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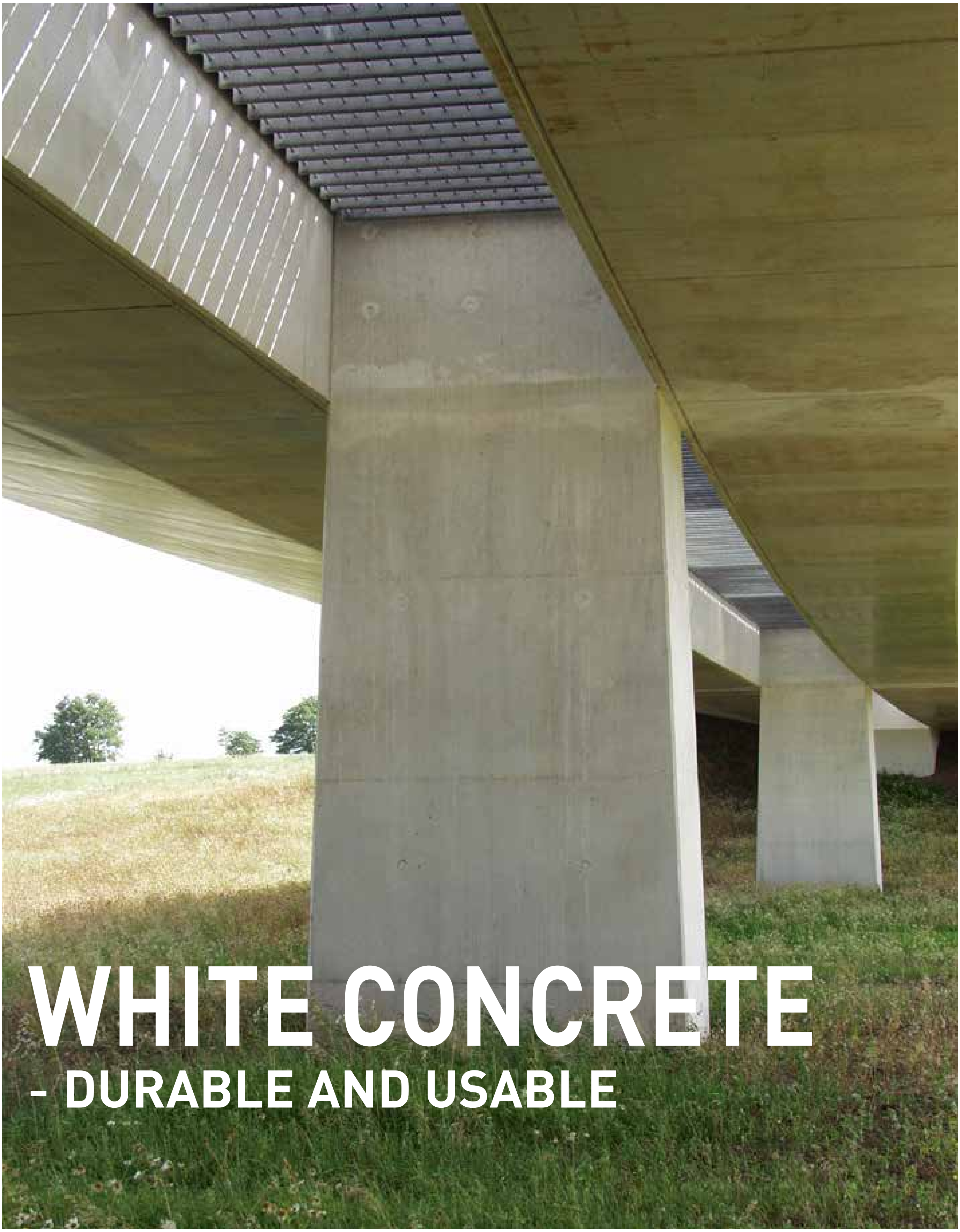

WHITE CONCRETE
- DURABLE AND USABLE

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AALBORG WHITE cement from Aalborg Portland A/S has many superior properties when used in concrete that must withstand an aggressive environment. Thus, concrete structures exposed to severe conditions (frost-thaw action, de-icing salts, chlorides, sulphates, etc.) like road bridges and maritime structures can be established with the required durability.

In addition to durability, concrete based on AALBORG WHITE can be produced and casted in the same way as concrete produced with more ordinary cement, including SCC concrete.

This article highlights the durability properties and gives instructions on the composition and mixing of SCC concrete with AALBORG WHITE.

