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# CONCRETE ADMIXTURES - SUSTAINABLE CONCRETE

Oliver Schwoon

*Sika Services AG, Tueffenwies 16, 8048 Zurich, Switzerland*
correspondence: schwoon.oliver@ch.sika.com

Abstract.
Durability of concrete, an important part of the sustainability theme, was, is, and will be one of the main topics for large infrastructure projects like the Gotthard base tunnel. For such important structures a service life of more than 80 years is expected. The prevailing underground conditions like water ingress, aggressive waters etc. will influence the choice of the concrete system and mix design. Therefore, a focus is on the potential damage mechanisms on the concrete like chloride ingress or sulfate attack. A well-designed concrete will be durable concrete which can withstand various external attacks and achieves or even extends the designed service life of the concrete structure. Based on the knowledge that the main damaging mechanisms for concrete are based on water penetration into the concrete, various measures can be taken to achieve concrete structures with significantly reduced permeability. These measure ranges from reduction of the water/binder-ratio, increasing the density of the concrete using silica fume, to the use of special admixtures in order to increase the durability of concrete. In an extensive research program, the influence of mix design components e.g. different admixture types, water/binder-ratio on hardened concrete properties like chloride resistance (chloride migration coefficient), sulfate resistance and water conductivity have been tested and analyzed.

Keywords: Admixtures, chloride migration coefficient, mix design, sulfate resistance.

## 1. Introduction

The durability of concrete, an important part of the sustainability theme, was, is, and will be one of the main topics for large infrastructure projects like the Gotthard base tunnel. For such important structures a service life of more than 80 years is expected.

Hardened concrete can be damaged by water containing sulfates which can occur in soil or dissolved in ground water. These sulfates reacts with the tricalcium aluminate hydrates (AFm) in the cement and forms ettringite (also thaumasite under certain conditions). That leads to increases in volume and to high internal pressure in the concrete structure and therefore cracking and spalling occurs [1].

Another aspect is on the protection of the reinforcement against chloride exposure or chloride ingree into the concrete. Chloride ions can migrate through the concrete mainly by diffusion, interact with the passivation layer of the steel and leading subsequently to corrosion of the steel reinforcement. Other ways of transportation of the chloride ions are capillary absorption as well as hydrostatic pressure [1].

The prevailing underground conditions like water ingress, aggressive waters etc. will influence the choice of the concrete system and mix design. Therefore, a focus is on the potential damage mechanisms on the concrete like chloride ingress or sulfate attack. A well-designed concrete will be durable concrete which can withstand various external attacks and achieves or even extends the designed service life of the concrete structure. Based on the knowledge that the main damaging mechanisms for concrete are based on water penetration into the concrete, various measures can be taken to achieve concrete structures with significantly reduced permeability. These measure ranges from reduction of the water/binder-ratio, increasing the density of the concrete using silica fume, to the use of special admixtures in order to increase the durability of concrete.

The focus of this paper is on the use of special admixtures to create a durable and therefore sustainable concrete.

## 2. Investigation and experimental set-up

In an extensive research program, the influence of mix design components e.g. different admixture types, water/binder-ratio on hardened concrete properties like chloride resistance (chloride migration coefficient), sulfate resistance and water conductivity have been tested and analyzed.

### 2.1. Testing methods

The fresh concrete was assessed by the flow table spread (EN 12350-5), density (EN 12350-6) and air void content (EN 123350-7) after mixing (5 minutes) and the flow table spread after 30 minutes.

Concrete cubes (150 × 150 × 150 mm) have been mad and evaluated after 28 days of curing (EN 12390-2) according to SIA 262/1 "Betonbau-Ergänzende Festlegungen" Annex A (Water conductivity), B (Chloride resistance) and D (Sulfate resistance).

