the *fib*-guideline this test does inadequately represent the true conditions inside the duct. Therefore the test methods recommended in the *fib*-guideline were taken over in the prEN 447:2004 and are much more relevant for practice. Transparent tubes must be used for the Wick-induced test and inclined tube test which contain strands in order to include the filtering effect of the strands.
However, the inclined tube test seems to be rather complicated for many normal laboratories because two 5 m long tubes with a diameter of approximately 80 mm are prescribed which must be fixed on their supports at an inclination of 30° and because the test is completed only after 24 hours, i. e. after a time at which the grout can not be removed again. Furthermore, as it is the case in practice, a pressure must be applied for filling the grout into the ducts and re-filling, respectively. This seems to be suitable for testing at the construction site but not in normal laboratories.
For the Wick-induced test only one tube with a length of 1 m and a diameter of approximately 80 mm, used in a vertical position is needed. The grout is simply poured into the duct. This test is much easier to carry out and delivers in addition to bleeding, results of volume change.
However its disadvantage is that no information on the effect of the pressure applied under practical conditions is obtained and that the duration of the test is 24 hours also here after which the grout can not be removed again from the tube and must be given to the waste after the test.
The threshold value of bleeding given in the EN 447:1996 is much higher than that in *fib*-guideline and prEN 447 because no strands are included which have a strong influence. It can not be said inasmuch as the measurement values obtained according prEN 445 and fib-guideline are comparable to that obtained by EN 445:1996.

Beside the technical difficulties connected with testing according the *fib*-guideline or prEN 445, the bleeding tests require relatively large quantities of grout even when tested according the Wick-induced test. Therefore the bleeding behaviour of grouts is often tested in laboratories according to EN 445:1996, as shown on figure 2. Compared to the Wick-induced and inclined test only a rough information is obtained that way. However, it might be good enough to compare the effect of admixtures such as superplasticizers, etc. on the bleeding behaviour in general.

The prEN 447:2004 contains a note that the requirements after three hours of rest "should be the same with grout kept at rest during 24 hours" but it is nor clear if it has to be tested or not. Only the inclined test according prEN 445: 2004 takes 24 hours but not the Wick-induced test which is completed when there is no further change within 1,5 hours (three consecutive readings). The latter seems to be most relevant and requirements should be given for that time (or the beginning of setting).

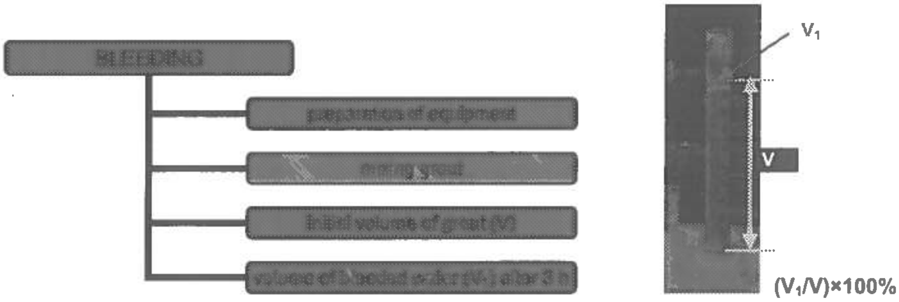

Figure 2. Measuring of bleeding according to EN 445:1996

2.2.2 Sedimentation

Sedimentation measurements are required only in the *fib*-guideline. The difference of the grout density between the top and bottom after the bleeding test is limited. This is considered as useful additional information, but it is relatively complicated to execute.

2.2.3 Setting times

To have enough time for injection, *fib*-guideline and prEN 447:2004 contain requirements for the beginning of setting and the latter standard also for the end of setting. The EN 447:1996 does not contain any requirement on setting. It seems to be more important to regulate the beginning of setting than its ending but it is no disadvantage to regulate both. The setting times must be seen in connection with bleeding and sedimentation and therefore the duration of all three tests should be identical.

