

**Subject: Metakaolin vs. Silica Fume as a Durability Enhancer (SB0187)**

As a supplement to the WHICON-report, this memo focuses on studying the possibility of using metakaolin instead of white silica fume as a durability enhancer. The reason for that being the extreme high price of white silica fume (approx. 3 times more expensive than metakaolin).

Some of the standard tests in WHICON were repeated on AALBORG WHITE® concretes containing 5 % metakaolin, at w/p ratios of 0.36 and 0.45.

The concrete compared in this memo have the following composition (units in kg/m<sup>3</sup> if nothing else stated)

	Mix 1	Mix 2	Mix E1	Mix 6	Mix 7	Mix E2
AALBORG WHITE®	371	390	371	316	333	316
White silica fume	20			17		
Metakaolin			20			17
Sand	670			680		
Stone 2/8	230			232		
Stone 8/16	865			876		
Water	140			150		
W/p	0.36			0.45		
Plasticizer	2.0	2.0	2.6	0.5	1.0	1.3
Superplasticizer	1.5	1.7	3.2	---	---	---
Air-entraining	0.19	0.20	0.26	0.2	0.4	0.22
Slump (mm)	150	160	150	170	160	140
Air content (vol-%)	6.2	5.9	5.2	6.9	6.7	6.3

The development of strength of the w/p 0.45 concrete containing metakaolin is very similar to that containing white silica fume (see Fig. 1) and both higher than the pure AALBORG WHITE® concrete.

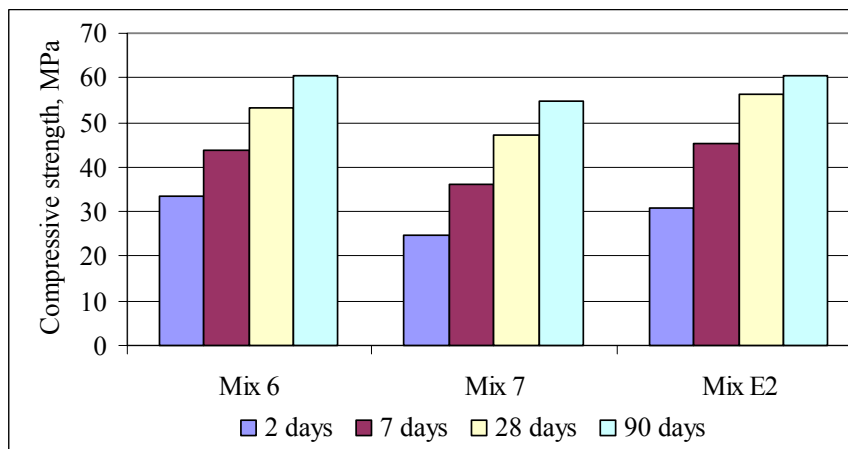


Fig. 1: Strength development of w/p = 0.45 concretes.

Fig. 2 shows the chloride ingress profiles measured according to NT BUILD 443. The samples were exposed to a 16.5% NaCl solution for 35 days, at a maturity of 28 days.

