Master's Thesis in Civil and Structural Engineering

Title:

Silica Green Stone as an SCM in concrete paving stones production

In order to reduce the total environmental footprint

Candidate: Lars Normann Hartz

Supervisors:
Rein Terje Thorstensen, UiA
Per Anders Eidem, SINTEF
Bjarte Øye, SINTEF
Svein Willy Danielsen

Introduction

Globalization and continuing population growth have led to the cement industry already having more CO_2-emissions than most entire nations. Sea levels rising, temperatures rising and millions losing their homes have led to agreements, like the Paris agreement, being signed to help reduce emissions and the cement industry are always searching for ways to follow these new goals.

Supplementary cementitious materials (SCMs) have been found to be one of the best ways for the cement industry to reach those reduced emission goals, by replacing large amounts of cement. Ironically these societal/climate changes have led to less production of some SCMs, more need of others and a constant need for new ones.

This Master's Thesis has been produced while working together with SINTEF, Eramet Norway, UiA and Aaltvedt Betong to research if Eramet's Silica Green Stone (SiGS) can be used to produce concrete paving stones. The thesis will hopefully show if moving into larger scale production is worth the effort for all involved.

Theoretical background

Earth-moist concrete (EMC) is a specially designed concrete used to produce paving stones. It has little regulation on materials, a high cement content, water/cement ratio < 0.4 and strictly fine aggregates. Paving stones are used universally and are sold by the billions. It also has little regulations on material composition. SiGS is a silicomanganese slag by-product from Eramet that has shown great promise for SCM use, with much of the same composition.

Research question

The questions about using SiGS in concrete paving stones led to this question:

How would changes in the solidification method and substitution level of SiGS, when used as an SCM, influence the quality of concrete paving stones?

Materials

The materials used on this project were air-cooled and granulated SiGS from two Eramet facilities. The compositions can be seen in figure 1 below, with air-cooled on the left.

Compound	Value	Unit	Status
Mn-Calc	5.0	NONE	
SiO2	44.9	%	
Al2O3	14.8	%	
CaO	23.8	%	
MgO	7.4	%	
K2O	0.70	%	
FeO	0.28	%	
B/A	0.94	NONE	
TiO2	0.128	%	
VISK	13.1	NONE	
BaO	0.65	%	
Na2O	0.33	%	
S	0.36	%	
MnO	6.5	%	

Compound	Value	Unit	Status
Mn-Calc	7.8	NONE	
SiO2	41.6	%	
Al2O3	17.8	%	
CaO	18.3	%	
MgO	8.5	%	
K2O	1.52	%	
FeO	0.20	%	
B/A	0.99	NONE	
TiO2	0.135	%	
VISK	11.3	NONE	
BaO	0.71	%	
Na2O	0.36	%	
S	0.59	%	
MnO	10.1	%	

Figure 1 XRF analysis of air-cooled and granulated SiGS

Method

To explore the research question many methods were used. First was a small literature study about a few problem areas that could need research. Then came production of paving stones with connected density and visual measuring. After that came laboratory testing on compressibility, tensile splitting strength, water absorption and resistance towards freeze-thaw deterioration. Finally came an additional laboratory method about inspecting long-term stability and visual/texture development.

Results and discussion

In order to better track results, all stones were given date, *FA* or *IN (for cement type), and a letter and number for SiGS type/amount.*

The comparison of air-cooled and granulated in fig. 2 SiGS shows that 12 of 20 times G-SiGS is best, 1 is identical and 7 times A-SiGS wins. These results show 20% to be better than 40%, but other results show 50% surprisingly high up.

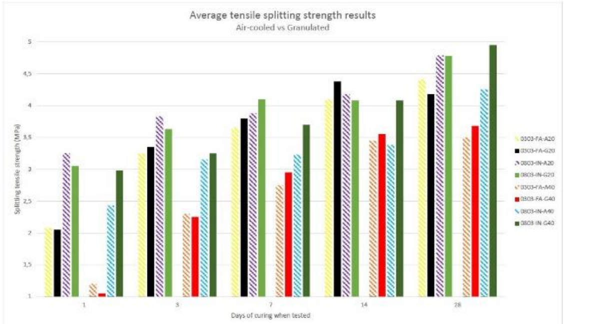

Figure 2: comparison of tensile splitting strength for air-cooled and granulated SiGS

Density varies a lot in standard production and fig. 3 shows that to be the case with SiGS also. The water absorption is under the demands in the standard, but it varies with no clear connection to SiGS amount/type, cement type or density, as the figure also shows.

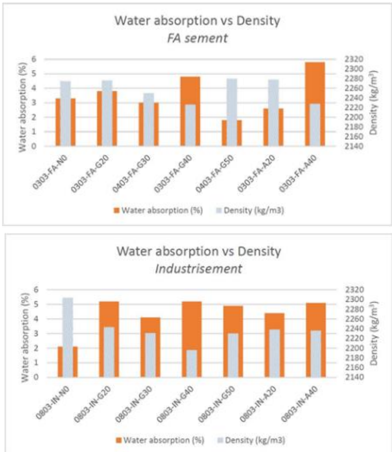

Figure 3: Comparison between water absorption and density

Conclusion

- It seems like only switching out different amounts of different SiGS types, and nothing else, will influence paving stone quality in very different ways. Most are negative, but still well within legal requirements.
- It seems like air-cooled SiGS might create a slightly better density than granulated, but there are contradicting results. It seems like density generally falls with increasing SiGS, but 50% replacement increases it again.
- It seems like air-cooled SiGS might be better against water absorption and that substitution level are not as important.
- It seems like compressibility is largely independent of SiGS type and substitution.
- It seems like SiGS itself is easy enough to work with in a full factory production setting.
- It seems like all SiGS combinations create consistent strength results, that granulated SiGS creates slightly better results, that increasing SiGS amounts decreases the strength, but that 50% creates interestingly strong results.
- It seems like air-cooled SiGS has a significantly worse frost resistance and that increasing the substitution also lowers the frost resistance.
- It seems like there is little chance of shrinkage /expansion and that granulated SiGS might create an unwanted chemical reaction and colour.