Limits of each test can be seen in Table 1 and will be referred to in the following chapters.

| Test | Limit |
|---|---|
| Sulfate resistance Lengthening [‰] | $\leq 1.0$ |
| Chloride resistance Chloride migration coefficient [$m^2/s$] | $\leq 10 \times 10^{-12}$ |
| Water conductivity $\left[g/\left(m^2.h\right)\right]$ | $\leq 1.0$ |

Table 1. Limits according to SIA 262/1 [2, 3].

| | Mix Design A | Mix Design B | Mix Design C | Mix Design D |
|---|---|---|---|---|
| Cement type | CEM I 42.5 | CEM I 42.5 | CEM I 42.5 | CEM I 42.5 |
| Cement amount [$kg/m^3$] | 300 | 350 | 300 | 350 |
| w/c-ratio | 0.58 | 0.45 | 0.58 | 0.45 |
| Max. grain size [mm] | 32 | 32 | 32 | 32 |
| Admixture 1 | Sika® ViscoCrete® | Sika® ViscoCrete® | Sika® ViscoCrete® | Sika® ViscoCrete® |
| dosage [%] | 0.0-0.2 | 0.6-0.8 | 0.0-0.2 | 0.6-0.8 |
| Admixture 2 | SikaControl® CRC | SikaControl® CRC | SikaControl® WT | SikaControl® WT |
| dosage [%] | 1.0 / 2.0 | 1.0 / 2.0 | 0.5 / 1.0 | 0.5 / 1.0 |

Table 2. Concrete Mix Design.

### 2.2. Concrete mix design

The mix design has been set for all trials except the needed amount of plasticizer or superplasticizer to achieve the aimed flow table spread (FTS). FTS has been targeted at around 50 ± 5 cm. Trials were conducted at two water/cement ratios (w/c-ratio): 0.58 and 0.45. The trials have been conducted with two different admixture technologies called SikaControl® CRC and SikaControl® WT. The first one achieves an improvement of the durability of the concrete by creating a more chemical resistant concrete, whereas the second one aims on the water resistance of the concrete.

SikaControl® CRC is an admixture based partly on hydroxyl combinations and one of the main effects is the in reduction in dry shrinkage and therefore shrinkage cracks. SikaControl® WT is a water resisting admixture which incorporates mainly pore blocking and hydrophobic technologies.

These concrete mix designs used in this investigation can be seen in Table 2.

## 3. Results

Concrete mixes with and without the special admixtures has been tested on different w/c-ratios in order to assess the performance and influence of the admixtures. Limits of the tests have been listed in Table 1.

### 3.1. Influence of the admixtures at a w/c-ration of 0.58

The results of the sulfate resistance, chloride resistance and water conductivity of the concrete cubes are shown in the following Figure 1 to 5.

It can be observed that a significant increase of the sulfate resistance and be achieved with already 1% of the SikaControl® CRC albeit not enough to stay below the set limits. An increase in dosage up to 2% let the cubes pass the test limits (Figure 1).

A similar trend is shown by the results of the chloride resistance tests. A reduction of the chloride migration coefficient can be realized with 1% of the SikaControl® CRC. But again, still not good enough to pass the test. As before an increase in dosage up to 2% results in staying below the limits (Figure 2).

Only the concrete with the higher dosage of SikaControl® WT using the mix design C stays below the limits of the sulfate resistance test (Figure 3).

The chloride migration coefficient is significantly reduced versus the reference by the use of SikaControl® WT and both dosages are below the test limits but showing only minor improvement from an increase in dosage (Figure 4).

SikaControl® WT displays a significantly reduction in water conductivity versus the reference with both dosages (Figure 5).

### 3.2. Influence of the admixtures at a w/c-ration of 0.45

The results of the sulfate resistance, chloride resistance and water conductivity of the concrete cubes are shown in the following Figure 6 to 9.

The reference concrete with a w/c-ratio of 0.45 passes the sulfate resistance test but leaves not much room for a margin of safety. Whereas both dosages of SikaControl® CRC pass the test and provide a healthy margin of safety (Figure 6).

All cube of the test set of mix design B pass the chloride resistance test. The positive influence of the special admixture SikaControl® CRC can be seen in the results and the reduction of the chloride migration coefficient. Further investigations are necessary regarding the higher results at the higher dosage against a lower dosage (Figure 7).

