Anders Andalen
Cathrine Ewertson

Comparison of Nordic Methods for Determination of the Compressive Strength of High-strength Concrete

Nordtest project no. 975-91

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Abstract

Comparison of nordic methods for determination of the compressive strength of high-strength concrete.

This study is a continuation of two earlier studies reported in /1/ and /2/. In these studies comparisons between methods for determination of compressive strength of concrete in the Nordic countries have been carried out. The compressive strength has been determined according to Swedish, Finnish, Norwegian and Danish standards, which means different ways of determining the strength. Shape and size of the test specimens, manner of curing and rate of loading are the three main factors that separate the standards. In this project the relations between the characteristic strengths in the Nordic countries also have been evaluated, according to the national rules. In the calculations, the relations between the test results of compressive strength have been used.

Two different concrete qualities have been tested, one made with Slite Std P cement and the other with Degerhamn Std P cement. For both qualities, 10 % of the cement was replaced by silica fume. Compressive strength was determinted at 3, 7 and 28 days respectively. Concrete with Slite Std P cement as binder was tested at intended strengths between 60 and 80 MPa and concrete with Degerhamn Std P cement between 100 and 120 MPa.

The tests show that clear-cut relations exist between the results obtained by the various methods and these relations are presented in diagrams. Nothing in the comparisons made indicates that the relations for high-strength concrete are different from previous results. In the diagrams all results from the three projects are included.

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Postal address:
Box 857, S-501 15 BORÅS,
Sweden
Telephone + 46 33 16 50 00
Telex 36252 Testing S
Telefax + 46 33 13 55 02

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Foreword

The project presented in this report has been carried out at the Building Technology Department of the Swedish National Testing and Research Institute in 1992, and is the direct continuation of projects previously completed in this subject area.

Funding has been provided by NORDTEST, Nordtest project no. 975-91.

The authors hereby express their sincere gratitude to all who have been involved in this project.

Borås, August 1995

Anders Andalen

Cathrine Ewertson

Summary

This study describes a project that is the direct continuation of two previous projects, described in /1/ and /2/. The projects comprise comparison amongst the methods used in the four Nordic countries (Sweden, Finland, Norway and Denmark) for determining the compressive strength of concrete. The main factors that distinguish the standards from one another are shape and size of test specimens, manner of curing, and rate of loading in compression testing. The project also reports the correlations between the characteristic compressive strength values (K and C values, respectively) for the Nordic countries.

For the present continuation project, only high-strength concrete has been cast. The project tested two concrete qualities, one made with Slite Std P cement and the other with Degerhamn Std P cement (a Portland cement with low alkali content and a low hydration heat value). For both qualities, 10% of the amount of binding agent was replaced by silica fume. Compressive strength was determined at 3, 7 and 28 days, respectively. Concrete with Slite Std P was tested at intended strengths between 60 and 80 MPa, and concrete with Degerhamn Std P between 100 and 120 MPa.

The test results show clear correlations between the results obtained using the methods of the different countries. The comparisons indicated no deviations from the results previously obtained regarding the correlations for the high-strength concrete. All the results from the three completed projects are presented in the diagrams.

The correlations between the characteristic values for compressive strength (K and C values, respectively) for the Nordic countries have been determined on the basis of these correlations between the test results obtained using the various Nordic methods and on the basis of the methods used in the different countries to calculate the control values, to be compared with the stipulated characteristic values.

1 Comparison of Nordic methods for determination of the compressive strength of high-strength concrete

1.1 Introduction

Two previous Nordtest projects, /1/ and /2/, have established that there are unambiguous correlations between results obtained using the different testing methods for determination of the compressive strength of high-strength concrete of the four Nordic countries. Compressive strength was determined in accordance with Swedish, Finnish, Norwegian and Danish standards. According to the standard of the four countries, the three main factors that distinguish the standards from one another are shape and size of test specimens, manner of curing, and rate of loading in compression testing. Two different qualities of concrete were tested: concrete with pure Portland cement and cement in which 10% of the amount of binding agent had been replaced with silica fume. The concrete was tested at intended strengths between 60 and 80 MPa.

The projects were restricted to concrete with a maximum intended strength of 80 MPa. In the future, use of high-strength concrete is expected to increase, and so similar comparisons of the Nordic methods will probably be in demand. For this reason, a continuation project has been carried out, in which the maximum intended strength was approximately 120 MPa.

This continuation project with high-strength concrete was performed at the Concrete Section of the Swedish National Testing and Research Institute in Borås, Sweden, in 1992. The test were carried out using the same methods and procedures as were used in the two previous Nordtest projects. Chapter 1.2.3 contains a more detailed summary of the testing methods used in the different countries.

In order to obtain useable correlations, the testing program was drawn up on the basis of: type of concerete, age at testing, and compressive strength. Two different binding agents were used: with Slite Std P cement and Degermanh Std P cement. In all the concrete compositions, 10% of the binding agent was replaced with silica fume. The age of the test specimens at testing was set at 3, 7 or 28 days. There different nominal compressive strengths were tested for concrete with Slite Std P: 60, 70 and 80 MPa. There different nominal compressive strengths were also tested for concrete with Degerhamn Std P cement: 100, 110 and 120 MPa. The term "nominal compressive strength" as used in this report is defined as mean cube strength at 28 days as tested according to the Swedish standard. Six test specimens were tested for every combination of concrete quality, age at testing, and intended compressive strength in accordance with the testing method of each of the four countries.

1.2 Testing program

1.2.1 Concrete

1.2.1.1 Materials used

The following materials were used to produce the concrete.

Cement

- Slite Std P
- Degerhamn Std P cement

Silica fume

Cementa Mikropoz. In calculating the equivalent water/cement ratio (vct_{ekv}), the quantity of silica fume was multiplied by a factor of 1.0.

Water

Tap water

Plasticizing and water reducing admixtures

Cementa 92 M was used in all the concrete mixes.

Aggregate

Fine (< 8 mm) natural gravel. Stone material (> 8 mm), consisting of natural coarse gravel. Maximum size 16 mm.

1.2.1.2 Concrete quality

Six different concrete qualities were produced. See table 1.2.1 for composition. In proportioning the concrete mixture, efforts were made to obtain a mean cube strength (at 28 days according to Swedish standard) in the interval of 60-120 MPa. For the mixes at 60, 70 and 80 MPa, Slite Std P cement was used, and for the mixes at 100, 110 and 120 MPa, Degerhamn Std P cement was used as binding agent. In all the mixes, some of the binding agent was replaced by silica fume.

When calculating the equivalent water/cement ratio, (vct_{ekv}), the activity coefficient for silica fume, SiO_2 was set at 1.0. The equivalent water/cement ratio was calculated as follows:

$$vct_{ekv} = \frac{W}{C + k \cdot R}$$

in which

W = weight of water + weight of water in plasticizing admixture
C = weight of cement
k = activity coefficient of admixture
R = weight of admixture

Table 1.2.1 Concrete composition

	Intended compressive strength in MPa at 28 days					
	60	70	80	100	110	120
Type of cement	Slite Std P			Degerhamn Std P		
Material composition						
Weighed amounts, kg/m³						
Cement	387	432	468	459	504	513
Silica fume	43	48	52	51	56	57
Water	192	162	150	145	127	118
Aggregate 0-8 mm	816	828	810	812	807	814
Aggregate 8-16 mm	885	897	950	953	947	956
Admixture	2.2	9.6	14.5	12.8	19.6	20.0
vct_{ekv} obtained	**0.45**	**0.35**	**0.31**	**0.30**	**0.25**	**0.23**
Measured consistency						
Slump measurement, mm	80	85	30	90	230	30/35*

* Test specimens manufactured from two batches of concrete.

1.2.1.3 Casting

Aggregate, cement and silica fume were mixed for approx. 1 minute in a 350 liter rubber-lined paddle mixer (Sandby SU350). The admixture was diluted in a little water and added with the remaining water, after which the concrete was mixed for approx. 3 minutes. Consistency was measured in terms of slump measurement pursuant to SS 13 71 21 after mixing was concluded.

The test specimens were produced as follows: cubes (150 mm) and cylinders were filled in two layers, each of which was vibrated. Vibration of the second layer continued until the surface of the concrete was even, shiny and coherent. Finally, the surface was rolled twice, back and forth, with a round steel roller. Cubes (100 mm) were filled with concrete in a single layer, and the procedure was otherwise identical to that used for the other test specimens. 4 x 3 x 6 test specimens were produced from each concrete quality, for testing in accordance with the method of each country.

All cubes were covered with plastic film when casting was completed, after which they were stored at 20 ± 2 °C. Approximately 30 minutes after casting was completed, the cylinders were capped. After this they were stored together with the cubes, lying down. After 24 hours all speciemens were removed from their moulds and labelled.

1.2.2 Curing

All test specimens were stored in their moulds for the first 24 h, covered with cling film, at 20 ± 2° C. After having been removed from the moulds, the test specimens were stored in water at 20 ± 2° C until testing, with the exception of the cubes that were to be tested in accordance with the Swedish standard. These were only stored in water for 96 h, after which the "Swedish" cubes were stored until testing in air at 20 ± 2° C and 40-60% relative humidity.

1.2.3 Test methods

The same test methods were used from each respective country as used in the previous projects. The testing procedure at 3, 7 and 28 days was as follows. The test specimens stored in water were removed from the water, and excess water dried off before testing. Each test specimen was weighed and measured. For cubes (150 mm), height was determined using a sliding caliper, and the mean cross-sectional area at a right angle to the direction of pressure using a measuring clamp. For cubes (100 mm) and cylinders (diameter = 150 mm and height = 300 mm), height and area were determined using a sliding caliper. Density was determined, and is given in this report, in kg/m^3, with the ten unit digit rounded off to 0 or 5. Subsequently, the test specimen was carefully centered in the compression testing machine and loaded to fracture. The failure load, i.e. the maximum load to which the test specimen could be subjected before fracture, was noted.

1.2.3.1 Testing according to the Swedish standard (S)

In Sweden, the compressive strength of concrete is tested pursuant to Swedish standard SS 13 72 10 "Concrete Testing - Hardened Concrete - Compressive Strength of Cubes". This standard stipulates the use of moulds that are durable and water tight, with an internal length, width and height = 150 ± 2 mm.

After having been removed from the moulds, the test specimens were stored in water at 20 ± 2° C for the next 96 h. After this and until testing, they were stored in air at 20 ± 2° C and 40-60% relative humidity. Thus the testing on day 3 was carried out on wet test specimens, while the testing on days 7 and 28 were carried out on dry test specimens.

The load rate was approx. 1 MPa/s.

1.2.3.2 Testing according to the Finnish standard (SF)

In Finland, the compressive strength of concrete is tested pursuant to Finnish standard SFS 4474 "Concrete. Compressive Strength". For the project, moulds with an internal length, width and height = 150 mm were selected.

The test specimens were stored in water at 20 ± 2° C until testing at 3, 7 and 28 days.

The load rate was approx. 1 MPa/s.

1.2.3.3 Testing according to the Norwegian standard (N)

In Norway, the compressive strength of concrete is tested pursuant to Norwegian standards NS 3667 "Hardened Concrete - Shape and Measurements of Test Specimens", NS 3668 "Hardened Concrete Compressive Strength of Test Specimens", and NS 3669 "Hardened Concrete. Casting and Curing of Test Specimens for Determination of Compressive Strength" . The compressive strength of the concrete was determined on cubs with a length, width and height = 100 mm.

After having been removed from the moulds, the test specimens were stored in water at 20 ± 2° C until testing.

The load rate was approx. 0.8 MPa/s.

1.2.3.4 Testing according to the Danish standard (DK)

In Denmark, the compressive strength of concrete is tested pursuant to Danish standards DS 423.20 "Hardened Concrete - Shape and Measurements of Test Specimens", DS 423.21 "Hardened Concrete. Production and Curing of Cast Test Specimens for Determination of Compressive Strength", and DS 423.23 "Concrete Testing. Compressive Strength" . From DS 423.20, cylinders with a diameter = 150 mm and a height = 300 mm were selected.

After having been removed from the moulds, the test specimens were stored in water at 20 ± 2° C until testing at 3, 7 and 28 days.

The load rate was approx. 1 MPa/s.

1.2.3.5 Summary of testing methods

Shape and size of specimens, method of curing, and load rate are the three most important factors separating the testing methods of the Nordic countries. Table 1.2.2 provides a summary of the respective methods used in this project.