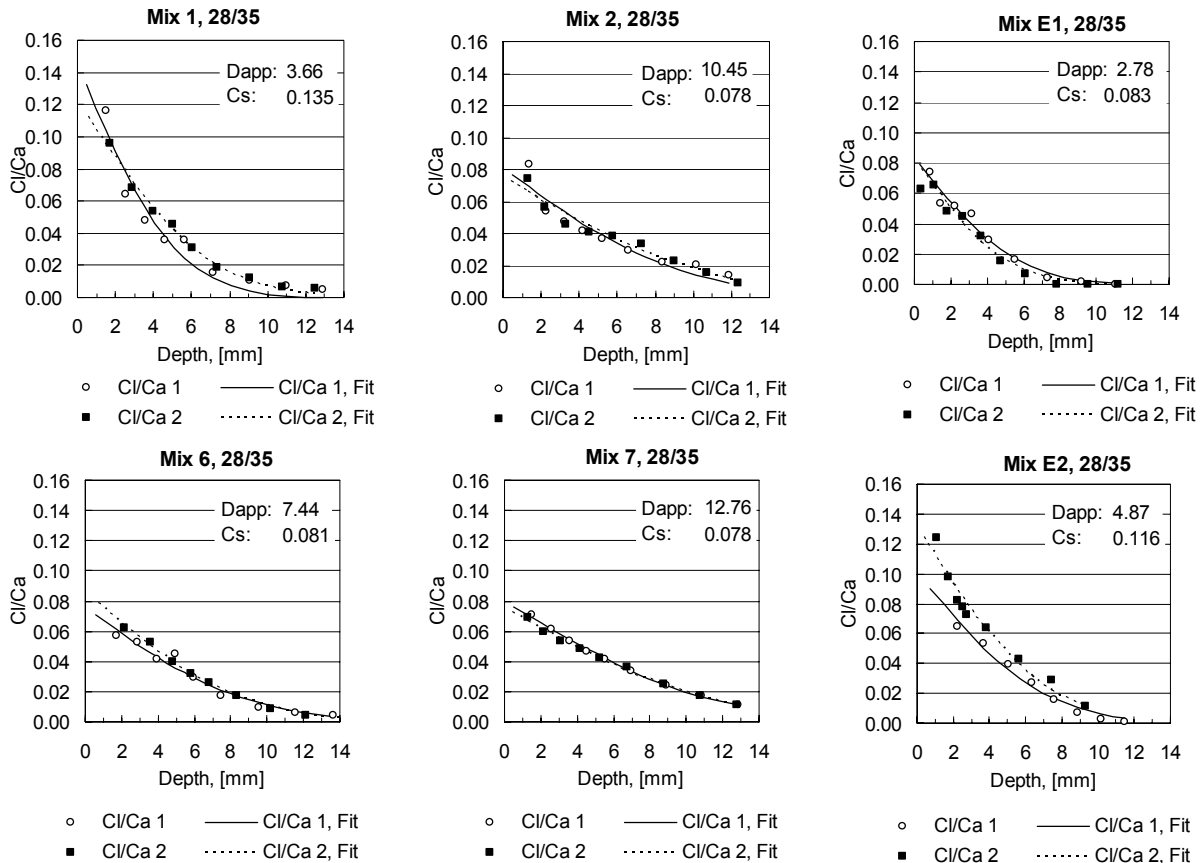


Fig. 2: Chloride ingress profiles measured according to NT BUILD 443, after 35 days of exposure to 16.5% NaCl solution (maturity at 28 days prior to exposure).

The addition of 5% metakaolin to AALBORG WHITE® effectively reduces the ingress rate of chlorides. Chlorides ingress approximately 30% slower than the obtained by a 5% white silica fume addition. The apparent diffusion coefficients for Mix E1 and Mix E2 are  $2.78 \cdot 10^{-12} \text{ m}^2/\text{s}$  and  $4.87 \cdot 10^{-12} \text{ m}^2/\text{s}$ , respectively, whilst the measured in Mix 1 and Mix 6 are  $3.66 \cdot 10^{-12} \text{ m}^2/\text{s}$  and  $7.44 \cdot 10^{-12} \text{ m}^2/\text{s}$ , respectively. This is further validated when comparing the total depth of chloride ingress, which is significantly lower for the metakaolin based concretes (see Fig. 2).

Table A shows the results obtained from colour measurements on concretes Mix 1, Mix 2 and Mix E1 28 days after casting.

