PROPERTIES OF NORWEGIAN BLENDED CEMENTS WITH AND WITHOUT SILICA FUME

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SYNOPSIS

In order to save energy and raw materials, NORCEM CEMENT is producing cement (MP30) where fly ash is added in the grinding process. The objective of this research program has been to document important properties for concrete and cement paste of MP30 cements in relation to comparable mixes of Ordinary Portland Cement (P30). Also, the effect of silica fume should be documented.

One P30 cement and three MP30 cements, one with 10%, one with 25% fly ash and one with 15% slag were included in the test program.

Concrete properties both in fresh state and in green state were tested along with long term durability properties. In cement paste, chemical and durability aspects were studied.

The main conclusions are that service performance for mixes with the new MP30 cements is approximately the same as in comparable mixes with P30 cement, especially as far as properties of fresh concrete and mechanical properties are concerned. Concretes with MP30 cements and silica fume is somewhat more influenced by incomplete curing than comparable mixes with P30 cement without silica fume. Carbonation rate is equal or somewhat faster in mixes with MP30 cements and silica fume than in comparable mixes with P30 cement without silica fume. The other durability parameters tested were better in mixes with MP30. The effect of silica fume in mixes with MP30 cements was approximately the same as in mixes with P30 cement.

Keywords: Blended cements, fly ash, slag, material properties, durability.

1 INTRODUCTION

In order to save energy and raw materials, NORCEM CEMENT is now producing cement where 20% of the cement is replaced by fly ash in the grinding process. Addition of preground slag in the grinding process is planned as well.

Three types of blended cements (MP30) are tested in comparison with an Ordinary Portland Cement (P30). The main goal with the new MP30 cements has been that service performance should be equal to or better than comparable mixes with P30 cement.

The objective of this research program has been to document important properties for concrete and cement paste of MP30 cements in relation to comparable mixes of P30 cement. Also the effect of silica fume should be documented.

The new cements are tested in three concrete strength grades and in cement pastes with three w/c-ratios. Different levels of silica fume additions are also included.

The test results are reported in 12 reports /1 - 12/, all in Norwegian.

2 MATERIALS AND PROGRAM

2.1 Materials

One P30 cement and three MP30 cements, one with 10%, one with 25% class F fly ash and one with 15% blast furnace slag were tested. Fly ash and preground slag was added during the grinding process of the cement. Chemical and physical data for the cements are given in /1/.

Silica fume from a silicon alloy factory was added in form of a slurry. Chemical and physical data for the silica fume is given in /1/.

The fine aggregate was a natural sand and the coarse aggregate was a crushed basalt. A limestone filler was used in the leanest mixes.

The water reducer was a lignosulphonate based liquid with 40% solid lignosulphonate and 60% water.The air entraining agent was a sodiumalylsulphate based liquid.

Distilled water was used both in concrete and cement paste mixes.

2.2 Concrete program

The concrete program included three strength grades (cube strength around 20 MPa (C15), 30 MPa (C25) and 50 MPa (C45)), four cement types and four levels of silica fume addition (0%, 5%, 10% and 15% by weight of cement). When silica fume was used, the cement content was reduced more than the fume addition to keep the strength level constant. A total combination of all the variables should result in 48 mixes, however, only 30 concrete mixes were produced. The main emphasis was given to the two highest strength grades and the three lowest silica fume contents. The desired slump value was 10-12 cm and 12-15 cm for concretes without and with silica fume, respectively. A minimum of 2 l/m^3 liquid water reducer was used in all mixes. If the silica fume content was higher than 20 kg/m^3, the water reducer was increased to 1 l per 10 kg fume. Detailed information on mix design are given in /2/.

In fresh concrete water demand, bleeding, rheological properties, air content and air bubble stability were tested. In green and hardened concrete compressive strength development was tested from 16 hours up to one year for different curing temperatures and humidities. Tensile strength development, E-modulus, shrinkage and permeability were recorded on concretes cured at different humidities. Tested durability parameters were frost resistance, carbonation and electrical resistivity. More detailed information on test methods are given in /1/.

2.3 Cement paste program

The cement paste program included the four cement types, three w/c+s-ratios (0.5, 0.7 and 0.9. s is silica fume) and four levels of silica fume (0%, 5%, 10% and 15% by weight of cement). All 48 mixes were produced and tested.

All the tests on cement paste were carried out on samples well cured in sealed plastic bottles. Pore water was tested for pH-level. Content of calsium hydroxide, chloride diffusion and sulphate resistance were tested. More detailed information on test methods are given in /1/.

3 RESULTS AND DISCUSSION

3.1 Fresh concrete /2/

Water demand was measured by the slump method. Fig 1 shows that water demand was approximately the same for the four cement types. When silica fume is used it is imperative that a water reducer be added in order to disperse the fine silica particles. In practical situations, the dosage of water reducer is increased proportional to silica fume content. Concrete with silica fume is normally more tough and sticky than concrete without. This is often compensated for by increasing the slump value somewhat in mixes with silica fume. In all the mixes shown in Fig. 1, the dosage of water reducer was approximately the same. Under these conditions, Fig 1 shows that the water demand increased by around 5 % in concretes with 10 % silica fume compared to concretes without.

Bleeding properties are summerized in Fig 2. The main findings were that concretes with MP30 cements showed a small reduction in bleeding compared to concretes with P30 cement. Silica fume addition resulted in reduced bleeding in spite of lower content of fines. The reason for this is that in the concretes with silica fume, the total specific surface is higher than in comparable mixes without fume.