Table 1.2.2 Summary of test methods

Test method	Shape and size of specimens	Method of curing *	Load rate
Swedish	150 mm cubes	24 h in mould 96 h in water 23 days in air	1 MPa/s
Finnish	150 mm cubes	24 h in mould 27 days in water	1 MPa/s
Norwegian	100 mm cubes	24 h in mould 27 days in water	0.8 MPa/s
Danish	Cylinders with ∅ = 150 mm h = 300 mm	24 h in mould 27 days in water	1 MPa/s

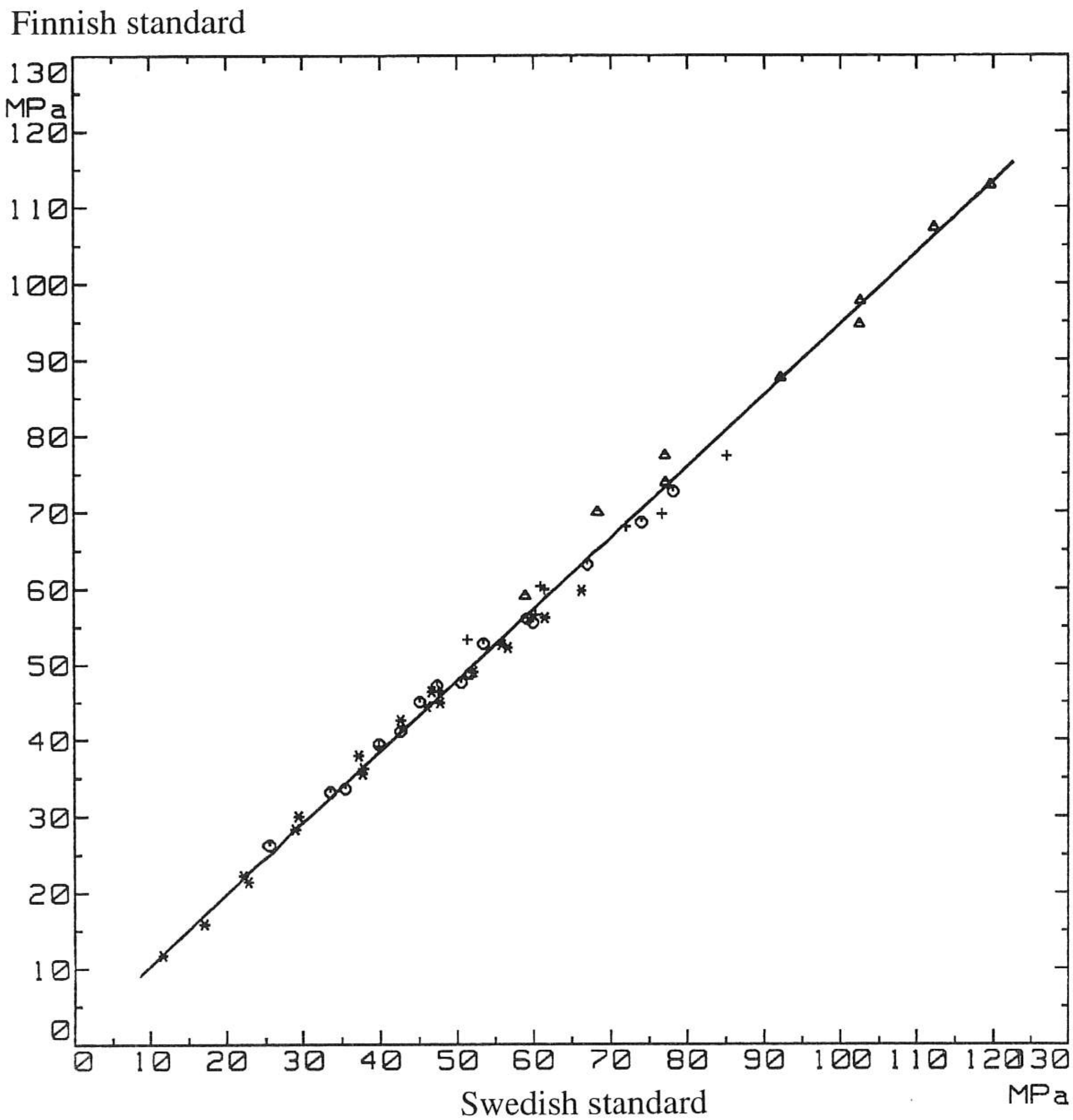
* Represents method of curing until testing at 28 days. For testing on days 3 and 7, curing was performed in accordance with the table until the relevant age, 3 or 7 days.

1.3 Test results

All the values for density and compressive strength obtained in testing high-strength concrete may be found in appendix 1. The results from the two previous projects may be found in /1/ and /2/. The table contains the mean value (m) for each series of six test specimens, with corresponding standard deviations (s) for compressive strength.

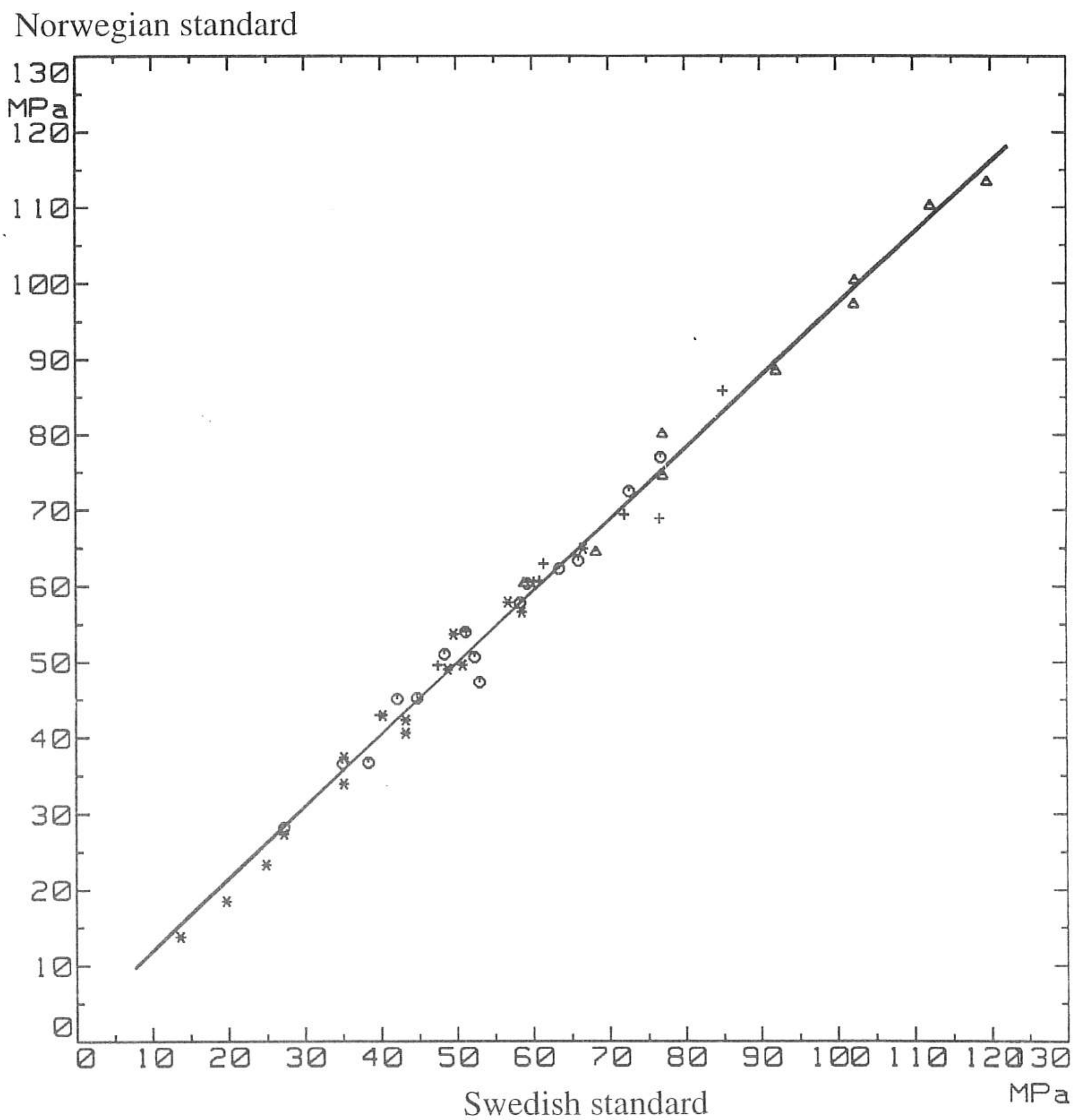
Figures 1.3.1 - 1.3.4 show the correlations between the results from two countries' methods. The diagrams comprises all results from the three Nordtest projects that have been carried out. For Norwegian methods NS 3667, NS 36678 and NS 3669, only one comparison with the Swedish method has been made for the lower compressive strengths in project two, because no complete test programme has been performed. Thus the correlations between the Finnish and Norwegian methods and between the Danish and Norwegian methods cannot be given. All results from the three types of concrete, the three ages and the ten compressive strengths have been noted in the diagrams. In each diagram, the results from testing have been marked with a straight line.

Correspondingly, figures 1.3.1 - 1.3.4 show the correlation between the results from two countries at the three tested ages in figures 1.3.5 - 1.3.8. All results from the three projects are indicated, as well as the straight lines associated with the points for the results from 3, 7 and 28 days, respectively. Figures 1.3.9 and 1.3.10 only contain the results of the most recent project. We have selected to approximate the correlations, using straight lines.



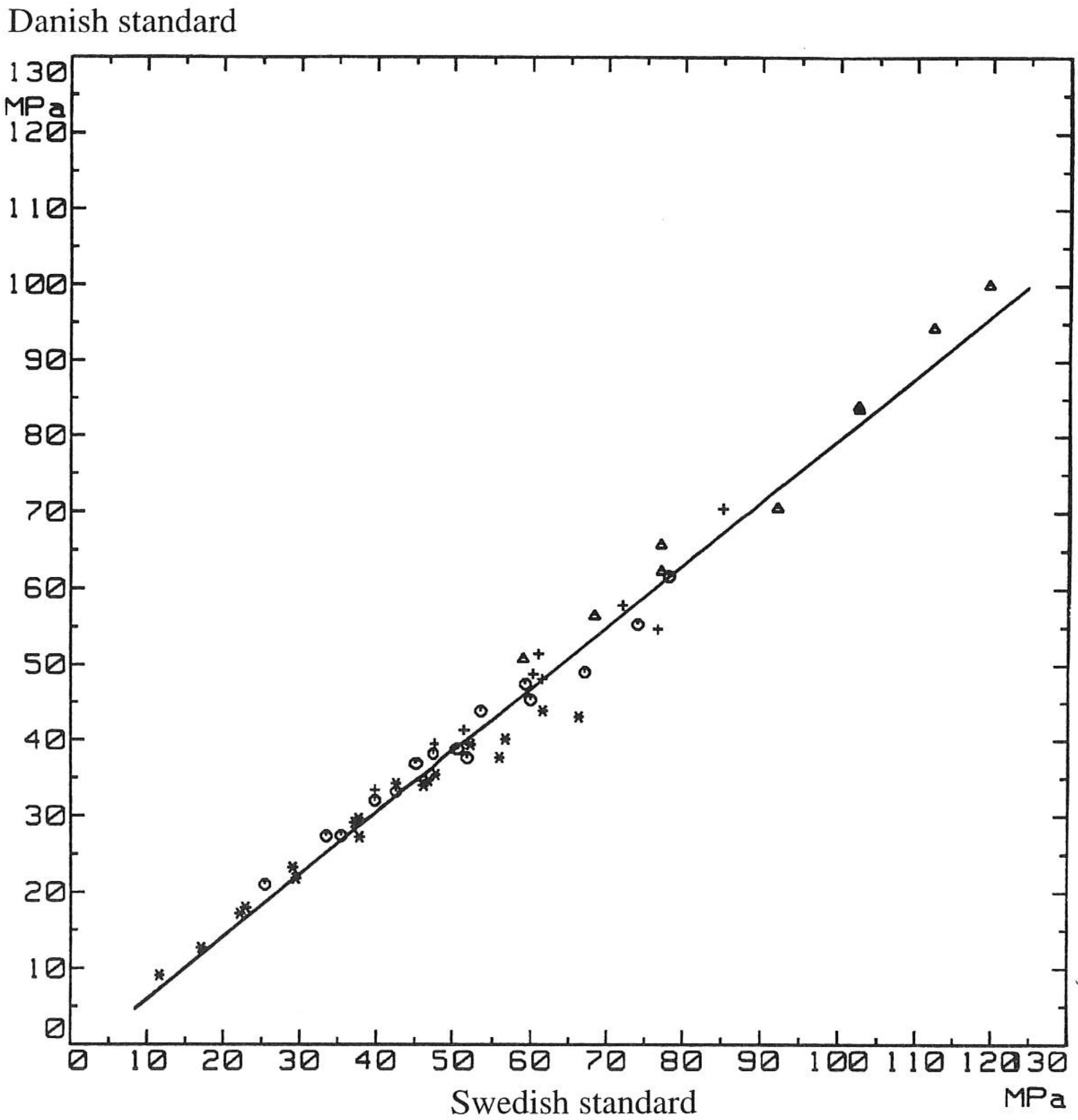
Previous projects:	*	concrete with Slite Std P
	o	concrete with Slite Std P and silica fume
Project on "high-strength concrete":	+	concrete with Slite Std P and silica fume
	Δ	concrete with Degerhamn Std P cement and silica fume

Figure 1.3.1 Correlation between the Swedish standard f_m (S) and the Finnish standard f_m (SF).
The equation for the straight line is f_m (SF) = 1.72 + 0.93 · f_m (S).
The coefficient of correlation is 0.997.