2.3 Volume change

Volume change of grout is primarily happening due to two effects, shrinkage and sedimentation of grout, which are usually combined in the practice. Expansion of the grout is desirable, and therefore the addition of expansive admixture recommendable.
Test methods for measuring volume change are given in table 3.

Table 3. Test methods and requirements for volume change

Grout property	Test method	Requirements		
		EN 447 (1996)	prEN 447 (2004)	*fib*-guideline (2002)
Volume change	Wick-induced test	---	equal to *fib*-guideline	when there is no further change in 3 consecutive readings (30 min intervals): between -0.5% and +5%
	(EN 445:1996) Cylinder or can method	after 24 hours: between -1% and +5%	---	---

According the *fib*-guideline and prEN 445:2005 the height of grout used for the Wick-induced bleeding test must be recorded at 15 minutes intervals for first hour and subsequently at 30 minutes intervals until there is no further change in three consecutive readings. This seems to be a progress compared to the EN445:1996. The equipment and test procedure according EN 445:1996 is shown on figure 3. In this test the volume difference between filling the glass cylinder or the cans immediately and 24 hours later is limited only. However, it is important to know how long and how fast the volume changes, in order to get the information how much the grout volume changes after injection. The lower limits given in the standards (-1.0% and -0.5%) mean that the grout must not shrink much but expansion is required. That volume contraction is not forbidden at all seems to be an imperfection because expansion is important in order to avoid voids and to fill the duct completely.

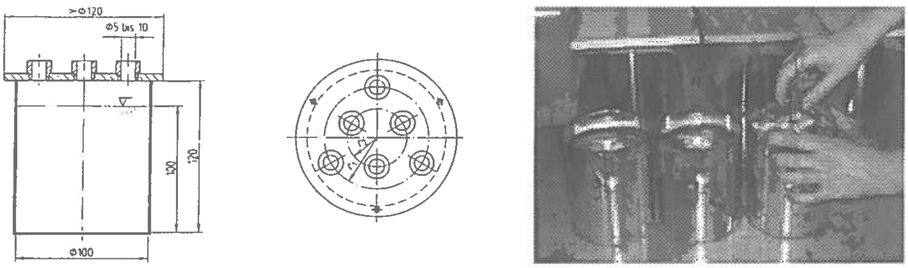

Figure 3. Equipment and measuring volume change after 24 hours according EN 445:1996

2.4 Compressive strength

The grout for bonded post-tensioned tendons must achieve minimum compressive strength to assure sufficient bond between prestressing steel and surrounding concrete. Requirements given in table 4, prescribe a minimum strength between 27 and 30 MPa.

The requirements seem to be good enough but it is not easy to understand why prEN 445:2004 goes back to the use of cubes for testing and why no longer prisms (as for cement according EN 196-1) or cylinders are allowed, and as it is prescribed in the EN 445:1996.

Table 4. Test methods and requirements for compressive strength

Grout property	**Test method**	**Requirements**		
		EN 447 (1996)	**prEN 447 (2004)**	***fib*-guideline (2002)**
Compressive strength	EN 445:1996 prism or cylinder	after 28 days: ≥ 30 MPa		---
	EN 12190 (40 mm cubes)		≥ 27 MPa after 7 days or ≥ 30 MPa after 28 days:	
	Cubes (50 - 100 mm) or cylinders (∅ 50 - 100 mm; ∅:height : 1:1)	---	---	after 7 days: "should exceed" 27 MPa"

3. CONCLUSION

Grout for bonded post-tensioning is a combination of Portland cement and water, along with different admixtures needed to obtain required properties. Grout is the final and the most important protection of tendons against corrosion and therefore it is from a great importance to ensure high performance of grouts.

In this paper the review of existing European standards and *fib* guidelines is given, with regard to their advantages and/or disadvantages. Further development on the prescriptions is needed, since European Standards EN 445 and 447 "Grout for prestressing tendons" as well as the *fib*-guideline "Grouting of tendons in prestressed concrete" give general guidance and define test procedures, but there is no guidance given on grout formulation.