Table A: Colour measurements on Mix 1, Mix 2 and Mix E1

	Hunter L	Hunter a	Hunter b
<b>Mix 1</b>	80.2	1.74	-0.65
<b>Mix 2</b>	80.5	2.4	-0.59
<b>Mix E1</b>	77.35	0.062	4.53

The addition of 5% white silica fume had little effect on the colour of the concrete. The Hunter a value was lowered a bit corresponding to a reduced red toning, visible to the human eye. The addition of metakaolin results in a small reduction on the Hunter L value (i.e. the concrete was less white), decreased Hunter a to almost zero (i.e. the concrete has no red-green toning) and increased Hunter b value (i.e. the concrete became more yellow toned). All of the changes in Hunter values resulting from the addition of 5% metakaolin are visible to the human eye.

Fig. 3 shows the adiabatic heat development of mixes Mix 1, Mix 2 and Mix E1.

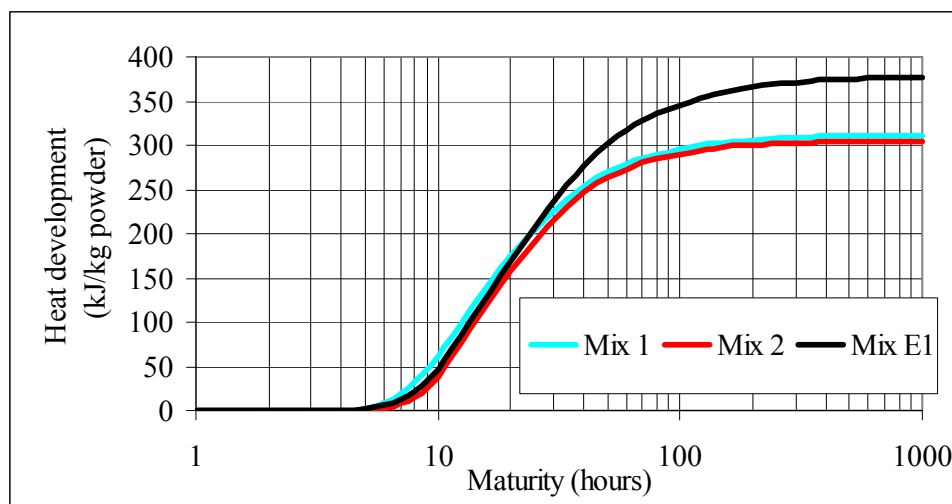


Fig. 3: Adiabatic heat development of concretes Mix 1, Mix 2 and Mix E1.

When fitting the measured heat development curves to Freiesleben’s maturity function, following values are obtained

$$Q(M) = Q_{total} \cdot \exp\left[-\left(\frac{\tau_e}{M}\right)^\alpha\right] \quad (M = \text{maturity in hours})$$

	Mix 1	Mix 2	Mix E1	Mix 6	Mix 7	Mix E2
<b>Q<sub>total</sub></b>	312	305	378	338	327	395
<b>T<sub>e</sub></b>	13.9	15.6	17.1	10.9	11.3	14.4
<b>Alpha</b>	1.49	1.63	1.37	1.09	1.05	0.96



The addition of 5% metakaolin increases significantly the total amount of heat developed during hydration ( $Q_{total}$ ). However, the rate at which the heat develops (related to the  $\alpha$ -value) is similar or even a bit lower than for Mix 1 and Mix 2.

If 5% metakaolin is to be added to an AALBORG WHITE® concrete, proper simulations should be carried out regarding the risk of thermal cracks, and appropriate insulation should be planned. There is no reason to believe that the tensile strength of Mix E1 and Mix E2 differ from that of Mix 1 and Mix 6, which were observed to be very high in the WHICON-study.

## Conclusion

With respect to chloride ingress, metakaolin is a better durability enhancer to AALBORG WHITE® concretes than white silica fume.

The development of compressive strength is similar to that obtained by a 5% addition of silica fume.

The colour of the concrete becomes yellow-toned upon a 5% addition of metakaolin.

Although the rate at which the heat develops during curing is somehow lower than pure AALBORG WHITE® concretes or white silica fume alternatives, the total development of heat is increased significantly. A thorough survey on the risk of thermal cracking should be carried out to select on proper curing action.