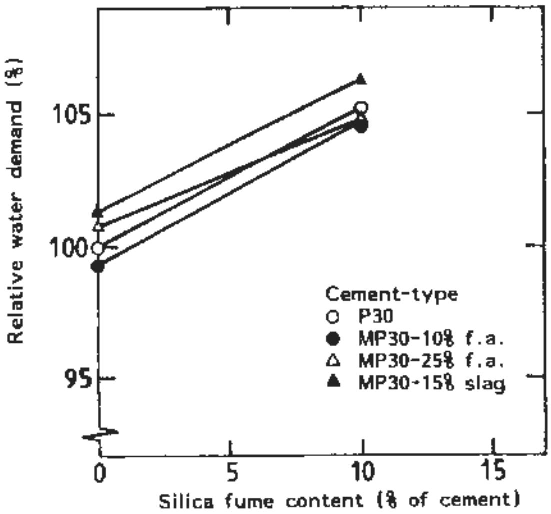

Fig 1. Mean water demand for concrete strength grades C25 and C45 with different cement types as a function of silica fume content /2/

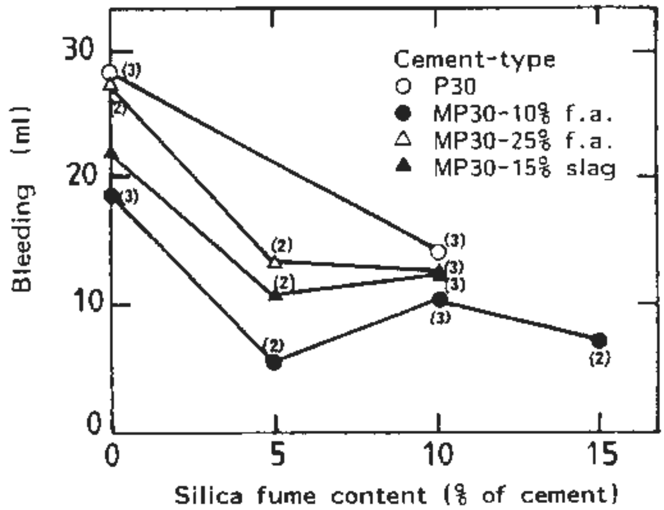

Fig 2. Mean bleeding in concretes with different cement types as a function of silica fume content /2/

Rheological properties were tested by slump value and three different methods where required energy to cause a certain deformation of the fresh concrete was measured (Modified Vebe, Flow test and Thaulows method). The various methods showed principally the same results. No practical difference between the cements were found. However, silica fume resulted in a higher energy consumption indicating a higher cohesion. In practice, this is normally compensated for by increasing the dosage of water reducer and by increasing the slump value somewhat.

Air content measured just after mixing showed no differences in mixes with different cement types and with/without silica fume when no air entrainment was used. When using air entrainment, it is known that rest carbon in the fly ash will absorb part of the admixture. In this test programme, only the MP30 cement with 25% fly ash required a higher admixture dosage to get the same air content. Mixes with silica fume generally showed a small reduction in required dosage.

Air stability in mixes with air entrainment was tested both in a slow rotating drum mixer imitating transportation and in a vibration test imitating casting and compacting. The results indicated that P30 cement gave the most stable mixes in the drum mixer test and addition of silica fume did not influence the results. The reason for this is probably that total content of fines was smaller in mixes with silica fume. When silica fume is used in addition to the cement, it is reported that air stability is improved /13/. According to the vibration test just after mixing, no influence of different cement types nor of silica fume was found. Results found after the mix had been 60 min in the drum and then exposed to the vibration test are shown in Fig 3, indicating that cement with the highest fly ash content gave the lowest air stability. Silica fume had no, or a small positive effect in mixes with constant strength level. It has to be pointed out that air stability is a function of many factors and in practical situations, other values than shown here may be found.

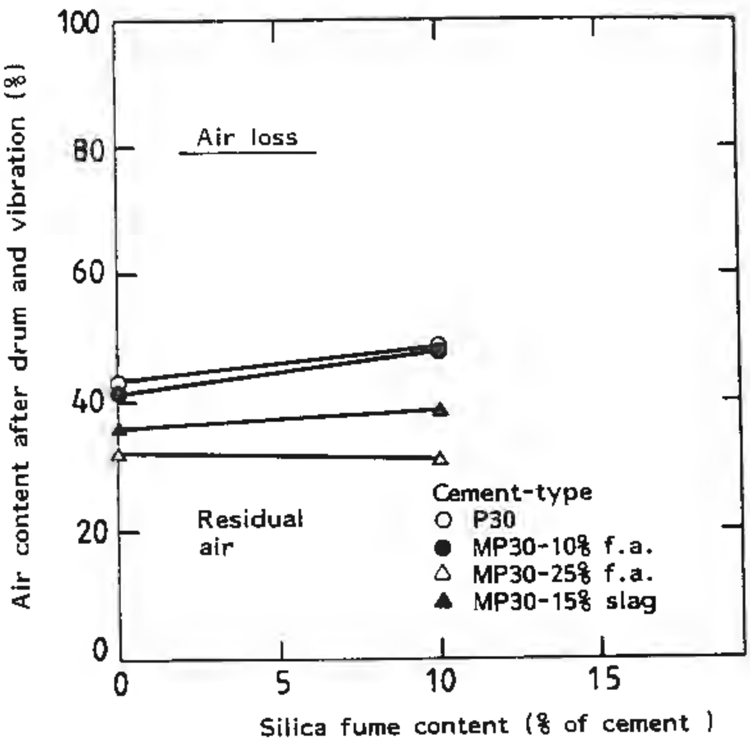

Fig 3. Air content in concrete after 60 min drum testing and then in the vibration test for 3 min in % of air content before testing depending on cement type and silica fume content /2/

3.2 Compressive strength development /3/

When part of the cement clinker is replaced by fly ash or slag, the early strength will be reduced. In the tested MP30 cements, this is compensated for by grinding the cements finer. When cured in standard environments (20°C in water), Fig 4 shows that the tested MP30 cements had strength developments close to that of P30 cement the first 28 days. After 28 days the strength gain increased with increasing pozzolan content. The MP30 cement commercially produced in Norway today has a fly ash content of 20% and the fineness is somewhat higher than in the tested cement with 25% fly ash. The practical experience is that strength gain the first 28 days is approximately the same as for cement MP30-10% f.a. in Fig 4 and as for MP30-25% f.a. in Fig 4 after 28 days.