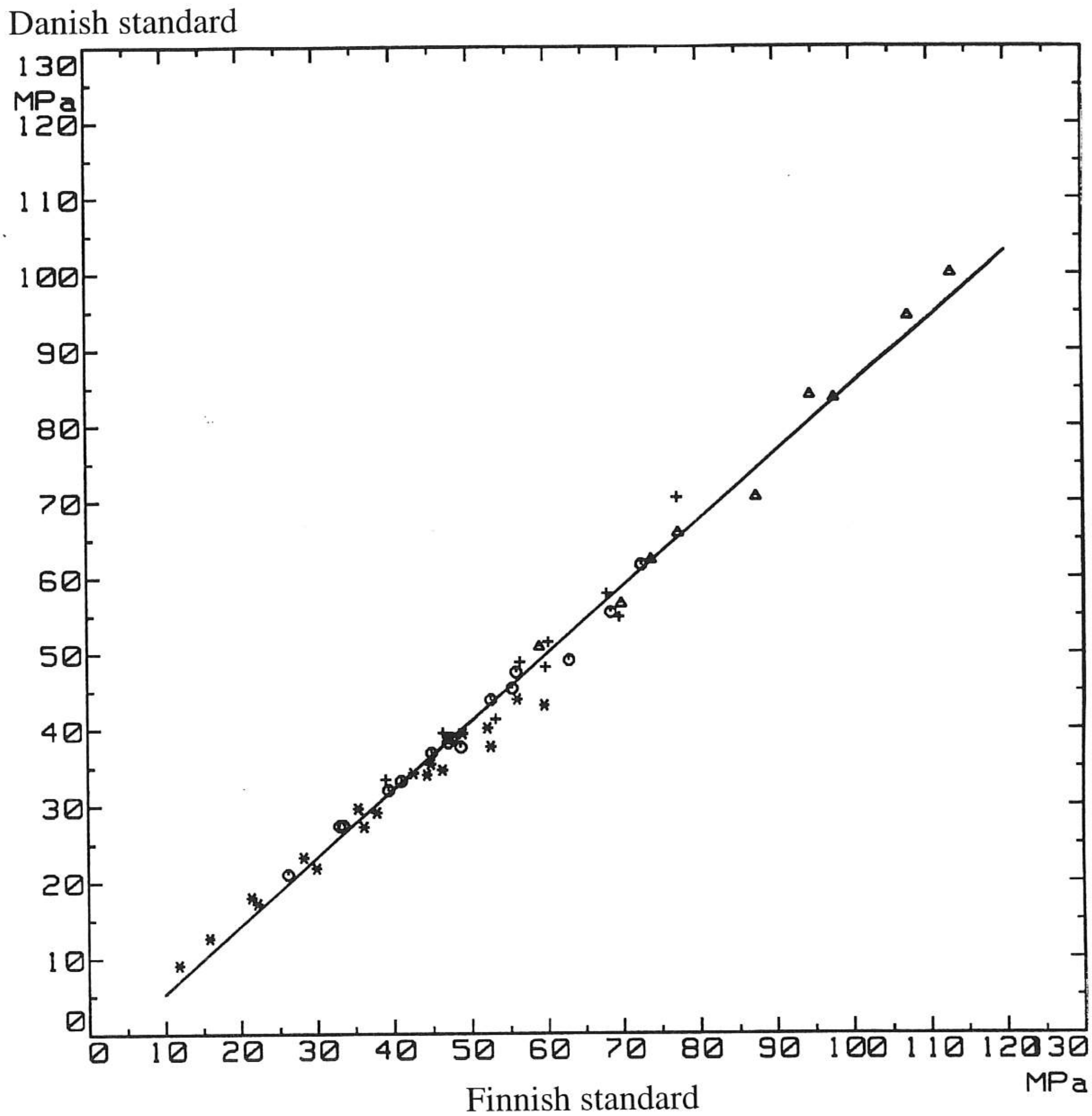
Previous projects:	*	concrete with Slite Std P
	o	concrete with Slite Std P and silica fume
Project on "high-strength concrete":	+	concrete with Slite Std P and silica fume
	Δ	concrete with Degerhamn Std P cement and silica fume

Figure 1.3.2 Correlation between the Swedish standard f_m (S) and the Norwegian standard f_m (N).
The equation for the straight line is $f_m (N) = 2.44 + 0.95 \cdot f_m (S)$.
The coefficient of correlation is 0.994.



Previous projects:	*	concrete with Slite Std P
	o	concrete with Slite Std P and silica fume
Project on "high-strength concrete":	+	concrete with Slite Std P and silica fume
	Δ	concrete with Degerhamn Std P cement and silica fume

Figure 1.3.3 Correlation between the Swedish standard f_m (S) and the Danish standard f_m (DK).
The equation for the straight line is f_m (DK) = -2.06 + 0.82 · f_m (S).
The coefficient of correlation is 0.989.



Previous projects:	*	concrete with Slite Std P
	o	concrete with Slite Std P and silica fume
Project on "high-strength concrete":	+	concrete with Slite Std P and silica fume
	Δ	concrete with Degerhamn Std P cement and silica fume

Figure 1.3.4 Correlation between the Finnish standard f_m (SF) and the Danish standard f_m (DK).
The equation for the straight line is f_m (DK) = -3.61 + 0.89 · f_m (SF).
The coefficient of correlation is 0.993.

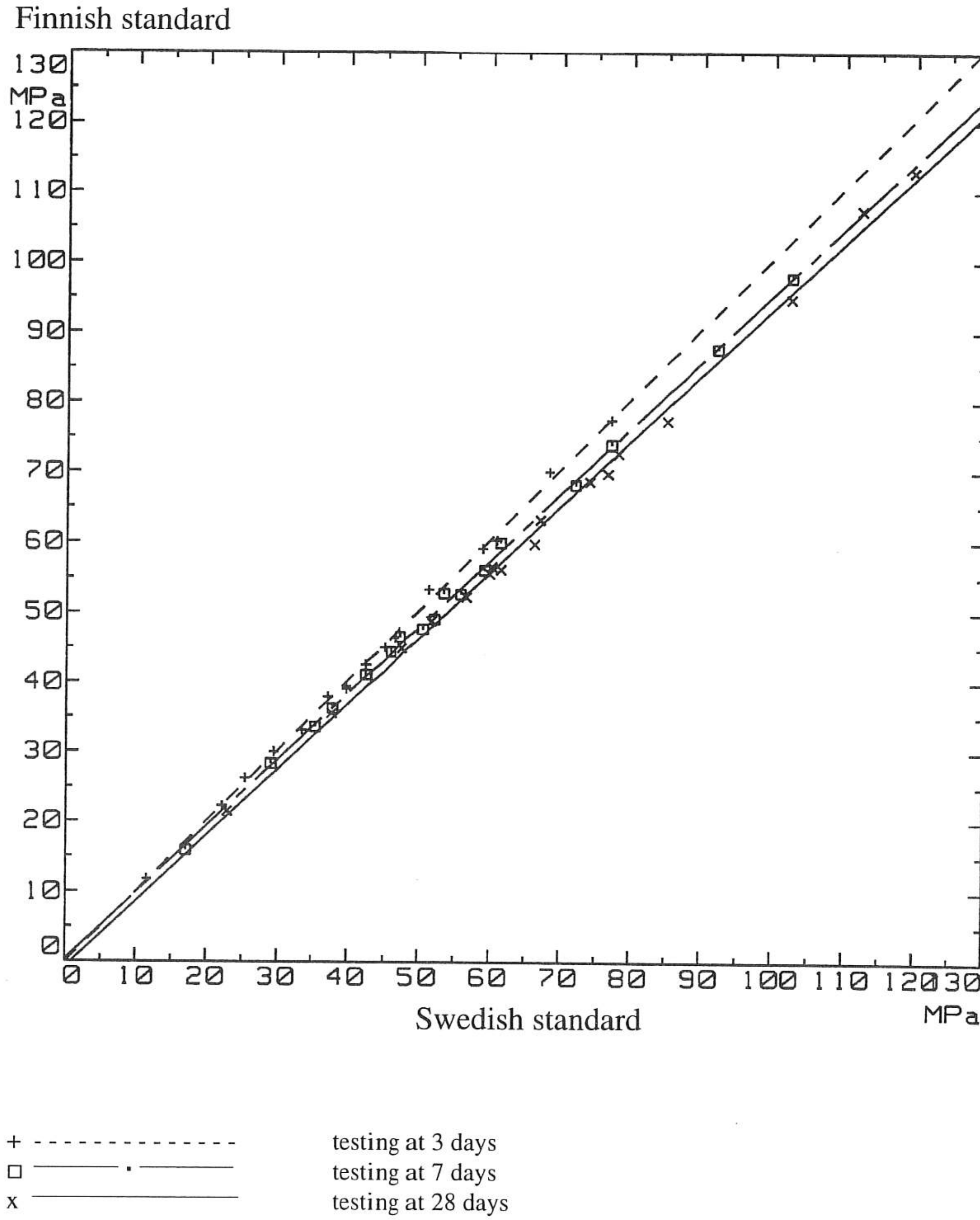


Figure 1.3.5 Correlation between the Swedish standard f_m (S) and the Finnish standard f_m (SF).

The equations for the straight line, with testing at the respective ages are:

3 days: $f_m (SF) = -0.14 + 1.01 \cdot f_m (S)$
7 days: $f_m (SF) = 0.29 + 0.95 \cdot f_m (S)$
28 days: $f_m (SF) = -0.88 + 0.94 \cdot f_m (S)$