DURABILITY

The composition of AALBORG WHITE causes the cement to be characterized as being alkali- and sulphate-resistant. The cement designation according to EN 197-1 and DS/INF 135 is: "CEM I 52.5 R - SR5 (EA)". Thereby AALBORG WHITE can be compared with the cement brand “Low-Alkali Sulphate Resistant cement” (CEM I 42.5 N - SR5 (EA)) from Aalborg Portland which is a cement traditionally used in Denmark for road bridges and structures exposed to sea-water.

AALBORG WHITE has good resistance to sulphate attack, with the content of the clinker mineral C_3A being relatively low, <5%; products from C_3A's reaction with water are decomposed in sulphate-containing environments [5]. In Denmark, however, it is rare for concrete structures to be subjected to sulphates to any significant degree.

The alkali content of AALBORG WHITE is less than 0.3% eq. Na_2O, which is low compared to many other types of cement. As the Danish concrete standard “DS/EN 206 DK NA:2019” (Danish National Addendum to EN 206) limits the amount of alkalis in concrete in all exposure classes except X0 and XC1, and the cement furthermore has a low chloride content (≤ 0.04%), it is easier to comply with the standard`s limitations using AALBORG WHITE than by using many other cements.

The durability of concrete based on AALBORG WHITE has previously been demonstrated and documented through several studies. In [1] different concrete compositions with AALBORG WHITE were compared with concrete based on a powder composition as concrete for the “Great Belt Fixed Link” in the following studies:

- Fresh Concrete Properties
- Strength properties (compressive, tensile and E-modulus)
- Frost/thaw resistance (cf. SS137244)
- Adiabatic heat development
- Chloride penetration (cf. NT BUILD 492 and NT BUILD 443)

The main findings of the studies were:

- The early strength development of white concretes waas higher than for the reference concrete
- The final strength level of white concretes was at the same level as of the reference concrete
- Heat of hydration in the early age for white concretes was higher than for the reference concrete

- Frost resistance of the white concretes are as good as for the reference concrete
- Addition of micro-silica in the amount of 5% results in chloride diffusion coefficients at the same level as of the reference concrete; the reference concrete contains 5% micro-silica and 10% fly ash.

In general, it has been documented that concrete based on AALBORG WHITE can be produced with the same level of durability as state-of the-art reference concrete based on “Low-Alkali Sulphate Resistant cement” . The studies have been validated by COWI A/S, [2].

WHITE CONCRETE AND SHRINKAGE

Regardless of the cement type, concrete will be exposed to various types of shrinkage. Concrete can, in principle, both shrink and swell, but since the concrete in the fresh state is water saturated, it is in practice only the shrinkage that has an effect.

In [3], shrinkage for concrete based on respectively AALBORG WHITE and “Low-Alkali Sulphate Resistant cement” is compared:

- AALBORG WHITE is expected to be slightly more sensitive to plastic shrinkage, as it has a higher fineness (Blaine) than “Low-Alkali Sulphate Resistant cement”. However, both cements have a tendency for bleeding, which often improves the conditions under which the plastic shrinkage is taking place, compared to other cements, by protecting the surface from harmful water evaporation. If fly ash and/or micro silica is added to concrete mixes based on “Low-Alkali Sulphate Resistant cement”, as is often the case, the risk of cracks induced by plastic shrinkage will increase significantly.
- The hydration shrinkage is the same for the two types of cement. However, the shrinkage proceeds faster for AALBORG WHITE, as the C_3S content and fineness is higher than for “Low-Alkali Sulphate Resistant cement”
- Self-drying shrinkage (autogenous shrinkage) is the same for the two types of cement when fully hydrated. Figure 1 shows drying shrinkage for concretes based respectively on AALBORG WHITE and “Low-Alkali Sulphate Resistant cement”. As expected, the shrinkage is initially larger for AALBORG WHITE, but after approx. 60 days the relative difference is below 5%, and is expected to be completely eliminated over time.

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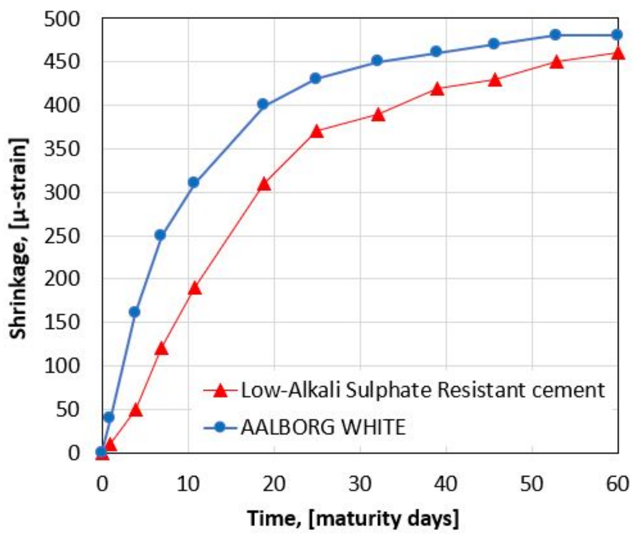

Figure 1 - Concrete shrinkage– free shrinkage.