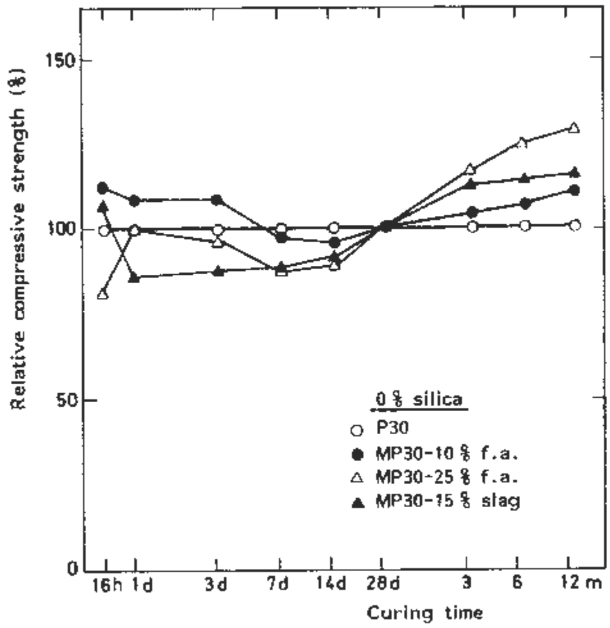

Fig 4. Relative compressive strength of concrete cured in water at 20°C depending on cement type and curing time. Concrete of P30 cement is 100% at any time. No silica fume was used /3/

<u>Curing in air at 20°C and 50 % RH</u>. The tests were carried out on 100 mm cubes exposed to drying from all six sides the day after casting. The most important test results are shown in Fig 5 and 6. Time at which strength level was maintained at the same level as in concrete cured in water was influenced by cement type and silica fume. When no silica fume was used (Fig 5), air curing had no negative effect up to 6 months for the P30 and the MP30-10% f.a. cements and up to 14 days for the two other cement types compared to water curing. With silica fume in the concrete (Fig 6), the negative effect came after approximately 7 days for all cement types and the effect was stronger than without silica fume. The reason for this is that the pozzolanic reaction will not start, or will be reduced when the concrete dries out early. Therefore when pozzolanic materials are used in cement or concrete, it is important to maintain good curing conditions long enough.

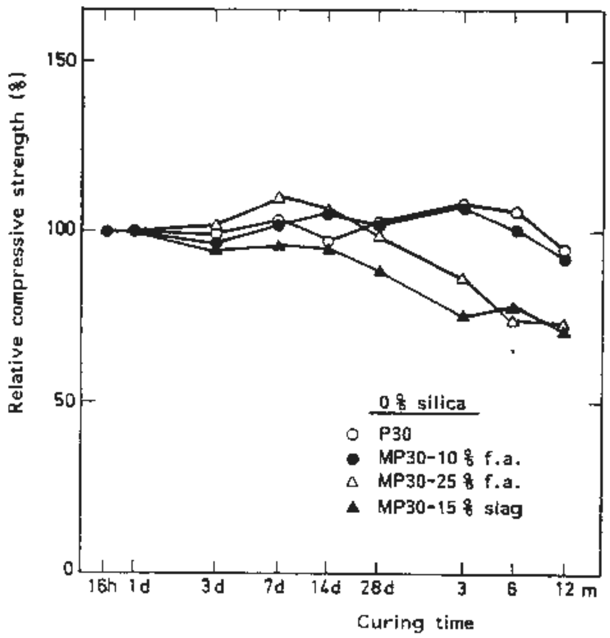

Fig 5. Relative compressive strength of concrete cured in air at 20°C and 50 % RH in % of strength of the same mixes cured in water at 20°C. No silica fume was used /3/

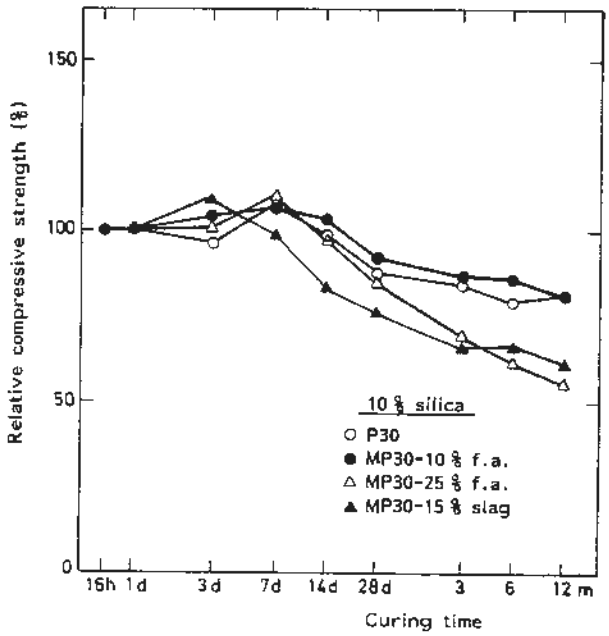

Fig 6. Relative compressive strength of concrete cured in air at 20°C and 50 % RH in % of strength of the same mixes cured in water at 20°C. 10 % silica fume by weight of cement was used /3/

Drying of 100 mm cubes from all six sides is a relatively tough exposure. Threfore the effect of different drying and curing condition was tested in a special programme /10/. When cubes dried out from one side only, the results were in principle as shown in Fig 5 and 6. However, the effect on compressive strength came later and it was much smaller, especially for concretes with silica fume.

<u>Curing in water at 5°C.</u> Both mixing, casting and curing was carried out at 5°C. After 28 days at 5°C, the curing continued in water at 20°C. Fig 7 and 8 show that early strength is very low when cured in water at 5°C compared with curing at 20°C for all cement types. Mixes without silica fume and with the two cements P30 and MP30-10% f.a. reached the same strength at 28 days both for 5°C and 20°C curing temperature. Mixes with the two other cements had lower strengths after 28 days curing. However, this was regained when the temperature was increased after 28 days. In mixes with 10 % silica fume, the strength gain was very slow at 5°C compared to 20°C curing temperature, especially from around 7 days. The same differences between the cements were observed both with and without silica fume.