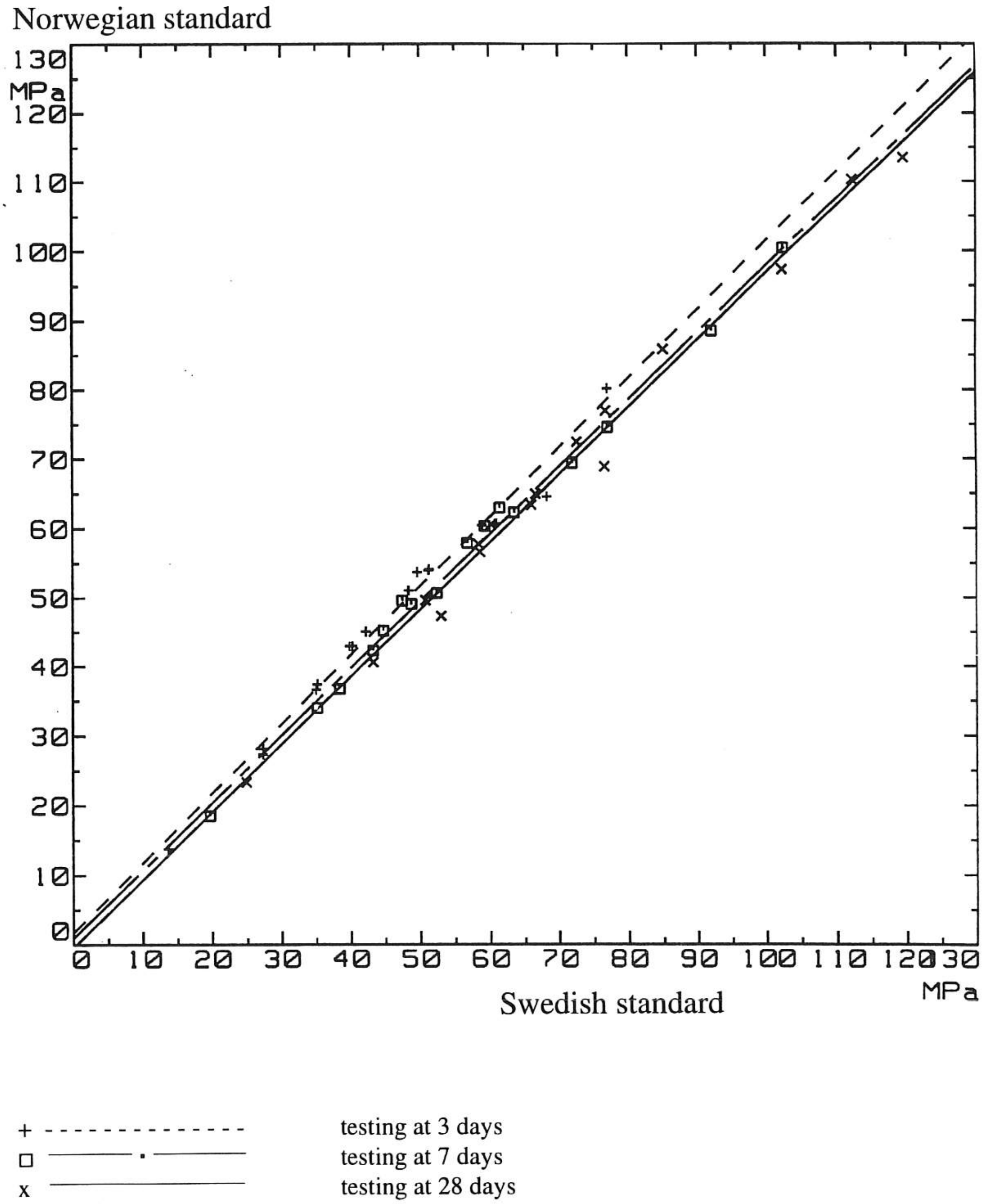
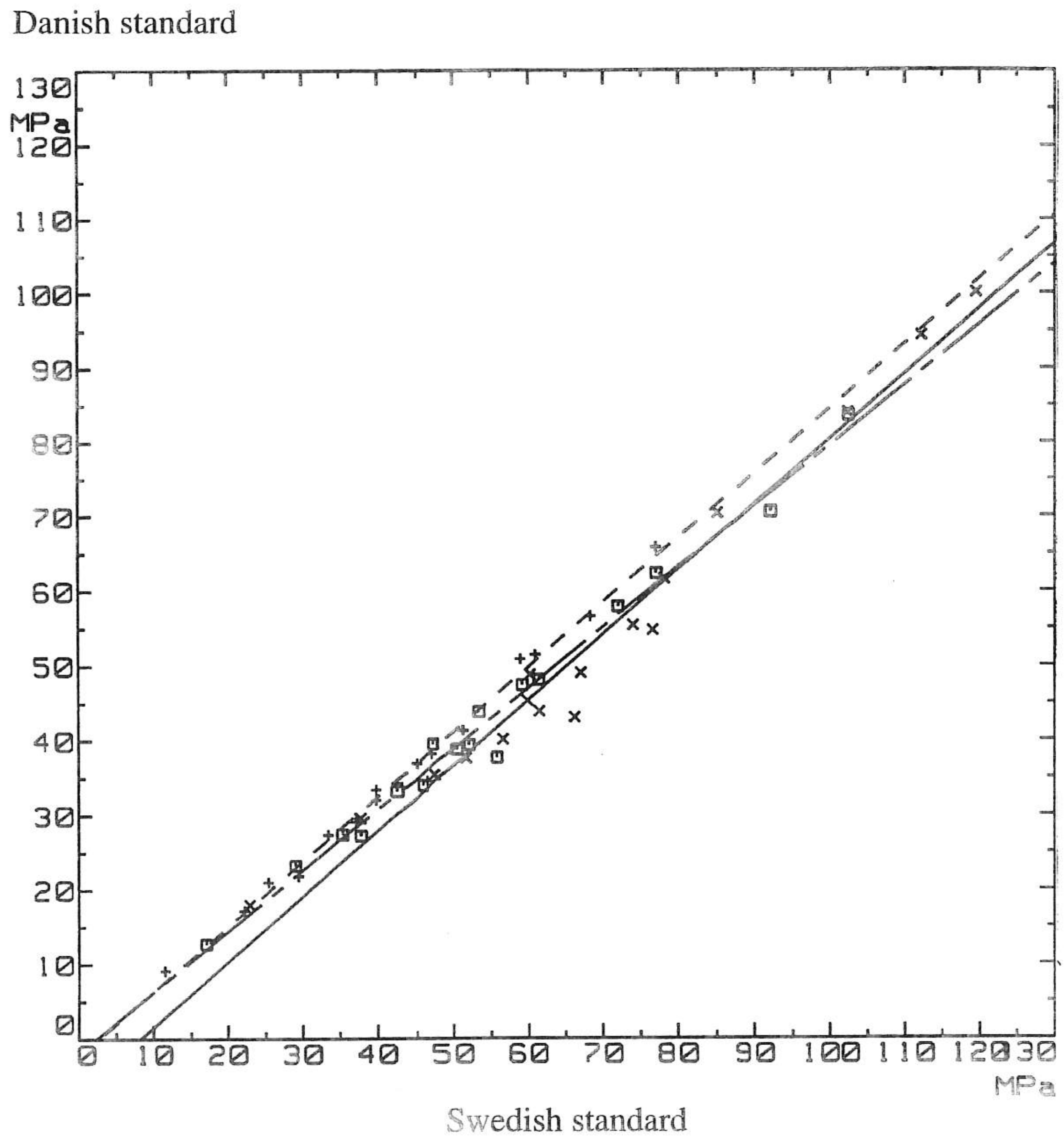


Figure 1.3.6 Correlation between the Swedish standard f_m (S) and the Norwegian standard f_m (N).

The equations for the straight line, with testing at the respective ages are:

3 days: $f_m (N) = 1.77 + 1.00 \cdot f_m (S)$
7 days: $f_m (N) = 0.99 + 0.97 \cdot f_m (S)$
28 days: $f_m (N) = -0.41 + 0.97 \cdot f_m (S)$



+ - - - - - - - - - - - - - testing at 3 days

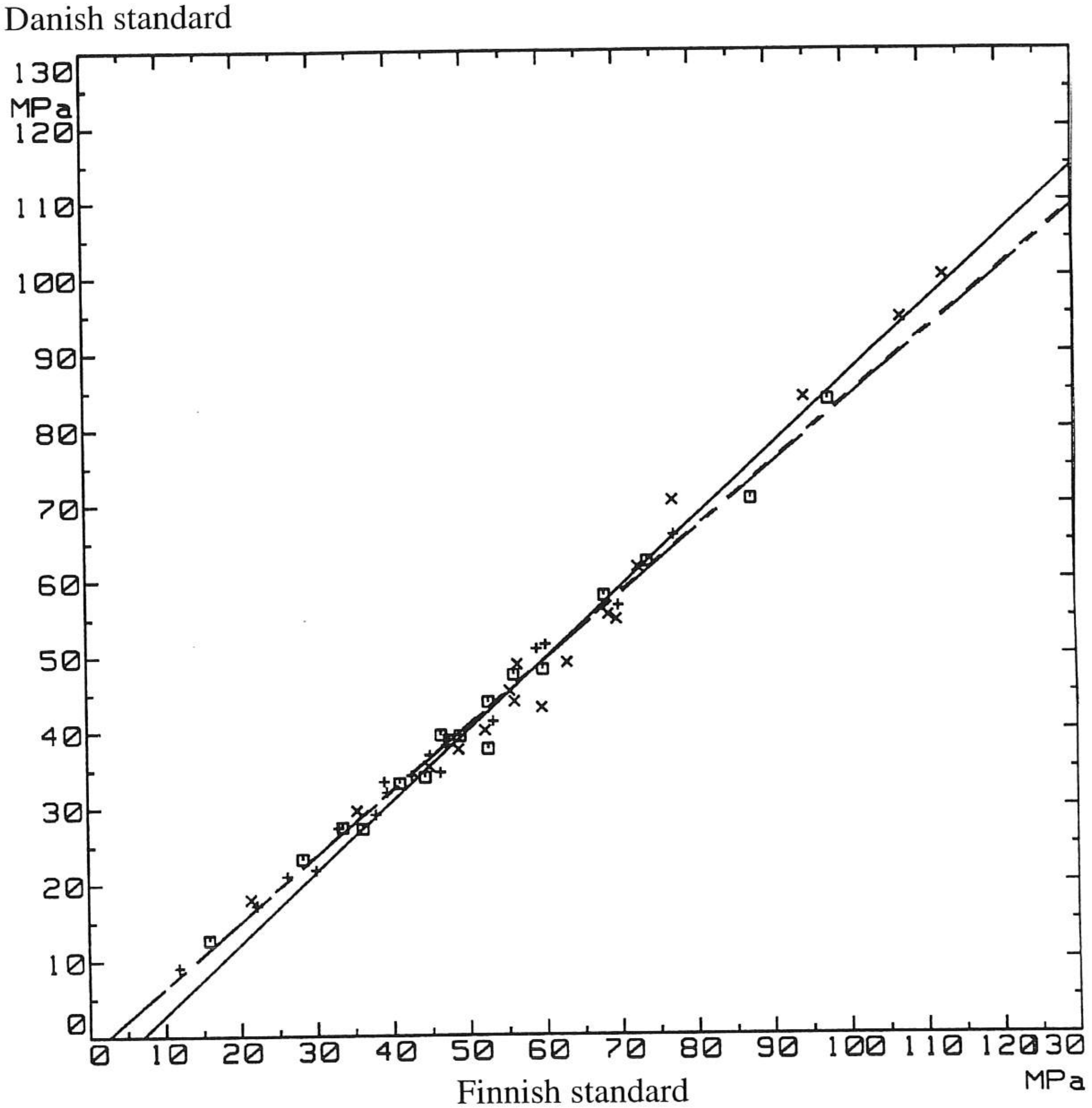
□ ———— · ———— testing at 7 days

x ———————— testing at 28 days

Figure 1.3.7 Correlation between the Swedish standard f_m (S) and the Danish standard f_m (DK).

The equations for the straight line, with testing at the respective ages are:

3 days: f_m (DK) = -2.33 + 0.87 · f_m (S)
7 days: f_m (DK) = -1.89 + 0.81 · f_m (S)
28 days: f_m (DK) = -7.18 + 0.88 · f_m (S)

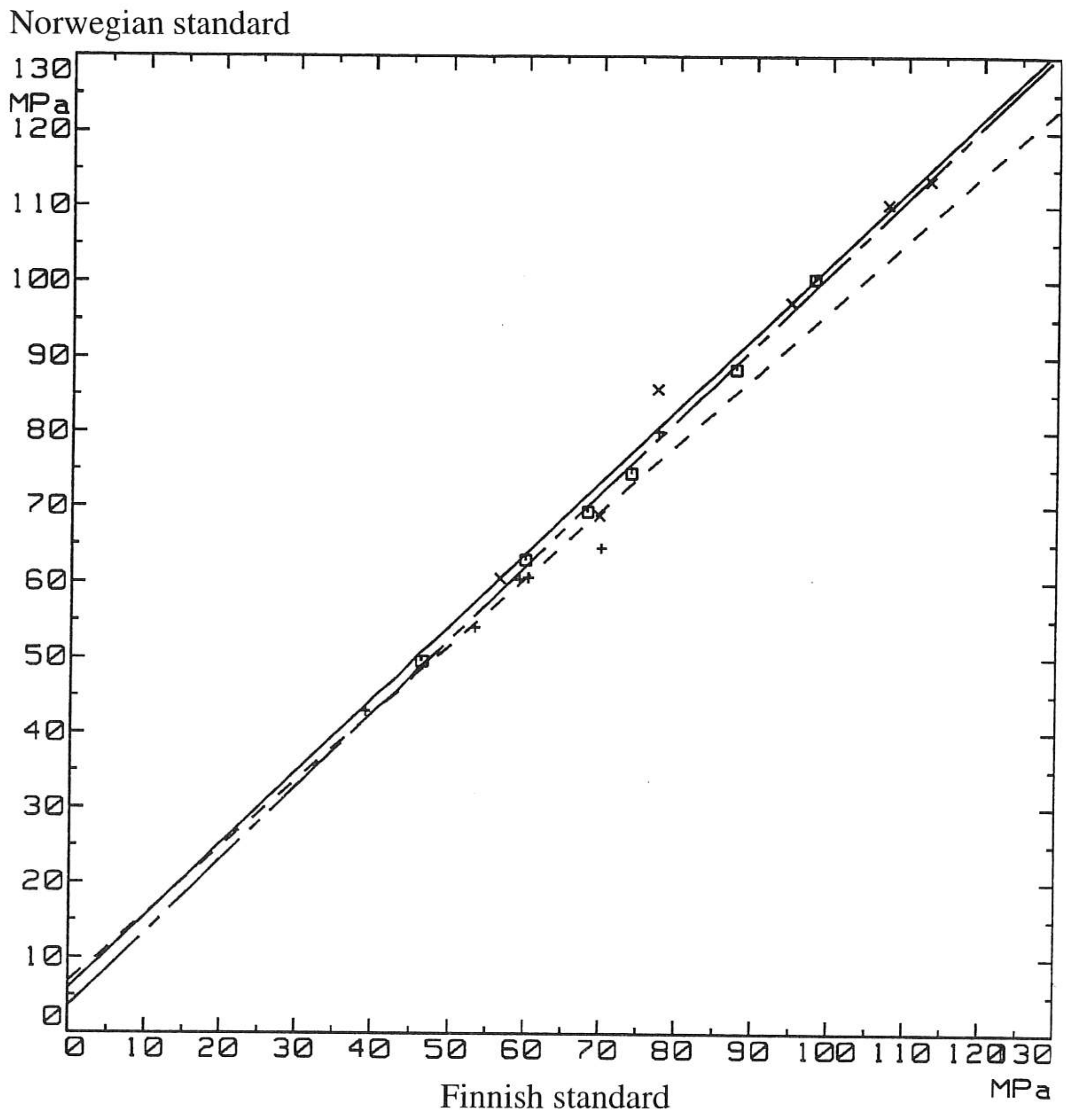


+ - - - - - - - - - - - - - testing at 3 days
□ ———— · ———— testing at 7 days
x ———————— testing at 28 days

Figure 1.3.8 Correlation between the Finnish standard f_m (SF) and the Danish standard f_m (DK).