Experience with concrete structures made of AALBORG WHITE based concrete, support the above considerations, and have shown that the differences in shrinkage, compared to "Low-Alkali Sulphate Resistant cement" do not cause problems in practice.

HARDENING OF WHITE CONCRETE

White cement develops more heat during hydration than "Low-Alkali Sulphate Resistant cement". In contrast, white cement develops compressive- and tensile-strength faster. Calculations made by COWI A/S shows that there is no greater risk of crack formation than if "Low-Alkali Sulphate Resistant cement" is used in a comparable concrete, [4].

The basis for the calculations are the same concrete compositions as used in the above mentioned durability studies, [1]. The overall conclusions of the calculations are:

- Concrete based on AALBORG WHITE develops more heat during hydration, and thus also greater temperature differences during the hardening process, than the grey reference concrete.
- The investigated white concrete, however, can withstand greater temperature differences than the grey reference concrete.
- This means that the risk of crack formation during the hardening for both concretes, white and grey, are comparable.

Overall, the calculations shows that the development in tensile strength of concrete based on AALBORG WHITE, in relation to the stresses introduced as a result of the temperature differences, is large enough to absorb these up to a higher temperature difference, than is the case for the reference concrete.

WHITE CONCRETE AS SCC

The prerequisite for a concrete to achieve good durability, in a given structure, is that it can be placed in the casting mold in a way that is usable in practice, while maintaining the quality of the concrete.

There are already many concrete producers that regularly are making well-functioning white SCC concretes, but what is obvious

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to some may be difficult for others.

Often, the starting point is an existing SCC concrete, where the most common attempt is to replace the grey cement (in Denmark usually CEM I 52.5R) with AALBORG WHITE in a 1: 1 ratio without further corrections. The result is often separation, bleeding or unacceptable workability of the concrete. Over time this has contributed to the perception that it is difficult to produce stable SCC concrete based on AALBORG WHITE.

Based on our own experiences and with input from customers, Aalborg Portland has worked on converting SCC concrete, based on grey cement, to SCC concrete, based on AALBORG WHITE. Several laboratory experiments have been carried out, where the result is simple rules of thumb for the conversion:

1. Replace grey cement with AALBORG WHITE 1:1
2. Reduce water content by 5%
3. Reduce superplasticizer content by 25%
4. Reduce air entrainer content by 50% (based on an air content of about 6%. If no air mixer has been used, it must be added!)
5. Make sample concrete mix and adjust to desired flow spread and air content.

One parameter that is important for the properties of SCC concrete is the sand fraction used. It is often observed that for white SCC concrete, single-grained light sand is used, containing relatively little filler (particle size below 0.25 mm). Thereby, the concrete may tend to lose stability and separate, and it generally becomes difficult to achieve the desired workability. One solution might be to increase the cement content or add other (white or light) filler with a grain size below 0.25 mm. Too much fines, on the other hand, will result in poor flow properties (rheology) and should therefore be avoided.

MIXING PROCEDURE

As with all SCC production, the mixing procedure is important in order to achieve robust flow properties. It is generally recommended to use something similar to the following mixing procedure:

1. Add aggregates and cement
2. Mix 10 seconds
3. Add water, air entraining agent and Lignosulphonate based plasticizer (if used)
4. Mix further for 20-30 seconds
5. Add superplasticizer
6. Mix 10-30 seconds to complete the mixing sequence.

This sequence ensures that the air entrainment agent is allowed to react in the concrete and form a robust pore structure before the superplasticizer interacts with various particle surfaces.

In general, it is important that there is a certain amount of good "chemical air" in the concrete for the mix to be stable. An air content of 5-7% provides a suitable consistency of any

SCC mix, while less air making the concrete fast-flowing with the risk of separation, and more air making the concrete more viscous and slower.

SUMMARY

Comparison of concrete based on respectively AALBORG WHITE and "Low-Alkali Sulphate Resistant cement" shows that the two types of concrete:

- have the same good durability
- have the same shrinkage properties
- have the same risk level for temperature-induced cracking
- can be produced and cast as SCC concrete.

Concrete based on AALBORG WHITE is therefore suitable for durable infrastructure projects and can be effectively cast.

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