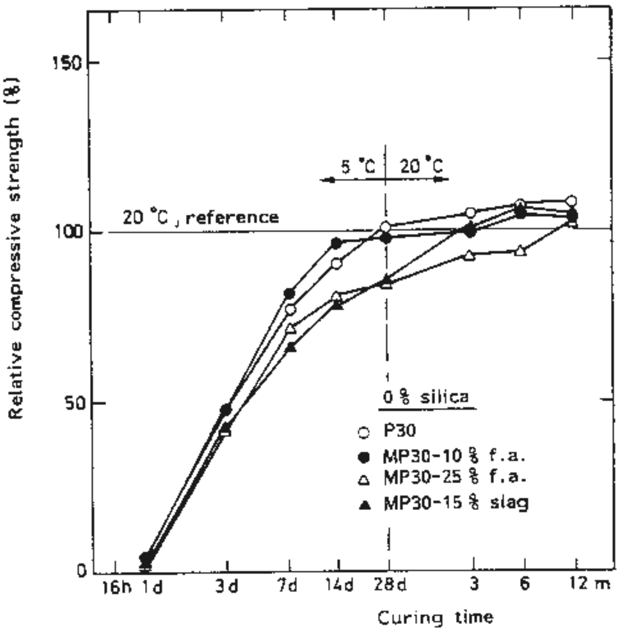

Fig 7. Compressive strength development of concrete cured in water at 5°C the first 28 days and then in water at 20°C in % of strengths for comparable mixes cured at 20°C continuously. No silica fume was used /3/

Also in mixes with silica fume, the strength was regained when the temperature was increased after 28 days. This means that concrete with silica fume or the two cements with lowest pozzolan content is more influenced by low temperature than mixes without silica fume and mixes with cements having the highest pozzolan content. This effect of silica fume is known from practical application as well.

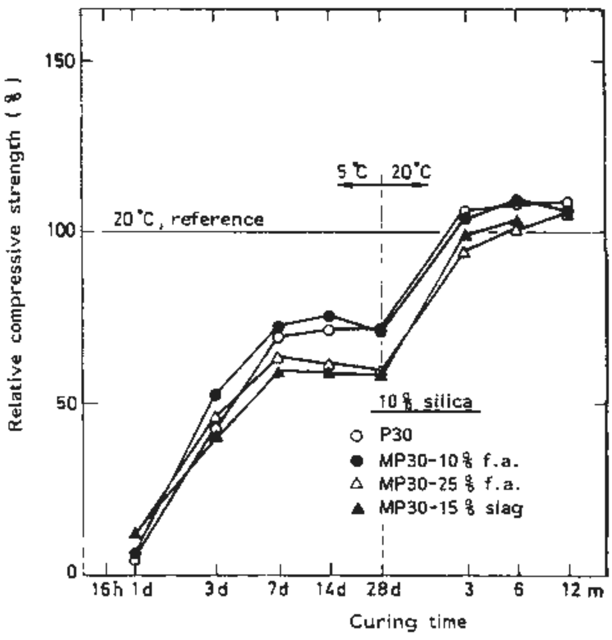

Fig 8. Compressive strength development of concrete cured in water at 5°C the first 28 days and then in water at 20°C in % of strengths for comparable mixes cured at 20°C continuously. 10 % silica fume by weight of cement was used /3/

Curing in water at 35°C. Mixing and curing was carried out at 35°C, casting at 20°C. After 28 days in 35°C, the curing continued in water at 20°C. Fig 9 and 10 show that early strength is very high when cured in water at 35°C compared with curing at 20°C for all cement types. However, the slag cement was somewhat behind at 16 hours. In mixes without silica fume, the strength.

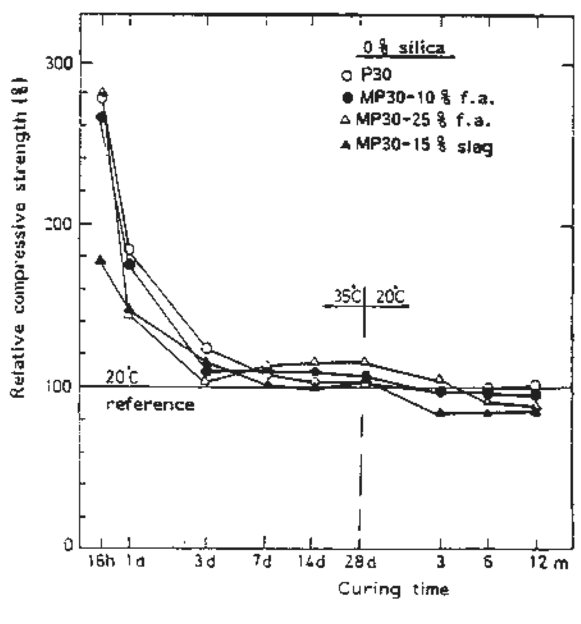

Fig 9. Compressive strength development of concrete cured in water at 35°C the first 28 days and then in water at 20°C in % of strengths for comparable mixes cured at 20°C continuously. No silica fume was used /3/

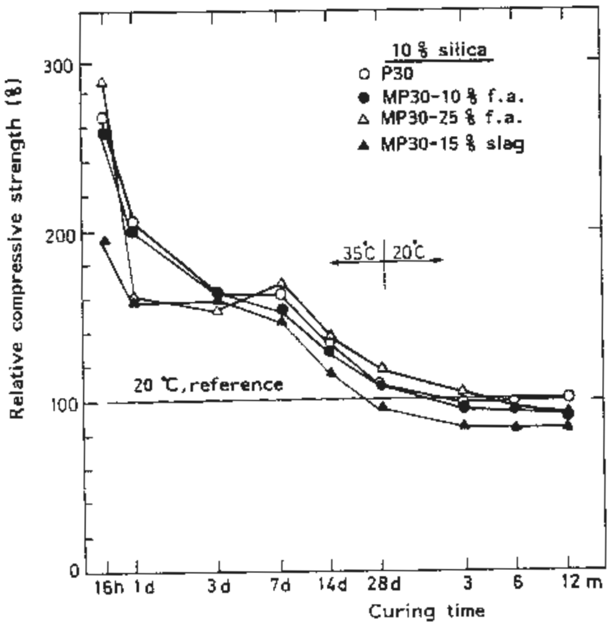

Fig 10. Compressive strength development of concrete cured in water at 35°C the first 28 days and then in water at 20°C in % of strengths for comparable mixes cured at 20°C continuously. 10 % silica fume by weight of cement was used /3/

level was approximately the same after 3 - 7 days curing both for 35°C and 20°C curing temperature. In mixes with silica fume the strength level was higher when cured at 35°C than at 20°C up to approximately 28 days. The long term strength was generally lower in all mixes cured at 35°C the first 28 days than in comparable mixes cured continuously at 20°C.