The equations for the straight line, with testing at the respective ages are:

3 days: f_m (DK) = -2.12 + 0.86 · f_m (SF)
7 days: f_m (DK) = -2.16 + 0.86 · f_m (SF)
28 days: f_m (DK) = -6.48 + 0.93 · f_m (SF)

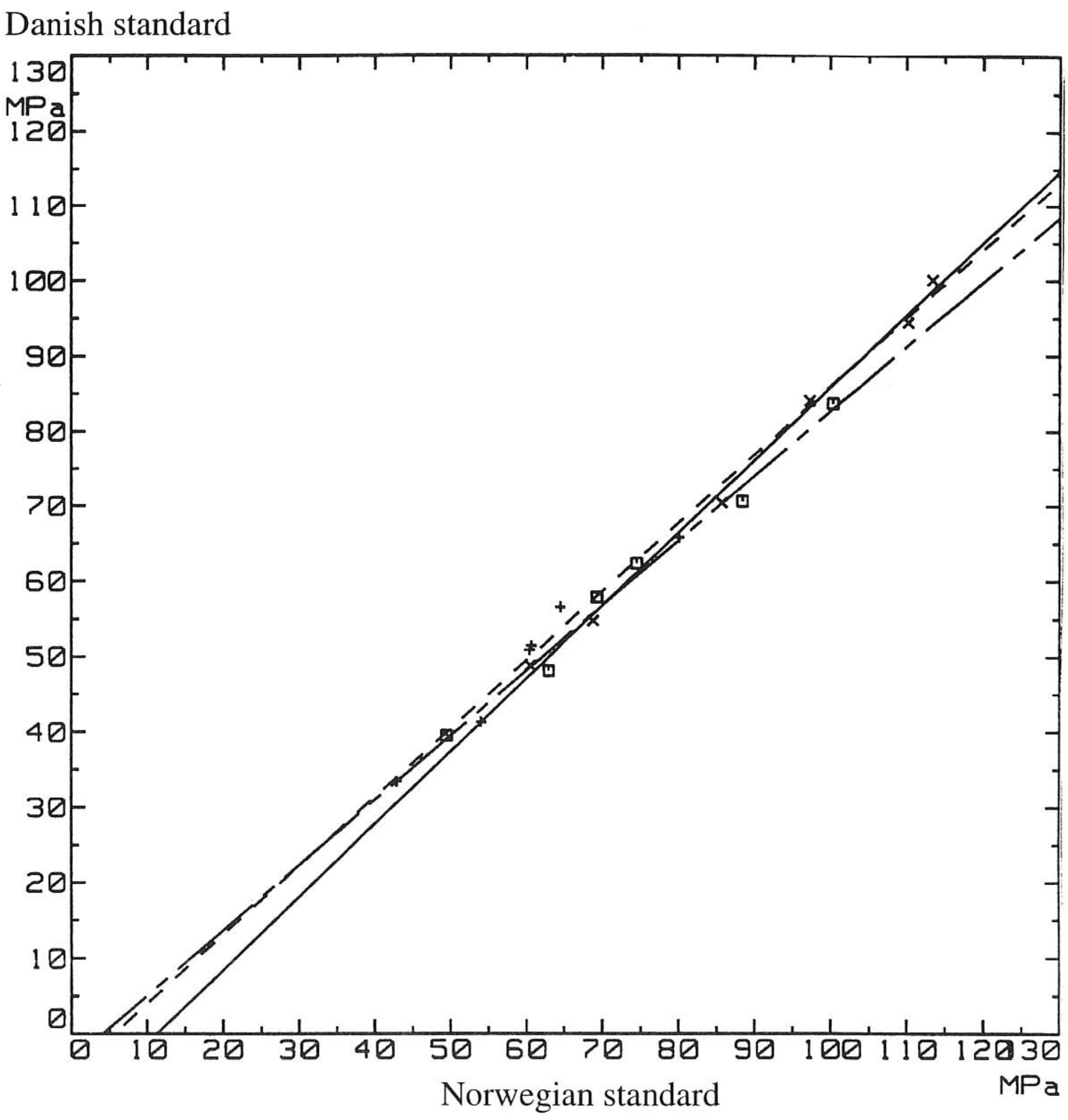


+	- - - - - - - - - - - - -	testing at 3 days
□	———— · ————	testing at 7 days
x	———————	testing at 28 days

Figure 1.3.9 High-strength concrete. Correlation between the Finnish standard f_m (SF) and the Norwegian standard f_m (N).

The equations for the straight line, with testing at the respective ages are:

3 days: $f_m (N) = 6.82 + 0.90 \cdot f_m (SF)$
7 days: $f_m (N) = 3.55 + 0.98 \cdot f_m (SF)$
28 days: $f_m (N) = 5.92 + 0.97 \cdot f_m (SF)$



+ - - - - - - - - - - - - - testing at 3 days
□ ———— · ———— testing at 7 days
x ———————— testing at 28 days

Figure 1.3.10 High-strength concrete. Correlation between the Norwegian standard f_m (N) and the Danish standard f_m (DK).

The equations for the straight line, with testing at the respective ages are:

3 days: $f_m \text{ (DK)} = -5.11 + 0.91 \cdot f_m \text{ (N)}$
7 days: $f_m \text{ (DK)} = -3.57 + 0.86 \cdot f_m \text{ (N)}$
28 days: $f_m \text{ (DK)} = -10.94 + 0.97 \cdot f_m \text{ (N)}$

1.4 Conclusions

Chapter 1 of this report describes the results of three Nordtest projects that compare Nordic methods for determination of the compressive strength of concrete. The following conclusions may be drawn:

- The results obtained gave useful diagrams for recalculation of the results obtained using one standard to another. Recalculation is necessary owing to the fact that the different standards stipulate different types of test specimens, methods of curing and rate loads.

- In each diagram , the points have been approximated with a line, and the equation for that line is given in the legend to the figure. The results from the latest project, with high-strength concrete, is very much in accord with the lines obtained for lower-strength concrete.

- For some combinations of test methods and intended compressive strengths, there is great standard deviations regarding the compressive strength of the concrete, see figure 1.4.1. The Figure shows the number of test specimens tested in each standard deviation class for all three projects. For the high compressive strengths (60-120 MPa), there was generally greater standard deviation. One explanation for this is that at the high levels of binding agent needed to achieve the intended compressive strengths, the concrete is extremely stiff.

- Figure 1.4.2 show the distribution of the methods of the different countries regarding the standard deviations obtained at testing. Results from all three projects are given, which means that somewhat more tests were carried out for Sweden and Norway. The diagram shows that the standard deviations are greatest for testing in accordance with the Norwegian and Danish methods, i.e. for cubes with 100 mm long sides, and for cylinders. For cylinders, the high level of standard deviation is probably attributable to the difficulty of obtaining acceptable test surfaces. It appears to be necessary, particularly for concrete in the high-strength classes, to grind the test surfaces, which was not done in this project.

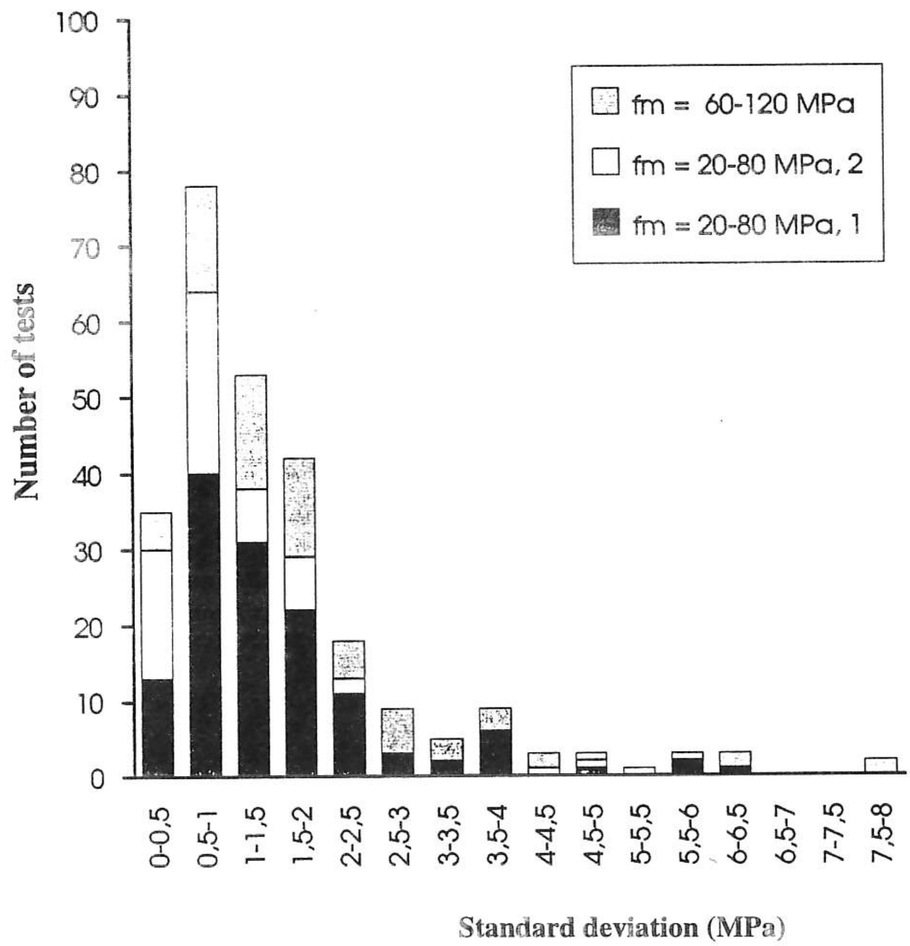


Figure 1.4.1 Number of tests in terms of standard deviations obtained when testing six test specimens. These results have been taken from Nordtest project no. 579-87 (fm = 20-80 MPa, 1), Nordtest project no. 816-89 (fm = 20-80 MPa, 2) and Nordtest project no. 975-91 (fm = 60-120 MPa).

