Investigation of sprayed concrete with environmentally friendly basalt fibers for tunnel linings

Rannsókn á sprautusteypu með umhverfisvænum basalt trefjum í stað notkunar á plasttrefjum

Iveta Nováková[1], Eythor R. Thorhallsson[2]
[1]Construction Research and Development, Innovation Center of Iceland, Arleynir 2-8, Reykjavik 112, Iceland
[2]Structural Engineering Laboratory, SEL, Reykjavik University, Menntavegi 1, Reykjavik 101, Iceland

Introduction

Icelandic landscape has a volcanic origin, and the coastline is full of steep hills, and deep fjords which make the development of transport network difficult. Mountain overpasses and long roads curling around coastlines of peninsulas are commonly extremely complex and rather expensive to maintain during the winter period. Tunnels contribute to safer transportation and reduce the time and length of journeys.

At the moment there are eleven open road tunnels in Iceland, and five of them have been open since the beginning of the 21st century. Furthermore, two new road tunnels are under construction. These numbers indicate the rapid development of road infrastructure which could be driven by a constantly rising number of tourists heading to.Iceland. Furthermore, it is important to mention the spillway tunnel system which is part of the Kárahnjúkar Hydropower Plant, and it is the longest tunnel in Iceland.

Most common material for tunnel lining is sprayed concrete due to its relatively easy and fast application, and low price in comparison to the other materials used for tunnel lining. Concrete tunnel lining is beneficial for larger tunnels like road, railway or big mining pits. Wood planks, steel frames and steel plates are usually used for the lining of.smaller mining pits or pedestrian tunnels. Sprayed concrete has lately replaced the traditional methods of lining tunnel profiles and become very important in stabilising the excavated tunnel sections. Various types of dispersed fibers could be used to improve properties of plain sprayed concrete, for example, brittleness and limited tensile and bending strength.

This study is focused on the development of sprayed concrete with environmentally friendly basalt fibers. Basalt fibers are a relatively new type of fibers which does not have stable use in concrete technology yet, but this is about to change with rising emphasis on environment-friendly materials. Currently, the most used fibers for dispersed fiber reinforcement are polymer macro or micro fibers and steel fibers which are either unecological or causing high carbon footprint.

Sprayed concrete

Sprayed concrete is a special type of concrete applied by spraying on the based layer, in case of tunnelling on bad rock. Different rules apply while designing a sprayed concrete, for example, higher content of fines, maximum aggregates size or necessity of accelerator agent addition. One of the most important properties of the sprayed concrete is the amount of rebound during application, setting time and flexure strength and bond strength of hardened concrete. Amount of rebound (fallout of concrete while spraying) for wet spraying method is from 5 to 15% and usually is washed away from the tunnel into surrounding area. This fact is a very important aspect of the used type of sprayed concrete. Fresh concrete with steel or polymer fibers is way less ecologically desirable than concrete with no fibers content. Above this all, polymer fibers are the worst used fibers due to their long disintegration half-time.

Figure 1 a) Krampe harex PP-fibers; b) Basaltex basalt fibres; c) various types of macro and micro fibres

Laboratory testing of sprayed concrete

Experimental work consists of a selection of suitable raw materials like cement, aggregates concerning maximum grain size and fines content, water, additions and admixtures. It is convenient to consider the use of supplementary cementitious materials to reduce cement content dose which varies between 380 to 500 kg/m^3. Within this testing, basalt fines were not added to omit more than one variable in mixes and also because used aggregates had high fine content which contributed to compact mix. Hardening accelerator admixture for faster hardening and plasticizer for obtaining more workable mix are two most common used admixtures in sprayed concrete.

Design of sprayed concrete was inspired by conventionally used sprayed concrete mix designs but converted to laboratory scale. Laboratory sprayer supplied by Fishstone GFRC can spray concrete with maximum particle 4 mm and as the concrete mix is moved only by its weight towards the sprayed outlet more flowable mix is required to omit blocking of the outlet. The presence of basalt fibers while spraying has not caused any blocking of the nozzle and rather helped to avoid segregation of the mix.

Concrete without fibers was made as reference mix and then mixes with 4, 6 and 8 kg of basalt fibres per 1 m^3 were prepared. Sprayed concrete was applied on tilted board which was inclined under 20 degree. Cement content, aggregate dose and amount of superplasticizer were kept constant, and a dose of water with accelerator slightly varied due to the addition of fibers. Shotcrete penetrometer from Mecmesin was used for measurements of early age strength in the range of 0 to 1,2 MPa.

Figure 3: Images of the surface of test samples with various dose of basalt fibres content.