Concrete containing silica fume had a lower early strength than comparable mixes. However, this delay was reduced when the curing temperature increased. As an example, the results showed that at 35°C the concretes with 10 % silica fume had lower strength up to three days than comparable mixes without silica fume. In /14/ it was found that the delay period was approximately one day for 50°C curing temperature.

3.3 Tensile strength development /3/

Pure tensile strength was tested on prisms both cured in water at 20°C and in air at 20°C and 50 % RH after demolding. When cured in water, no special effects of the different cements or silica fume was observed.

However, when cured in air, the tensile strength was lower than for water curing and this difference increased with increasing pozzolane content in the cement and with silica fume content. The effect was stronger for tensile than compressive strength. A reason for this may be an increased formation of microcracks in concrete containing pozzolans when it dries out. This will result in stress concentrations which will influence tensile more than compressive strength. Therefore in concrete of blended cements or with silica fume, it is important to secure good curing conditions.

3.4 E-modulus /3/

The E-modulus was recorded on cylinders from some mixes after 6 months curing both in water at 20°C and in air at 20°C and 50 % RH. The results showed that E-modulus was not influenced by cement type or silica fume when E-modulus was related to compressive strength. The E-modulus was less influenced by drying than compressive strength.

3.5 Shrinkage /7/

Free shrinkage was measured on prismes exposed to two different curing conditions before drying in air at 20°C and 50 % RH. The two curing conditions were one day in the casting mold before exposure and 28 days in water at 20°C before exposure. The different cement types did not show any difference in weight loss or shrinkage. Neither use of silica fume nor curing condition showed any special effect on shrinkage, however, early drying seemed to result in somewhat higher early shrinkage when the concrete was cured in water before exposure.

Free shrinkage measurements on concrete give limited information on shrinkage potential in the paste, or relaxation properties and microcracking in the concrete. None of these properties were measured. However, by comparing tensile strength and compressive strength, there may be a tendency to an increased number of microcracks when blended cements or silica fume were used. Whether this is a result of a low relaxation value or a low shrinkage potential, cannot be stated from the measurements.

Plastic shrinkage measurements have not revealed any difference between the cement types /15/. However, silica fume has an increasing effect on plastic shrinkage independent of cement type.

3.6 Permeability /4/

Water permeability is an important property both for the durability of the concrete itself and for reinforcement corrosion. In order to simulate practical situations, the test specimens were cured in water for 28 days and then in air for 6 months. Water permeability was tested by pressing water through the sample at a pressure of 4 MPa (400 m water head).

The interpretation of the results was difficult. However, concrete with MP30-cements seemed to be denser then comparable concrete with P30 cement.

Earlier tests /16-20/ have revealed relatively small differences in permeability between concretes with blended cements and ordinary portland cement when the test samples were well cured in water. However, when the samples were dried before testing, the permeability was found to be highest in concretes with blended cements, especially when drying started early.

In concrete with silica fume, the permeability was lower (denser concrete) than in comparable mixes without silica fume. This is also reported earlier /14,16,21/ for concrete which did not dry out before testing. In /16/ it is reported that the permeability increased when silica fume was used in concretes with blended cements while no practical effect was found in concrete with silica fume and ordinary portland cement. This is contrary to results reported in /22/.

The general impression from this and earlier tests is that both blended cements and silica fume contribute to a denser concrete when the samples are kept continuously wet before testing. However if the concrete dries out, especially at an early age, the result may be the opposite. The reason seems to be that drying causes an increased number of microcracks with increasing pozzolan content.

Capillary suction is a more common exposure than water pressure from one side, but has not been tested in this program. However, it should be mentioned that no direct correlation between these two properties has to exist.

3.7 Durability

In practice, durability may be dependent on a combination of various types of exposure. In this test program, some of the most important durability factors were tested individually.

Frost resistance /6/ was tested in principle according to ASTM C666, procedure A with freezing and thawing in water. However, the curing conditions were different as the samples were first cured in water at 20°C for 28 days, then in air at 20°C and 50 % RH for 6 months, and finally for 14 days in water.

Due to large scattering consistent results were not found. However, the results do not indicate that concretes with MP30 cements have a reduced frost resistance compared to concretes of P30 cement at the same strength level.

Air pore structure was not found to be different in concretes with the various cements. However, practical use of MP30 cements shows that it is somewhat more difficult to obtain good pore structure when using MP30 cement compared to P30 cement. Neither did use of silica fume show any consistent effect on pore structure.

The test results from concretes with silica fume did not reveal a high degree of correlation between frost resistance and silica fume dosage. Earlier tests /23/ have shown that silica fume contribute favourably to frost resistance, especially when the dosage is lower than 15 % of the cement weight. Contrary to earlier test, where silica fume has been used as an addition to the cement, this test program compares concretes with and without silica fume of the same strength grades. The special curing condition with a long drying period may also have affected the frost resistance. Drying will influence the pore structure in an unfavourable way as far as frost resistance is concerned.

Sulphate resistance /24/ was tested on P30 cement pastes with addition of fly ash and silica fume. The blended cements tested were therefore somewhat different from the MP30 cements. Like in other reported tests, it was found that 20 % replacement with fly ash improved sulphate resistance. The effect of pozzolans is best when specific surface and content of amorphous silica are high /25/. This favours silica fume which is also documented experimentally /24,25,26/.