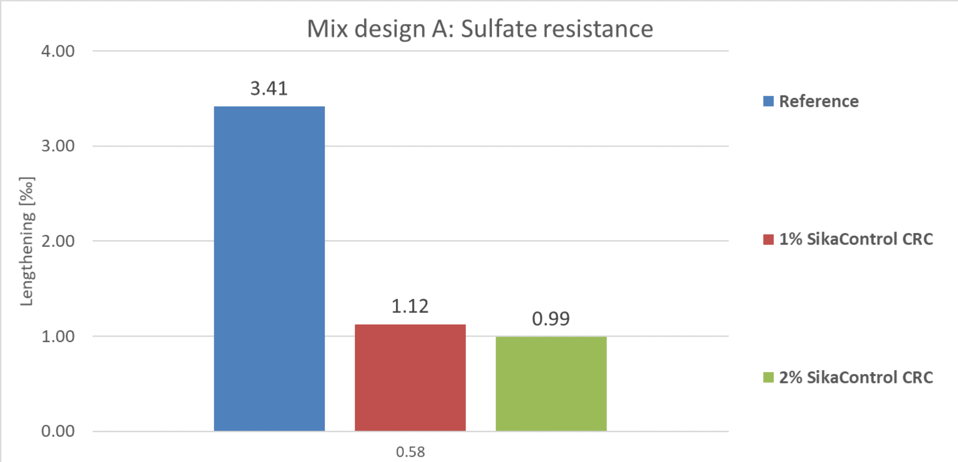


Figure 1. Mix design A: Sulfate resistance.

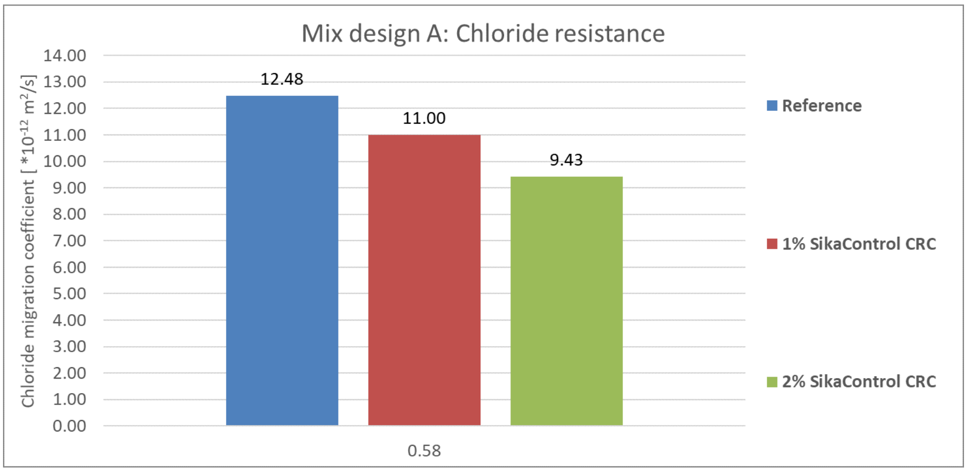


Figure 2. Mix design A: Chloride resistance.

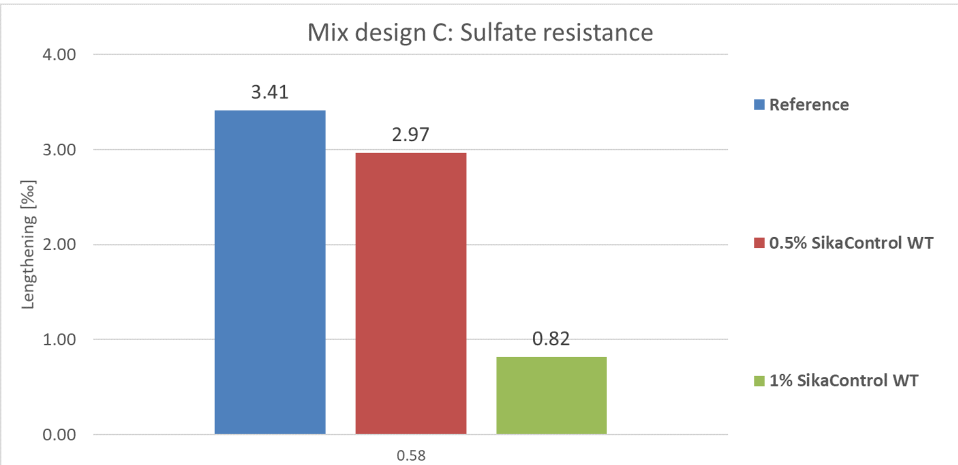


Figure 3. Mix design C: Sulfate resistance.