Conclusion

Sprayed concrete was designed and tested in laboratory condition, and therefore some changes had to be done to regular mix design for field sprayed concrete. Maximum aggregates grain size was 4 mm, and basalt fibers dose 0, 4, 6, 8 kg/m^3 which required a slight rising of water and accelerator content. Measurements of early age strength by penetrometer was performed 6, 20, 40 and 60 min after termination of spraying. Sample with basalt fibers were more compact and performed better in the sense of the constant layer and lower segregation. It could be stated that early age is gained faster with a higher dose of basalt fibers. All tested samples were classified into class J2 according to ÍST EN 14487-1Further testing will be focused on properties of hardened sprayed concrete tested according to European standards.

Why basalt fibers?

Currently, many research teams around the world are investigating problematics focused on fiber reinforced concrete with various types of fibers including also basalt fibers. Basalt fibers dispose of many convenient mechanical and physical properties, and it might be stated, that they are more durable in aggressive conditions than glass fibers and significantly cheaper than carbon fibers.

A study conducted by Vito NV [1] was focused on a comparison of basalt and glass fibers and their energy efficiency differences during the production. Results showed that basalt fibers have the same heat and electricity consumption, but there is an absence of emission processing, usage of boric acid, amount of waste and much lower required amount of epoxy resin for composites. In total relevant contribution of 10 considered factors riched 80 % in case of basalt fibers while it was 100 % for glass fibers. Also, resource depletion and water depletion is significantly higher in connection of glass fibers. The requirement of boric acid for glass production is one of the main drawbacks in the sense of the environmental profile.

Basalt rock has a lower melting temperature than iron ore or silica sand which are raw materials for the production of fibers for dispersed concrete reinforcement. Polymer fibers do not require high melting temperature, but they are less environmentally friendly. Input materials for the production of basalt fibers could be exclusively basalt rock or bland of basalt rock with other minerals. Production of the continuous filament is more sensitive than the production of rock wool, and therefore the chemical composition of input materials has to be closely monitored, and also not every basalt rock is suitable.

Icelandic basalt is young mineral, and its chemical composition is commonly more variable, which is not suitable for presently used technologies for continuous filament production. Nevertheless, this might change due to innovations of presently used technologies for basalt continuous filament production and allowed less strict criteria on input raw material.

Table 1: Properties of various material based fibers

	Krampe Harex PM12/18 [2]	Basaltex BCS17-25.4-KV13 [3]
Material type	Polyplopylene	Basalt
Diameter [μm]	18 ± 10 %	17
Length [mm]	12 ± 10 %	24.4
Density [kg/m^3]	900	2 670
Degradation temperature [°C]	not specified	600 - 700
Melting point [°C]	170	1 350
Tensile strength [N/mm^2]	300	4 840
Young´s modulus [N/mm^2]	1 550 ± 16 %	88 000 ± 5%

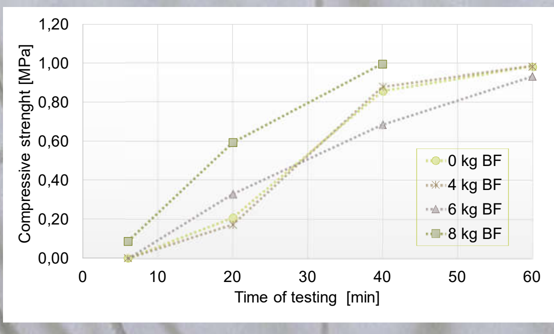

Figure 2: Comparison of early age compressive strength gain of sprayed concrete with 0, 4, 6 and 8 kg of basalt fibres tested by penetrometer.

Resalt evaluation

All prepared mixes prove satisfying behaviour in the fresh state and also during the early phase of ageing. The consistency of fresh sprayed concrete was getting more compact and little bit stiffer with rising amount of basalt fibers. To omit difficulties with spraying slightly higher water content and accelerator dose was added. Testing of early age compressive strength according to ÍST EN 14488-2 Method A was performed 6, 20, 40 and 60 min for termination of spraying. Sample with 8 kg of basalt fibres was not measurable at 60 min because the strength exceeded measurable range of penetrometer. In the sample with 6 kg of basalt fibers were visible small fiber agglomeration caused by imperfect mixing procedure.

References

[1] K. Boonen, G. Janssens and S. Manshoven; Summary report on the environmental potential of basalt fibres versus glass fibres. Vito NV, 2017.
[2] Technical Data Sheet, https://www.krampeharex.com/typo3temp/pdf/PDB_KrampeHarex-Kunststofffaser-PM_12_18.pdf?1491462084
[3] Technical Data Sheet, http://www.basaltex.com/files/cms1/BAS220_1270_P.pdf

500.0 um

Nýsköpunarmiðstöð Íslands
HÁSKÓLINN Í REYKJAVÍK
REYKJAVIK UNIVERSITY
VEGAGERÐIN