The results in /24/ show that replacement of P30 cement with 8 % ground blast furnace slag reduced the sulphate resistance. This is generally contrary to reported results /25/. However, in /27, 28/ it is shown that the content of aluminium oxide in the slag is of great importance for its sulphate resistance.

In /25/ it is concluded that cement type in general is of minor importance regarding sulphate resistance compared to high concrete quality and good workmanship, which will prevent aggressive gases and liquids from penetrating into the concrete.

Reinforcement corrosion is a process which may be divided into two periods. In the first (initiation) period, carbonation and/or chloride penetration takes place but no reinforcement corrosion occurs. When carbonation and/or chlorides have reached the reinforcement, the reinforcement corrosion may start (propagation period). The corrosion rate is governed by oxygen diffusion, humidity and electrical resistivity of the concrete.

a) Carbonation /11/ The reduced content of lime in blended cements have raised the question whether the carbonation will go faster in blended cements than in ordinary portland cement. Carbonation was tested in several concrete strength grades with the different cements both with and without silica fume. Different curing and exposure conditions were included in the test program. Carbonation was tested by the phenolphtalein method. Some of the results are shown in Fig 11.

Concretes with the cements P30 and MP30-10 % f.a. had approximately the same resistance against carbonation. However, concretes with the two other MP30 cements showed faster carbonation. This is not in agreement with other results from our laboratory which did not show any differences between the four cement types /29/. In later tests /30/ it is shown that carbonation rate is reduced when cement fineness is increased. The MP30 cement on the Norwegian market today has a lower fly ash content (20 %) than the tested MP30-25 % f.a. and is furthermore ground to a higher fineness.

Addition of silica fume reduced the resistance against carbonation for all the tested cements. The negative effect was generally becoming stronger with increasing pozzolane content for concretes having high w/c+s ratio. At w/c+s ratios around 0,7 and lower, silica fume had no negative effect on carbonation rate.

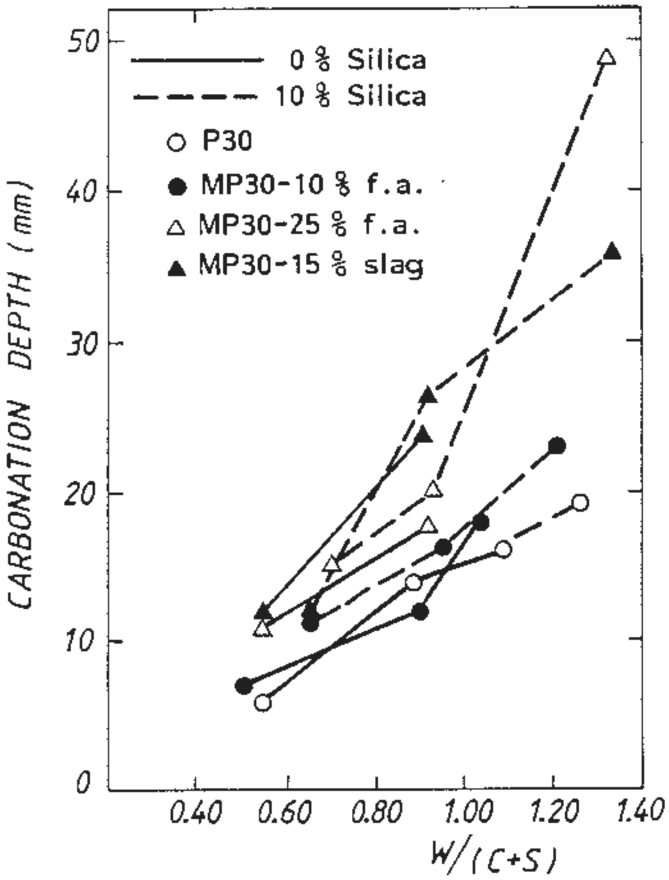

Fig 11. Absolute carbonation depths for samples stored in air at 20°C and 50 % RH for three years as a function of cement type, silica fume and w/(c+s) ratio /11/

If the "efficiency factor" for silica fume is put equal to one, it seems that carbonation rate is approximately the same as in concrete without silica fume with the same w/c-ratio. However, in this situation the strength of concretes with silica fume will be higher than without. This means that in concrete of the same strength grade, carbonation rate will be higher in concretes with silica fume. This means that the initiation period due to carbonation will be equal or somewhat shorter when MP30 cements or silica fume are used, compared to the use of P30 cement.

b) Chloride penetration /8/ Chloride penetration was tested in cement pastes where w/c+s ratio, cement type and silica fume dosage varied. The tests were carried out on well cured samples using a pure diffusion method described in /8/.

The results were consistantly showing significantly reduced chloride penetration in pastes of MP30 cements compared to pastes with P30 cement. Fly ash showed slightly better properties than slag as shown in Fig 12. Addition of silica fume reduced the chloride penetration considerably as shown in Fig 13.

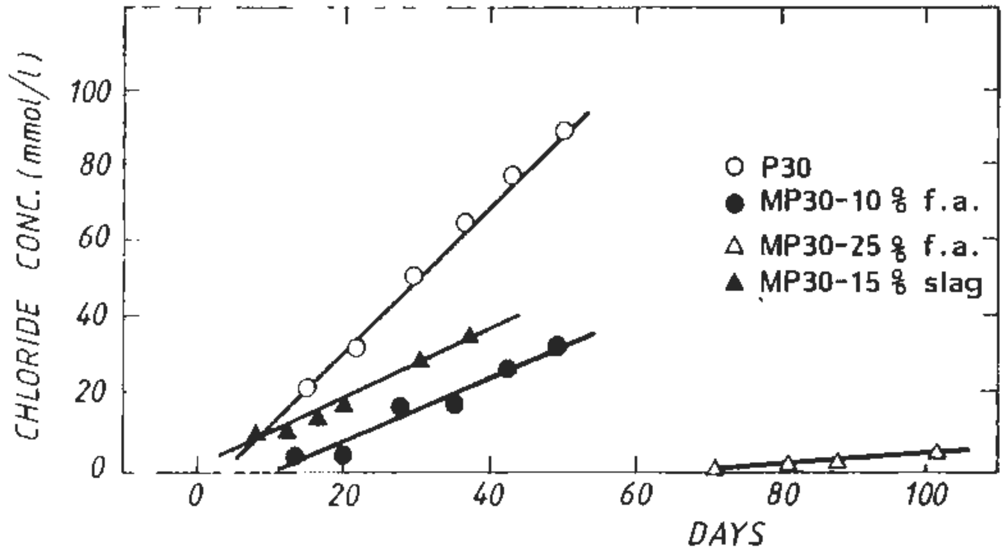

Fig 12. Chloride diffusion through disks of cement paste of different cement types with w/c ratio equal to 0.5. No silica fume was added /8/