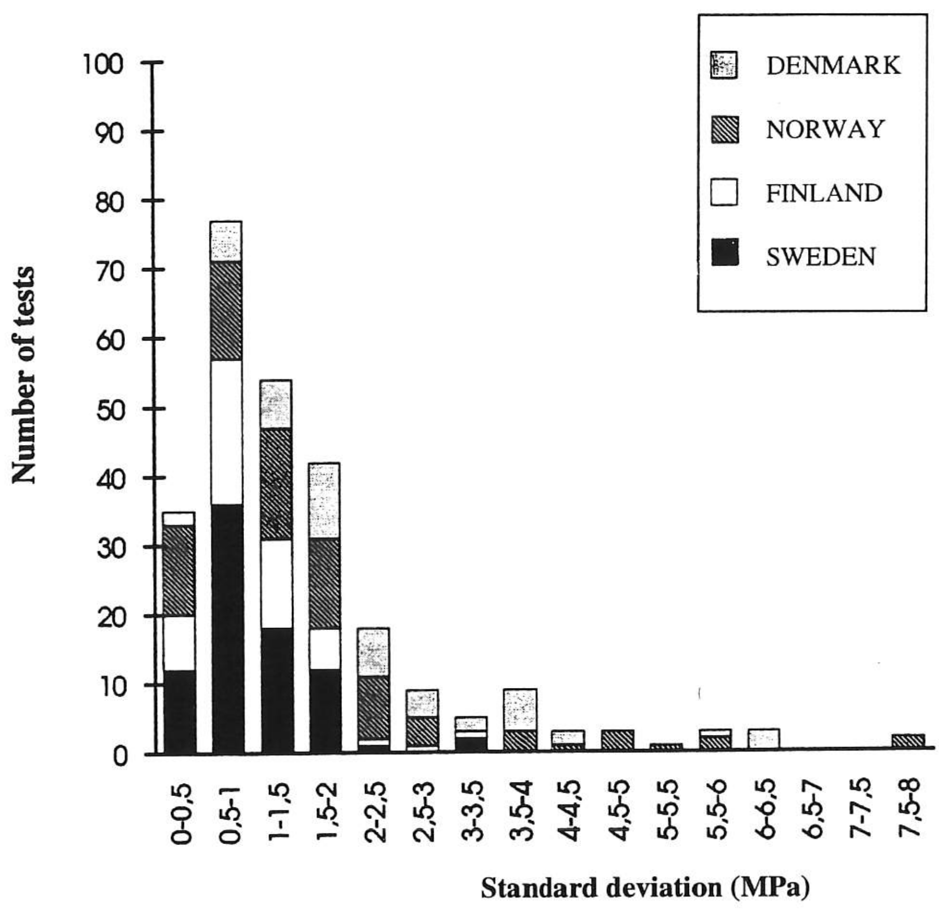


Figure 1.4.2 Number of tests from the four Nordic countries in terms of standard deviations obtained when testing six test specimens. These results have been taken from all three projects.

2 Correlations between the characteristic compressive strengths in the Nordic countries (K and C values, respectively)

2.1 Introduction

Concrete is normally classified in terms of compressive strength obtained by testing. For each compressive strength class, a value is given. This is the “characteristic value”, which is to be verified through testing. In the Nordic countries, different methods are used to determine the compressive strength of concrete, as described in chapter 1.2.3. Different methods are also used to calculate the control values which are to be compared with the stipulated characteristic values for each compressive strength classification. Chapter 1.3 describes results obtained from testing the compressive strength of concrete using the Swedish, Finnish, Norwegian and Danish standards. Figures 1.3.1-1.3.10 show the correlations between the results regarding compressive strength for the methods of two countries at a time, in the compressive strength interval of 10-110 MPa. This chapter describes a method for comparing compressive strength categories, as evaluated using the method of each respective country.

2.2 Methods for evaluation of characteristic compressive strength values

2.2.1 Sweden

In Sweden, the compressive strength of concrete is evaluated pursuant to the “Provisions for Concrete structures 79, 2nd ed, vol. 2, chapter 7.3.3.2. Evaluation of compressive strength in continuous testing” is carried out as follows:

$f_k\ (S) \leq f_m\ (S) - 3$ for $n = 3$

$f_k\ (S) \leq f_m\ (S) - 1.4 \cdot s$ for $n \geq 9$

Moreover, the compressive strength value of the individual test is to be greater than f_k (S) - 4 MPa and $0.8 \cdot$ (S).

Abbreviations:

f_k (S) = characteristic compressive strength value in Sweden (K value)

f_m (S) = mean of the spot sample values in Sweden

s = standard deviation of the spot sample

n = number of test specimens

2.2.2 Finland

In Finland, the compressive strength of concrete is evaluated pursuant to the Finnish Building Provisions, part B4, chapter 6.3.5. Calculation of compressive strength using standard tests, is carried out as follows:

f_k (SF) $\leq f_m$ (SF) - $k \cdot s$	for $6 < n < 16$,	$k = 1.65$
	for $n > 16$	$k = 1.5$

Under controlled manufacturing conditions, k is set at 1.4. If fewer than 25 tests are included in the calculation of s, the standard deviation may be no less than 2 MPa.

Abbreviations:

f_k (SF) = characteristic compressive strength value in Finland (K value)

f_m (SF) = mean of the spot sample values in Finland

s = standard deviation of the spot sample

n = number of test specimens

2.2.3 Norway

In Norway, the compressive strength of concrete is evaluated pursuant to NS 3420, chapter 1.5, as follows:

f_k (N) $\leq f_m - k \cdot s$

when the value of k is as given below, depending on the number of test specimens:

n	3	4-5	6-10	11-20	20
k	2.5	2.0	1.7	1.5	1.4

Moreover, the compressive strength value of the individual test is to be greater than 80 % of f_k.

Abbreviations:

f_k (N) = characteristic compressive strength value in Norway (K value)

f_m (N) = mean of the spot sample values in Norway

s = standard deviation of the spot sample

n = number of test specimens

2.2.4 Denmark

In Denmark, the compressive strength of concrete is evaluated pursuant to DS 411, chapter 8.1.1. When random sample checks are carried out, the following formula is used:

f_k (DK) $\leq f_m$ (DK) / k_n

$k_n = \exp((1/\sqrt{n}+2.28)\ \delta - 0.1875)$

$$\delta = \frac{s}{f_m\ (DK)}$$

Abbreviations:

f_k (DK) = characteristic compressive strength value in Denmark (C value)

f_m (DK) = mean of the spot sample values in Norway

s = standard deviation of the spot sample

n = number of test specimens

δ = coefficient of variation for the random sample

2.3 Calculation of the correlation between the characteristic compressive strengths in the Nordic countries (K and C values, respectively)

Using the equations presented in sections 2.2.1 - 2.2.4 and the lines in figures 1.3.1 - 1.3.10, it is possible to calculate the correlation between the characteristic compressive strengths in the different countries (i.e. K values in Sweden, Norway and Finland, and C values in Denmark). The results of such calculations are presented in table 2.1, and in figures 2.1 - 2.6.

The correlations are influenced by the number of test specimens in a test series, as well as by the distribution of test results. In the present case, calculations have been made for 3, 9, and 15 test specimens and for 6 test specimens for Finland, as 6 is the minimum number accepted there. The distribution was set at 2 or 4 MPa, which may be considered normal values, cf. figures 1.4.1 and 1.4.2.

As indicated in the results, the correlations between the characteristic values in the different countries is normally only slightly influenced by the parameters number of test specimens and distribution. However, this is not necessarily true when the number of test specimens is small (3) and when distribution is great (4 MPa).

Standard deviation	Number of specimens		
	3	9	15
		$f_k(SF)=0,93f_k(S)+1,0$	$f_k(SF)=0,93f_k(S)+1,0$
	$f_k(N)=0,95f_k(S)+0,3$	$f_k(N)=0,95f_k(S)+1,7$	$f_k(N)=0,95f_k(S)+2,1$
	$f_k(DK)=0,98f_k(S)-5,4$	$f_k(DK)=0,98f_k(S)-5,0$	$f_k(DK)=0,98f_k(S)-5,1$
		$f_k(N)=1,02f_k(SF)+0,7$	$f_k(N)=1,02f_k(SF)+1,1$
s=2 MPa		$f_k(DK)=1,06f_k(SF)-6,3$	$f_k(DK)=1,06f_k(SF)-6,1$
	$f_k(DK)=1,03f_k(N)-5,7$	$f_k(DK)=1,04f_k(N)-6,9$	$f_k(DK)=1,04f_k(N)-7,2$
		$*f_k(SF)=0,93f_k(S)+1,5$	$*f_k(SF)=0,93f_k(S)+1,5$
		$*f_k(N)=1,02f_k(SF)+0,1$	$*f_k(N)=1,02f_k(SF)+0,5$
		$*f_k(DK)=1,06f_k(SF)-6,8$	$*f_k(DK)=1,06f_k(SF)-6,7$
		$f_k(SF)=0,93f_k(S)+0,3$	$f_k(SF)=0,93K(S)+0,3$
	$f_k(N)=0,95f_k(S)-4,7$	$f_k(N)=0,95f_k(S)+1,0$	$f_k(N)=0,95K(S)+1,8$
	$f_k(DK)=0,96f_k(S)-9,7$	$f_k(DK)=0,97f_k(S)-6,5$	$f_k(DK)=0,97K(S)-6,3$
		$f_k(N)=1,02f_k(SF)+0,6$	$f_k(N)=1,02f_k(SF)+1,4$
s=4 MPa		$f_k(DK)=1,04f_k(SF)-6,9$	$f_k(DK)=1,04f_k(SF)-6,7$
	$f_k(DK)=1,02f_k(N)-4,9$	$f_k(DK)=1,02f_k(N)-7,5$	$f_k(DK)=1,02f_k(N)-8,1$
		$*f_k(SF)=0,93f_k(S)+1,3$	$*f_k(SF)=0,93f_k(S)+1,3$
		$*f_k(N)=1,02f_k(SF)-0,4$	$*f_k(N)=1,02f_k(SF)+0,4$
		$*f_k(DK)=1,04f_k(SF)+7,9$	$*f_k(DK)=1,04f_k(SF)-7,7$

Table 2.3.1 Correlation between characteristic values for the Nordic countries at different numbers of test specimens and different standard deviations. For correlations marked with an asterisk, k = 1.4 has been assumed when evaluating f_k (SF) (under controlled concrete manufacturing conditions). In other equations, k was set at 1.65 for calculation of f_k (SF), cf. chapter 2.2.2.

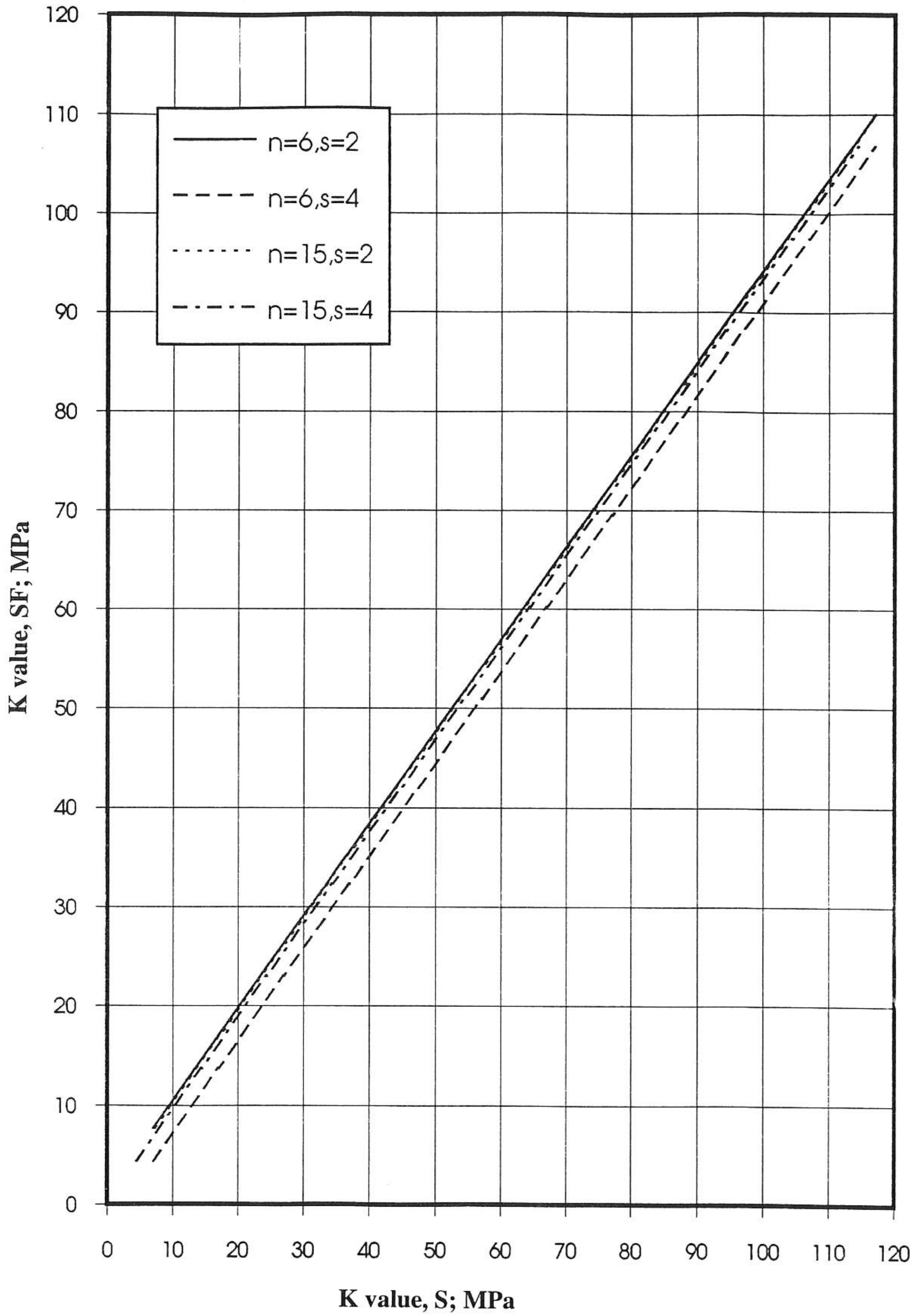


Figure 2.3.1 Correlation between K values in Sweden and in Finland (K value = f_k). For calculation of f_k (SF), k was set at 1.65, although under controlled concrete manufacturing conditions the value k = 1.4 may be used, cf. table 2.3.1.