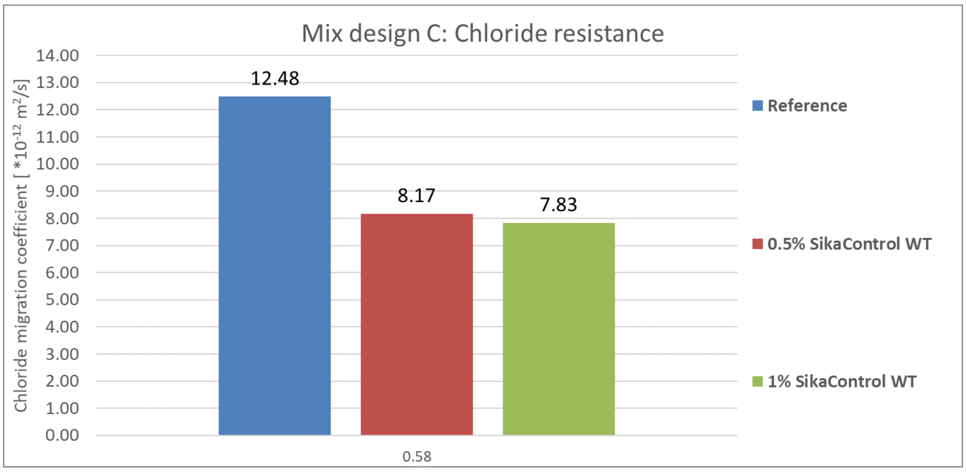


Figure 4. Mix design C: Chloride resistance.

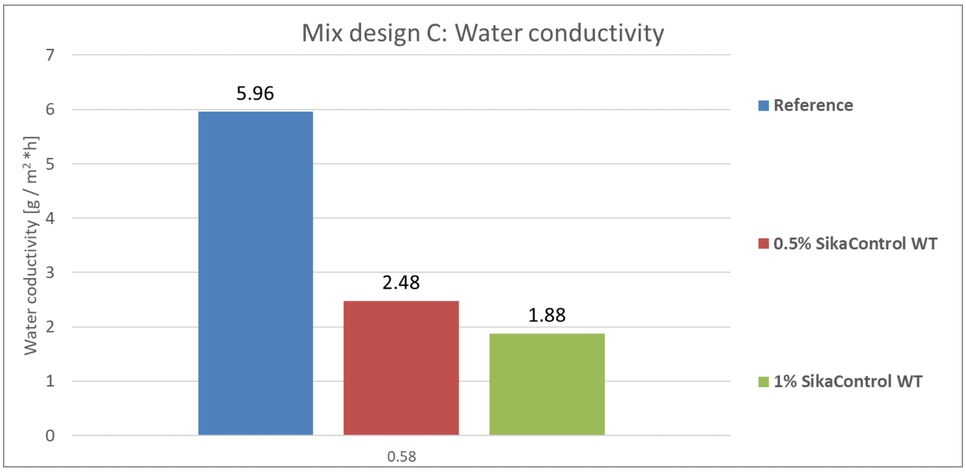


Figure 5. Mix design C: Water conductivity.

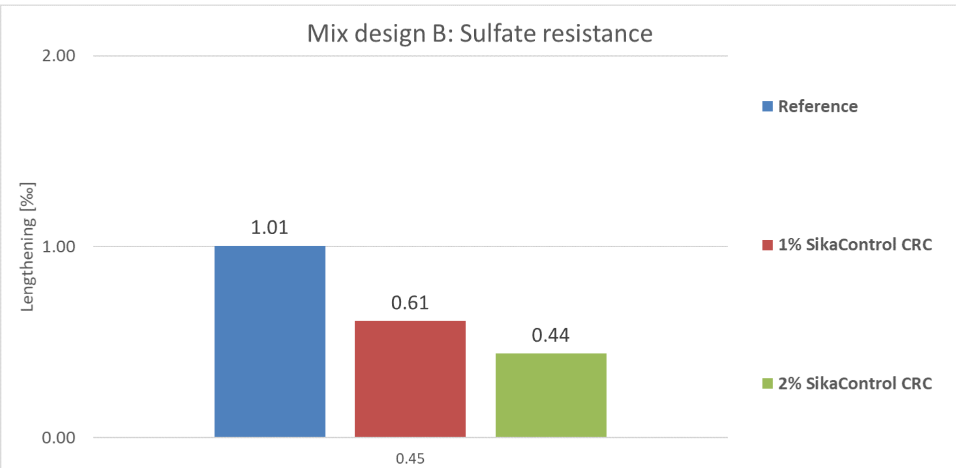


Figure 6. Mix design B: Sulfate resistance.