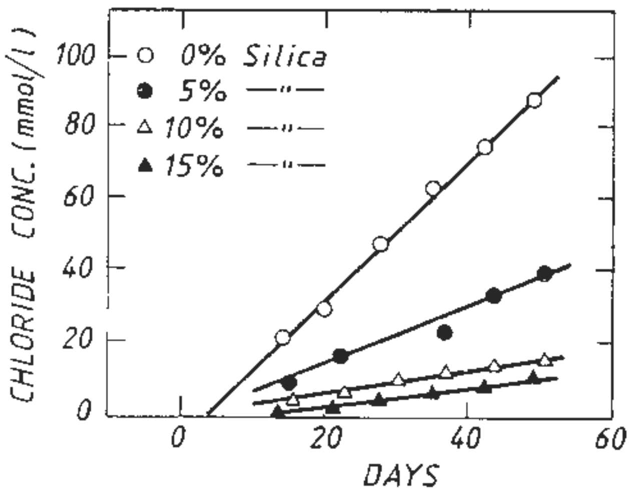

Fig 13. Chloride diffusion through disks of P30 cement with different silica fume dosages with w/c+s ratio equal to 0,5 /8/

The effect of silica fume was highest in combinations where the diffusion rate was highest without silica fume, i.e. in pastes of P30 cement and for the highest w/c-ratios.

The results were consistant and positive both for the MP30 cements and silica fume. This means that the initiation period due to chloride penetration will be doubled many times when MP30 cements and silica fume are used compared to the use of P30 cement.

c) Electrical resistivity /5/ The electrical resistivity is one of the factors controlling the corrosion rate in the propagation period. The resistivity was measured on samples cured for six months where saturation level, cement type, concrete strength and silica fume dosage varied.

In dry samples, the electrical resistivity was so high in all mixes that no corrosion can occur. In saturated samples, the resistivity increased somewhat with increasing dosage of fly ash or slag in the cement. This tendency was strongest in mixes with low w/c-ratios. Addition of silica fume resulted in a considerably increased resistivity as shown in Fig 14 for MP30-10 % f.a. cement. The effect was most visible for concrete with P30 cement and the highest w/c+s ratios.

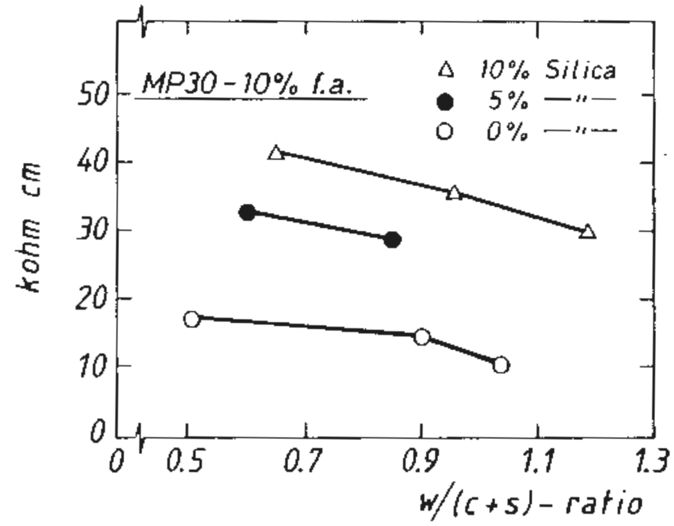

Fig 14. Specific electrical resistivity in concrete as a function of silica fume dosage and w/c+s ratio in saturated samples /8/

Chemical analysis of pore water pressed out of cement samples indicated that the increased electrical resistivity obtained by adding pozzolans partly was due to reduced ion concentration in the pore water and partly to changes in the pore system.

d) **Reinforcement corrosion rate.** This is not tested directly in this program. However, some judgement may be done. As pointed out earlier, the initiation period due to carbonation may be equal to or somewhat shorter in concretes with MP30 cements compared with P30 cements. When using silica fume, the initiation period is supposed to be somewhat reduced in concretes of the same strength grades, especially in lean mixes.

The initiation period due to chloride penetration will be longer in concretes with MP30 cements and with silica fume compared with P30 cement without silica fume.

The corrosion rate is governed by oxygen diffusion and electrical resistivity. Both MP30 cements and silica fume result in a higher electrical resistivity which means a reduced corrosion rate if resistivity is the dominating factor. In submerged structures the oxygen diffusion is the dominating factor. This is not measured in this program. However, it is reasonable to suppose that use of MP30 cements will reduce oxygen diffusion. Also, when using silica fume, the same conclusion is supposed to be drawn provided the w/(c+s) ratio is constant.

The total judgement is therefore that expected reinforcement corrosion problems are unchanged or somewhat reduced in concretes of same strength grade with MP30 cements compared to comparable concretes with P30 cement. The total effect of silica fume is somewhat more doubtful when the strength grade is the same in concrete with and without silica fume.