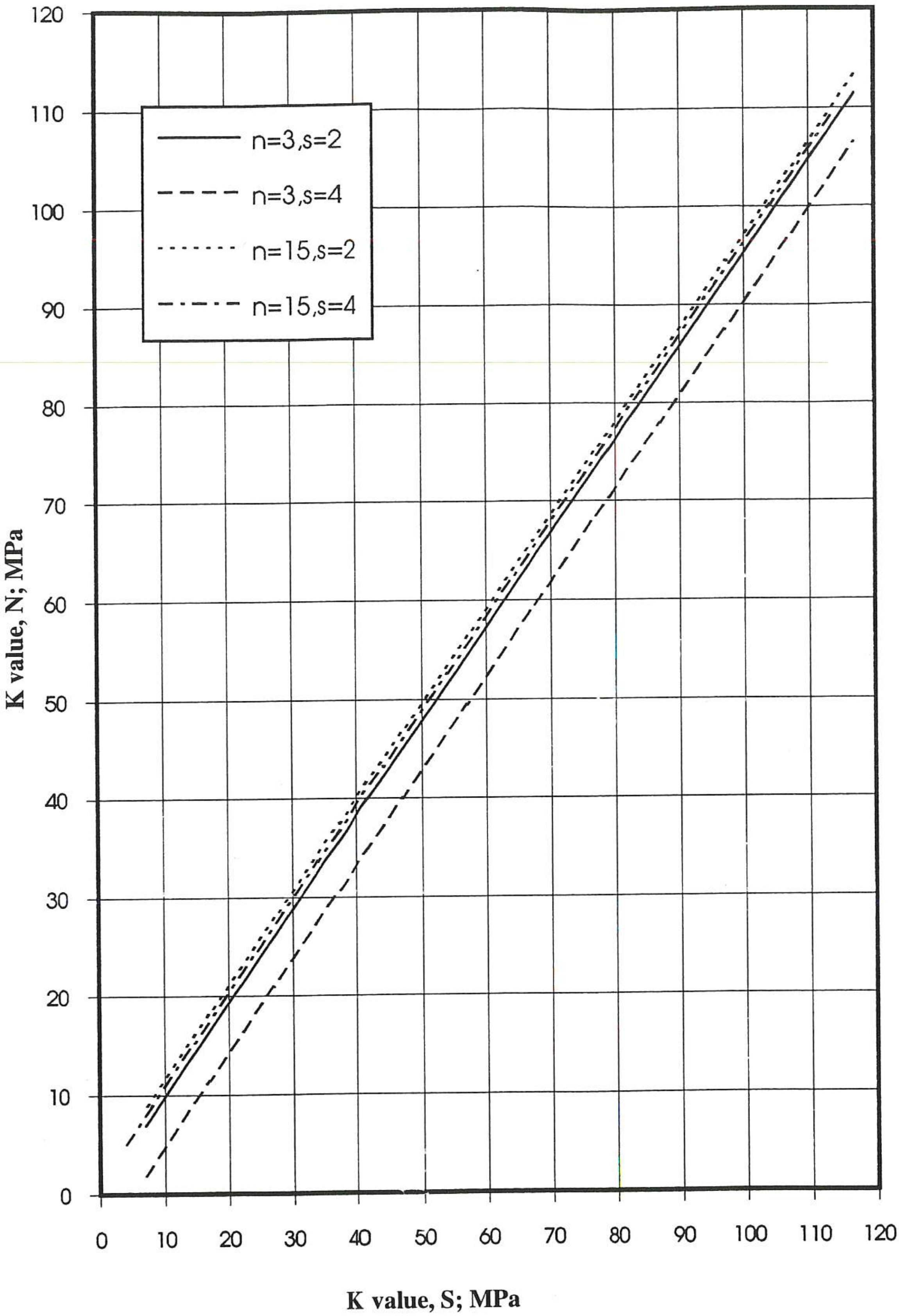


Figure 2.3.2 Correlation between K values in Sweden and in Norway (K value = f_k).

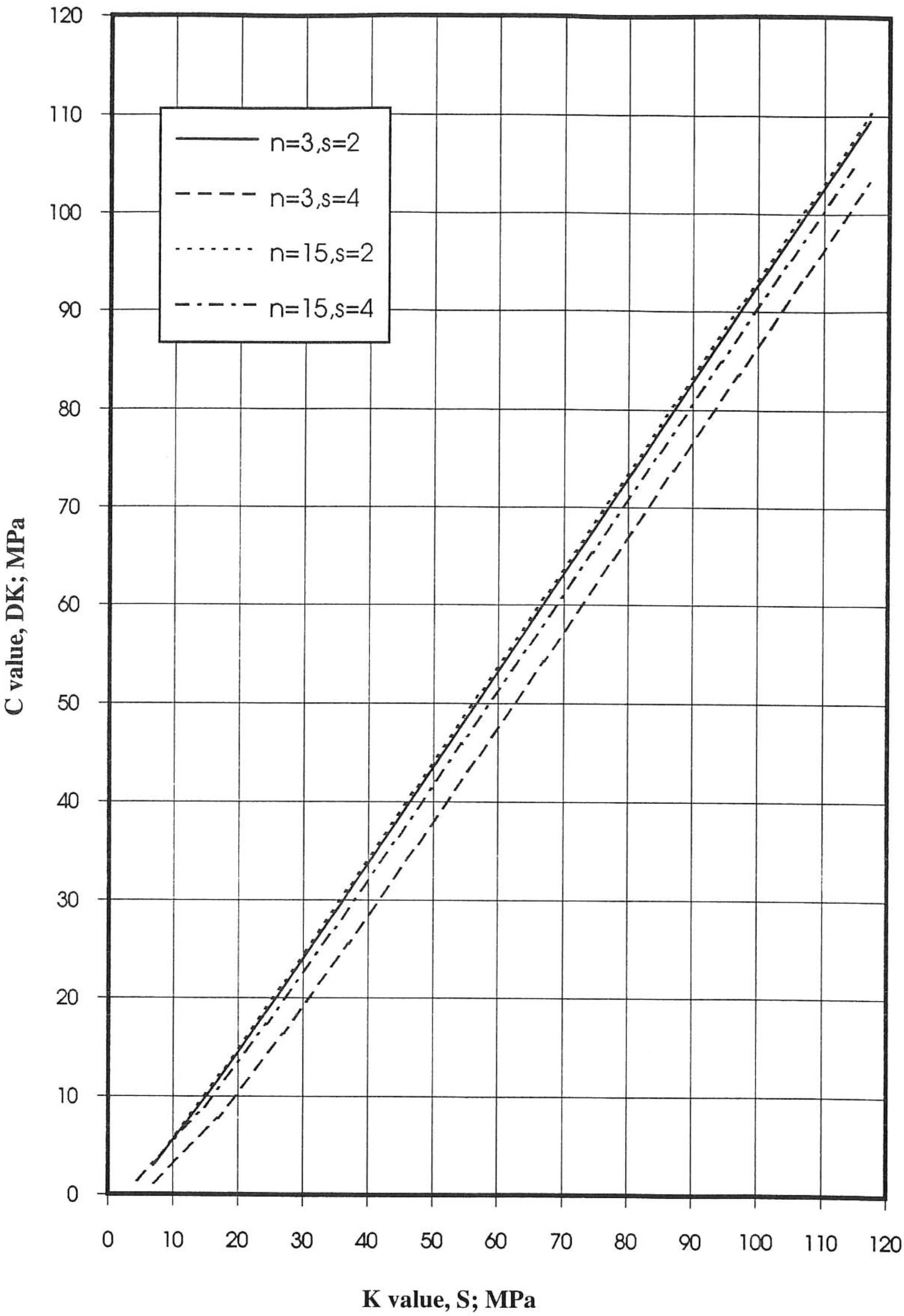


Figure 2.3.3 Correlation between K values in Sweden and C values in Denmark (K value and C value = f_k).

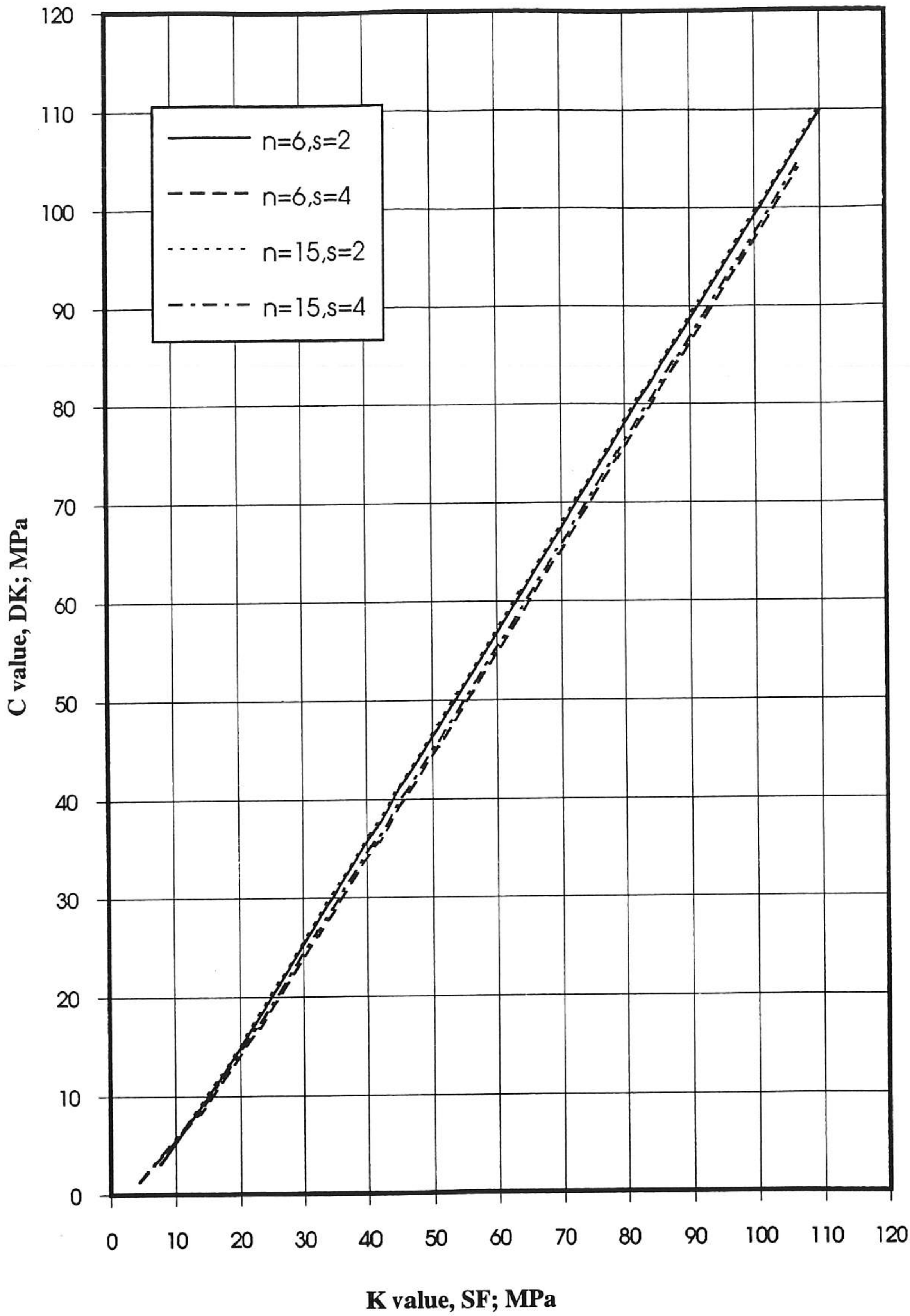


Figure 2.3.4 Correlation between K values in Finland and in C values in Denmark (K value and C value = f_k). For calculation of f_k (SF), k was set at 1.65, although under controlled concrete manufacturing conditions the value k = 1.4 may be used, cf. table 2.3.1.