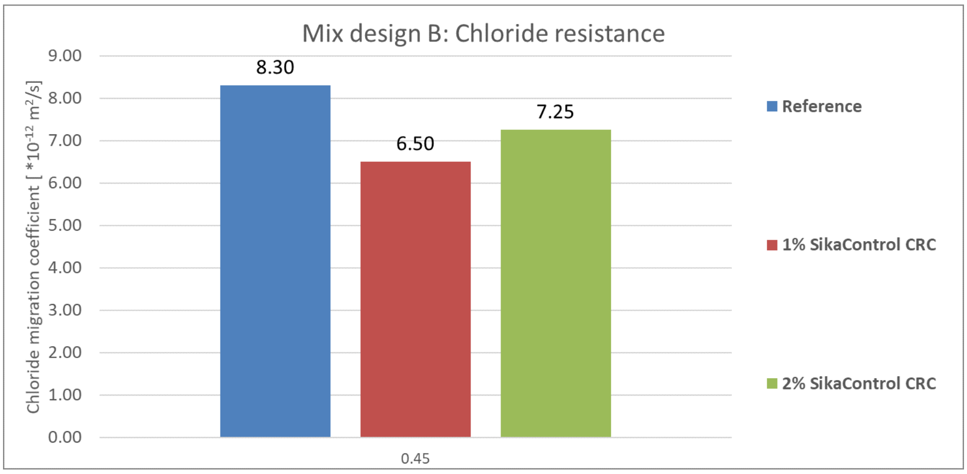


Figure 7. Mix design B: Chloride resistance.

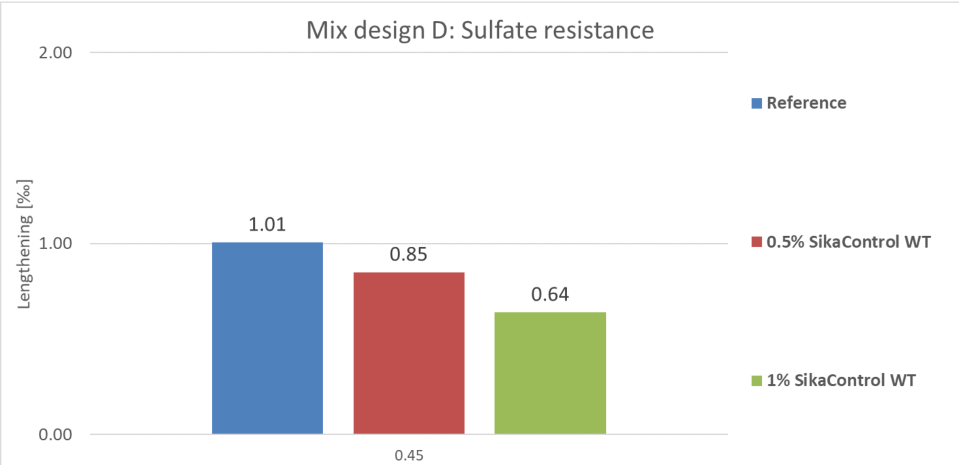


Figure 8. Mix design D: Sulfate resistance.

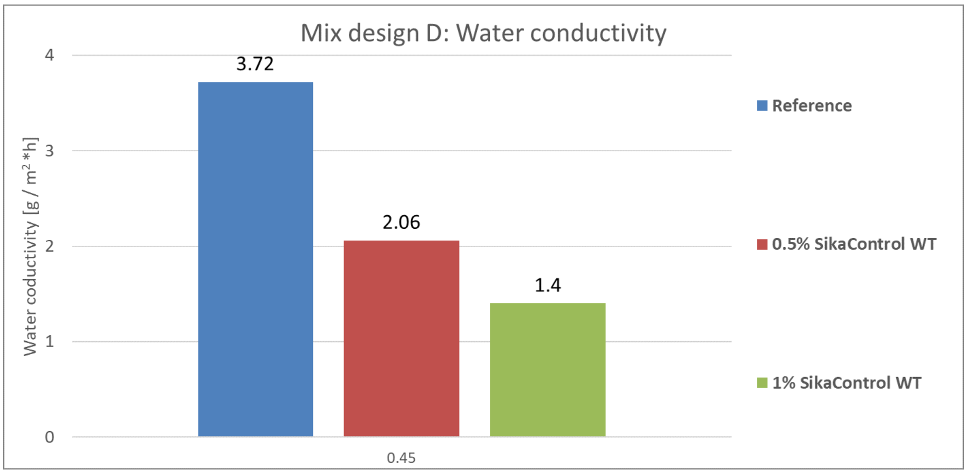


Figure 9. Mix design D: Water conductivity.