4 CONCLUSION

It is somewhat difficult to present short conclusions because the whole paper represents conclusions from a comprehensive research program. However, the following main conclusions may be drawn.

a) The service performance of concretes with MP30 cements seems to be equal to or better than that of comparable concretes with P30 cement. This is especially valid for fresh concrete properties and mechanical properties.

b) The properties of concretes with MP30 cements and/or silica fume are somewhat more influenced by curing condition than those of concretes with P30 cement and without silica fume.

c) Except for carbonation rate, durability parameters for concretes with MP30 cements and/or silica fume seems to be equal to or better than those of concretes with P30 cement and without silica fume.

d) For practical purposes silica fume behaves principally in the same way in combination with MP30 cements as it does with P30 cement.

REFERENCES

/1/ Maage M., Vennesland Ø. and Gautefall O.: Modified Portland Cement. Subreport 1. Objective, program, test methods and limitations. Report STF65 A85019, SINTEF div FCB, 1985 (In Norwegian)

/2/ Maage M. and Dahl P.A.: Modfied Portland Cement. Subreport 2. Mix design and properties in fresh state. Report STF65 A85022, SINTEF div FCB, 1985 (In Norwegian)

/3/ Maage M. and Hammer T.A.: Modified Portland Cement. Subreport 3. Strength development and E-modulus. Report STF65 A85041, SINTEF div FCB, 1985, (In Norwegian)

/4/ Hammer T.A. and Maage M.: Modified Portand Cement. Subreport 4. Water permeability. Report STF65 A85040, SINTEF div FCB, 1985, (In Norwegian)

/5/ Gautefall O. and Vennesland Ø.: Modified Portland Cement. Subreport 5. Electrical resistivity and pH-level. Report STF65 A85042, SINTEF div FCB, 1985, (In Norwegian)

/6/ Smeplass S. and Maage M.: Modified Portland Cemetn. Subreport 6. TAS and frost testing. Report STF65 A86012, SINTEF div FCB, 1986 (In Norwegian)

/7/ Hammer T.A. and Maage M.: Modified Portland Cement. Subreport 7. Shrinkage. Report STF65 A86013, SINTEF div FCB, 1986 (In Norwegian)

/8/ Gautefall O., Havdal J. and Vennesland Ø.: Modified Portland Cement. Subreport 8. Chlorid diffusion. Report STF65 A86014, SINTEF div FCB, 1986 (In Norwegian)

/9/ Meland I.: Modified Portland Cement. Subreport 9. Calsiumhydroxide content in blended cements with and without silica fume. Report STF65 A86015, SINTEF div FCB, 1986 (In Norwegian)

/10/ Rønne M. and Maage M.: Modified Portland Cement. Subreport 10. Strength development at different curing conditions. Report STF65 A86016, S1NTEF div FCB, 1986 (In Norwegian)

/11/ Rønne M. and Maage M.: Modified Portland Cement. Subreport 11. Carbonation in concrete with blended cements and condensed silica fume. Report STF65 A86061, SINTEF div FCB, 1986 (In Norwegian)

/12/ Maage M.: Modified Portland Cement. Subreport 12. Summaries and judgements. Report STF65 A87001, SINTEF div FCB, 1987 (In Norwegian)

/13/ Okkenhaug K.: Effect of silica fume on air pore stability with air entraining admixture alone and in combination with water reducer. Report STF65 A83031, SINTEF div FCB, 1983 (In Norwegian)

/14/ Sandvik M.: Property development in concrete where part of the cement was replaced by silica fume. BML-report 83. 204, Trondheim, 1983 (In Norwegian)

/15/ Johansen R.: Cracking tendency by plastic shrinkage. Report STF65 A80016, SINTEF div FCB, 1980 (In Norwegian)

/16/ Johansen R.: NS3420-Introduction of environmental classes. Norwegian Concrete Day, 1984 (In Norwegian)

/17/ Kasai Y., Matsui I., Fukushima Y. and Kamohara H.: Air Permeability and Carbonation of Blended Cement Mortars. American Concrete Institute Special Publication SP-79, Vol 1, 1983

/18/ Tynes W.O.: Comparision of properties of mass concrete containing 3- and 6- in max size crushed limestone coarse aggregate. US Army Eng. Water ways Exp. Station. Tech. Report No 6-748, Nov 1966

/19/ Gohring C.: Gasdurchlässigkeit von Betonen und ihr Einfluss auf die Korrosionbeständigkeit in Salzlosungen. Wiss. Zeitschrift d. hochschule f. Architektur u. Bauwesen Weimar 21, 1974

/20/ Reinsdorf Dippel: Permeabilität von Beton und Mörtel. Deutsche Bauakademie zu Berlin. 1971

/21/ Gjørv O.E.: Water permeability as a quality parameter for concrete durability. NIF course 1983 (In Norwegian)

/22/ Sandvik M.: Silica Fume Concrete. Heat evolution and properties development. Report STF65 A83063, SINTEF div FCB, 1983 (In Norwegian)

/23/ Sellevold E.J. and Nilsen T.: Condensed silica fume in concrete. A world review. Elkem A/S Chemicals, Norway, 1986

/24/ Meland I.: Sulphate resistance of different cements. Report STF65 A82004, SINTEF div FCB, 1982 (In Norwegian)

/25/ Dingsøyr E., Justnes H., Kjennerud A., Meland I. and Søpler B.: Service performance of concrete. Report No 4. Chemical effects. Report STF65 A86053, SINTEF div FCB, 1986 (In Norwegian)

/26/ Fiskaa O.M.: Concrete in aluminous shale. Publication No 101, Norwegian Geotechnical Institute, Oslo 1973 (In Norwegian)

/27/ Ludwig U. and Därr G.M.: Uber die Sulfat beständigkeit von Zementmörtel. Forschungsberichte des Landes Norreim-Westfalen. Nr 2636

/28/ Mehta P.K.: Effect of Fly Ash Composition on Sulfate Resistance of Cement. ACI Journal, Nov-Dec 1986

/29/ Meland I.: Carbonation in cements with fly ash and standard portland cement with and without silica fume. Report STF65 A85049, SINTEF div FCB, 1985 (In Norwegian)

/30/ Meland I.: Blended cements. Effect of cement fineness on hydration and carbonation in cement paste of OPC and cement with fly ash with and without condensed silica fume. Report STF65 A86071, SINTEF div FCB, 1986 (In Norwegian)