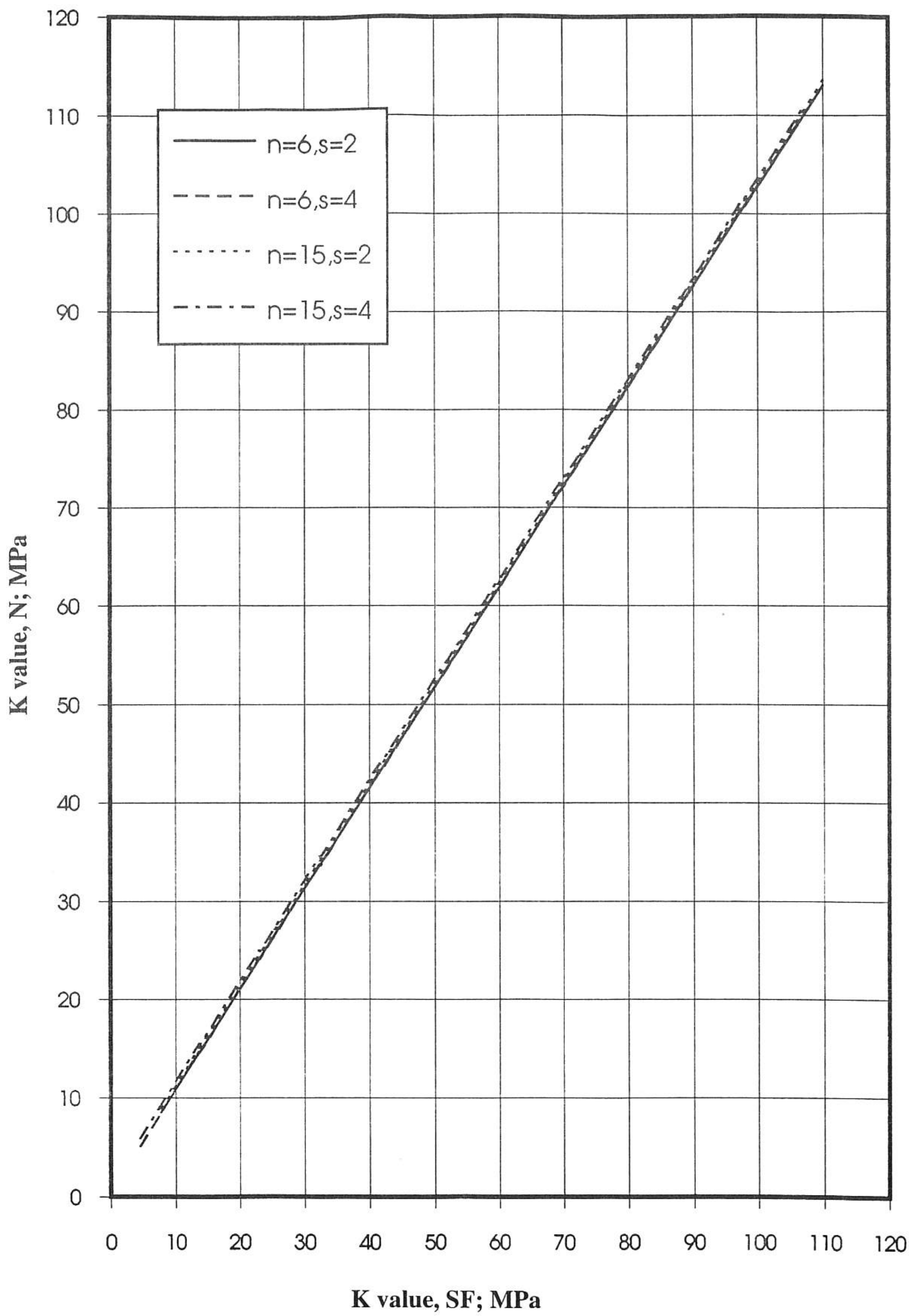


Figure 2.3.5 Correlation between K values in Finland and in Norway (K value = f_k). For calculation of f_k (SF), k was set at 1.65, although under controlled concrete manufacturing conditions the value k = 1.4 may be used, cf. table 2.3.1.

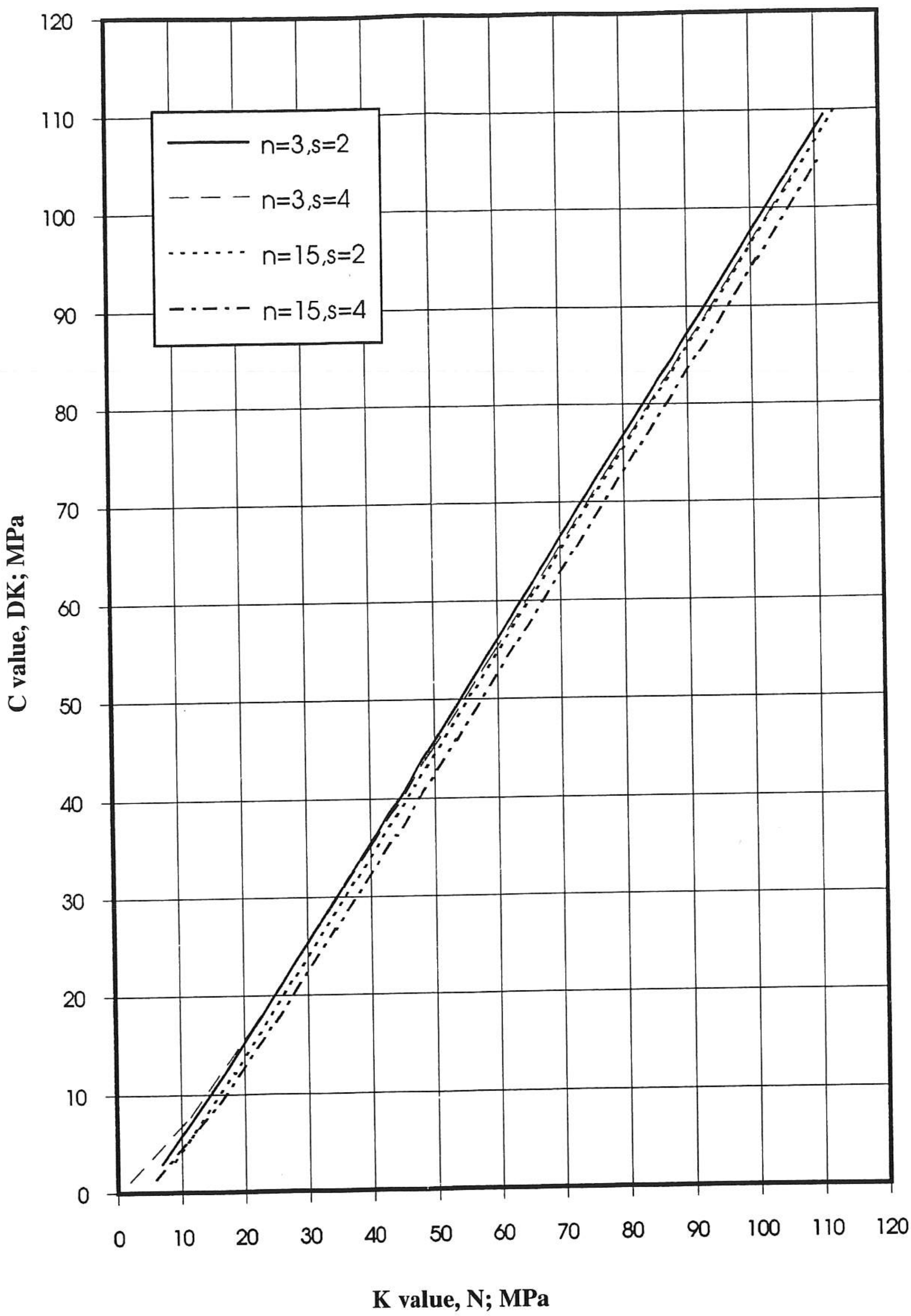


Figure 2.3.6 Correlation between K values in Norway and C values in Denmark (K value and C value = f_k). For calculation of f_k (SF), k was set at 1.65, although under controlled concrete manufacturing conditions the value k = 1.4 may be used, cf. table 2.3.1.

3 References

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Appendix 1.1

Test results

Table 1.1 Test results for concrete with Slite Std P and silica fume as binding agent. Density is given with the ten unit digit rounded off to 0 or 5.
m = mean and s = standard deviation for six test specimens.

Intended compressive strength	Age		Swedish standard	Finnish standard	Norwegian standard	Danish standard
60	**3 days**					
	Density (kg/m³)	m	2350	2350	2350	2400
	Compressive strength (MPa)	m	39.8	39.1	42.9	33.4
		s	1.0	1.2	1.6	2.2
	7 days					
	Density (kg/m³)	m	2350	2350	2350	2450
	Compressive strength (MPa)	m	47.5	46.5	49.5	39.5
		s	0.9	0.3	1.2	1.7
	28 days					
	Density (kg/m³)	m	2350	2350	2400	2400
	Compressive strength (MPa)	m	60.2	56.5	60.5	48.8
		s	0.5	1.0	1.6	1.6
70	**3 days**					
	Density (kg/m³)	m	2350	2400	2400	2400
	Compressive strength (MPa)	m	51.3	53.3	54.0	41.3
		s	0.5	0.4	1.1	3.6
	7 days					
	Density (kg/m³)	m	2350	2400	2400	2350
	Compressive strength (MPa)	m	61.4	59.9	62.9	48.1
		s	0.8	1.0	1.0	2.5
	28 days					
	Density (kg/m³)	m	2350	2350	2400	2400
	Compressive strength (MPa)	m	76.6	69.7	68.8	54.7
		s	1.4	0.8	7.8	6.4

Appendix 1.2

Table 1.1 Test results for concrete with Slite Std P and silica fume as binding agent. Density is given with the ten unit digit rounded off to 0 or 5.
m = mean and s = standard deviation for six test specimens.

Intended compressive strength	Age		Swedish standard	Finnish standard	Norwegian standard	Danish standard
80	**3 days**					
	Density (kg/m^3)	m	2400	2400	2400	2400
	Compressive strength (MPa)	m	60.9	60.3	60.6	51.4
		s	0.9	0.8	1.0	3.0
	7 days					
	Density (kg/m^3)	m	2400	2400	2400	2450
	Compressive strength (MPa)	m	72.0	68.1	69.3	57.8
		s	0.6	0.6	1.4	1.8
	28 days					
	Density (kg/m^3)	m	2400	2400	2450	2450
	Compressive strength (MPa)	m	85.1	77.3	85.7	70.4
		s	2.0	2.7	2.3	2.8

Appendix 1.3

Table 1.2 Test results for concrete with Degerhamn Std P cement and silica fume as binding agent. Density is given with the ten unit digit rounded off to 0 or 5. m = mean and s = standard deviation for six test specimens.

Intended compressive strength	Age		Swedish standard	Finnish standard	Norwegian standard	Danish standard
100	**3 days**					
	Density (kg/m³)	m	2450	2400	2450	2450
	Compressive strength (MPa)	m	58.9	59.1	60.4	50.8
		s	1.2	0.5	1.4	2.0
	7 days					
	Density (kg/m³)	m	2400	2450	2450	2450
	Compressive strength (MPa)	m	77.1	73.9	74.5	62.3
		s	1.2	1.3	2.8	2.7
	28 days					
	Density (kg/m³)	m	2400	2400	2400	2400
	Compressive strength (MPa)	m	102.4	94.7	97.3	84.0
		s	0.8	1.4	2.2	5.6
110	**3 days**					
	Density (kg/m³)	m	2450	2450	2450	2450
	Compressive strength (MPa)	m	68.3	70.0	64.5	56.5
		s	1.2	0.7	5.0	3.6
	7 days					
	Density (kg/m³)	m	2450	2450	2450	2500
	Compressive strength (MPa)	m	92.1	87.6	88.4	70.6
		s	1.1	1.1	2.0	6.3
	28 days					
	Density (kg/m³)	m	2450	2450	2450	2500
	Compressive strength (MPa)	m	112.3	107.4	110.3	94.4
		s	3.3	2.0	2.6	4.4

Appendix 1.4

Table 1.2 Test results for concrete with Degerhamn Std P cement and silica fume as binding agent. Density is given with the ten unit digit rounded off to 0 or 5.
m = mean and s = standard deviation for six test specimens.

Intended compressive strength	Age		Swedish standard	Finnish standard	Norwegian standard	Danish standard
120	**3 days**					
	Density (kg/m³)	m	2450	2450	2450	2500
	Compressive strength (MPa)	m	77.0	77.4	80.1	65.8
		s	1.6	1.5	1.8	2.5
	7 days					
	Density (kg/m³)	m	2450	2450	2450	2500
	Compressive strength (MPa)	m	102.5	97.8	100.4	83.6
		s	1.9	1.4	3.8	4.4
	28 days					
	Density (kg/m³)	m	2450	2450	2450	2500
	Compressive strength (MPa)	m	119.6	113.0	113.5	100.1
		s	3.1	1.8	7.7	3.5