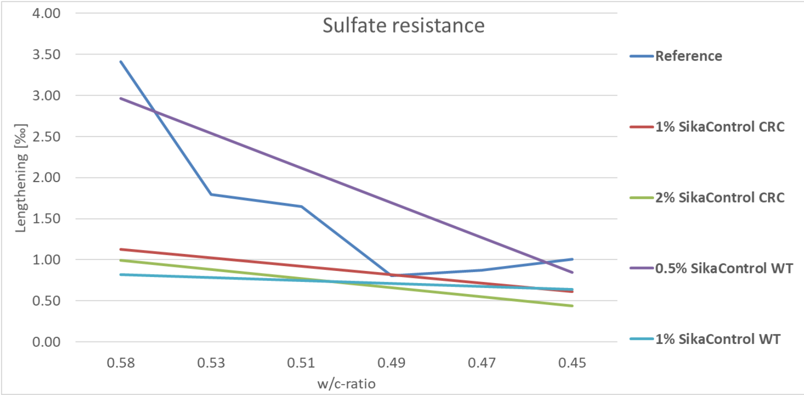


Figure 10. Reference concrete with various w/c-ratios: Sulfate resistance.

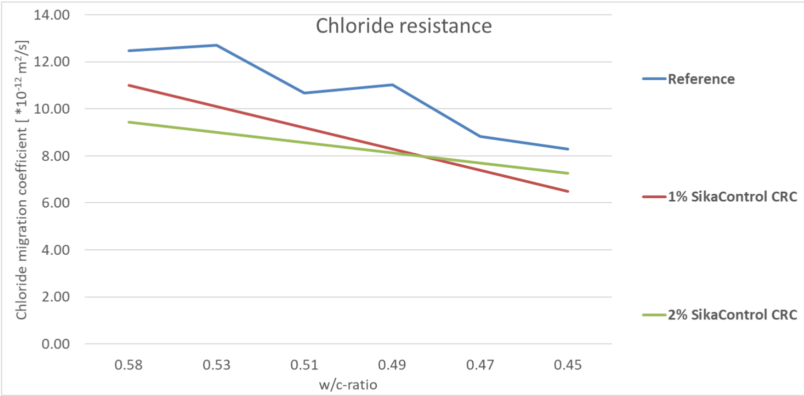


Figure 11. Reference concrete with various w/c-ratios: Chloride resistance.

The use of mix design D incorporating the admixture SikaControl® WT will pass the test at both tested dosages and show a significant improvement against the reference concrete (Figure 8).

As seen before SikaControl® WT displays a significantly reduction in water conductivity versus the reference with both dosages (Figure 9).

## 4. Conclusions

The investigation has shown that the use of these special admixtures like SikaControl® CRC and/or SikaControl® WT improve the durability of a concrete in respect to chloride and sulfate resistance and/or water conductivity. It will allow the concrete designer to choose an appropriate w/c-ratio and still maintain a margin of safety in regard to the named durability tests.

Furthermore, the results of the many tests conducted showed that a certain variance within the test itself has to be accounted for and a margin of safety is necessary. Figure 10 displays the results of the sulfate resistance test of a reference concrete with different w/c-ratios. The results of the trialled admixtures and mix designs are shown included in Figure 10 as well. It should be noted that those are only the w/c-ratios of 0.58 and 0.45 connected by a straight line.

Especially at higher w/c-ratios a significant positive influence can be achieved by the use of the tested admixtures. As for mix designs with lower water w/c-ratios a higher margin of safety can be accomplished.

Same conclusion as before can be drawn when it comes to the chloride resistance and the tested mix designs and special admixtures.

Next to well-known measure like reduction of w/c-ratio, use of SCM etc. in order to increase the durability and therefore the service life of a structure the tested special admixtures will give concrete designers, specifiers, contractors and/or concrete producers another valuable tool to fulfil the challenging requirements of important infrastructure projects or any other needed concrete.

## References

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[2] The Swiss Standards Association. SIA 262/1:2013 Betonbau - Ergänzende Festlegungen, *Zurich: Schweizer Ingenieur- und Architektenverein*, 2013.

[3] The Swiss Standards Association. SN EN 206:2013+A1:2016-C1:2019, *Zurich: Schweizer Ingenieur- und Architektenverein*, 2013.