Cold Regions Science and Technology 111 (2015) 1–12

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Experimental study on debonding of shotcrete with acoustic emission during freezing and thawing cycle

Ganesh Mainali *, Savka Dineva, Erling Nordlund

Division of Mining and Geotechnical Engineering, Luleå University of Technology, 971 87 Luleå, Sweden

ARTICLE INFO

Article history:
Received 21 March 2014
Received in revised form 14 October 2014
Accepted 26 November 2014
Available online 6 December 2014

Keywords:
Rock–shotcrete interface
Debonding
Freezing
Thawing
Acoustic emission

ABSTRACT

Studying the deterioration of shotcrete due to freezing and thawing is important for improvement of the understanding of the failure mechanisms/debonding of shotcrete in cold regions. Water leakage in a tunnel leads to ice growth during freezing temperature and ultimately creates favorable environment for fallouts of shotcrete and rock. Repeated freezing and thawing of shotcrete lead to development of new micro cracks and propagation of pre-existing micro cracks. In this study, test panels of granite with dimension 800 × 800 × 80 mm covered with 50-mm thick shotcrete were subjected to freezing and thawing action in a controlled environment. The initiation and the development of freeze-induced micro cracks in shotcrete-rock interface were studied by continuously monitoring acoustic emissions (AE) and temperature. The clustering of the AE events during freezing and thawing indicates that micro cracks appeared in the shotcrete-rock interface and caused adhesion failure. The larger number of AE events in the panels, with access to water during freezing, confirmed that water contributes to material deterioration and also reduces the adhesive strength. The test results showed that most of the acoustic emission occurred during the freezing cycle and the number of acoustic emission events did not increase with the successive increase of the number of freezing and thawing cycles.

1. Introduction

Road and railway tunnels in cold regions are often affected by problems related to water leakage and freezing temperatures. Freezing and thawing may occur several times during the winter season due to temperature fluctuations and can widen and propagate the cracks/joints causing an increase in the water leakage and the formation of unstable blocks/volumes of rock thus increasing the risk of fallouts. Water leakage into a tunnel can also lead to ice growth in the form of icicles and pillars along the tunnel contour during freezing temperature. A number of studies have shown that functional damage due to icing and frost damage is common in countries such as Austria, Germany, France, Norway, Switzerland, China, Japan (ITA, 1991; Lai et al., 1999; Thomachot et al., 2005; Zhang et al., 2004, 2007).

Over the past twenty years, Swedish Transport Administration (STA) has observed an increased number of incidents involving shotcrete and rock fallouts due to ice formation in railway tunnels. Several cases of rock and shotcrete fallouts in different tunnels in Sweden (e.g. Bergträsk, Aspen, Herrljunga and tunnels) have been reported by Andrén (1995). Field observations were undertaken by Andrén (2008) in five Swedish railway tunnels from the autumn of 2004 until the summer of 2005. The results show that the water leaking into the tunnels begins to freeze and ice formations such as icicles and ice pillars form in the beginning of the winter. This causes major problems related to train operation, derailment, short-circuit and safety of working environment.

Shotcrete is commonly used as surface support in Swedish railway tunnels. The bonding or adhesion of shotcrete to the rock is influenced by many factors such as mineralogy, textural features, strength and surface roughness of the rock and shotcrete mixture. Most of the previous studies of rock-shotcrete interaction and debonding focused on factors such as the surface roughness, rock strength, Young's modulus, discontinuities, adhesion strength and shrinkage shotcrete, the thickness of the shotcrete lining, and the rock bolts. There are only a few studies on debonding of rock-shotcrete due to frost action, e.g. Andrén (2009). A comprehensive knowledge of the interaction of the rock-shotcrete interface during freeze-thaw conditions is still lacking.

Concrete and shotcrete are porous materials. The pores in these materials are under saturated conditions, partly or fully filled with water. When water freezes, it undergoes a volumetric expansion of about 9% due to phase transition into ice. One of the main damaging factors to the shotcrete is the hydraulic pressure, which increases when water becomes confined due to rapid freezing. The other damaging factor is growth of ice lenses. This process is longer when the freezing rate is slower because water can continue leaking for a long time (Fridh, 2005). It is known that icicles usually stop growing when the temperature drops rapidly (rapid freezing rate). This is due to the fact that the cracks which supply water for formation of ice lenses become frozen. The excavation process affects also the rock beyond the desired

* Corresponding author. Tel.: +46 920492467; fax: +46 920492818.
E-mail address: Ganesh.Mainali@ltu.se (G. Mainali).

http://dx.doi.org/10.1016/j.coldregions.2014.11.014
0165-232X/

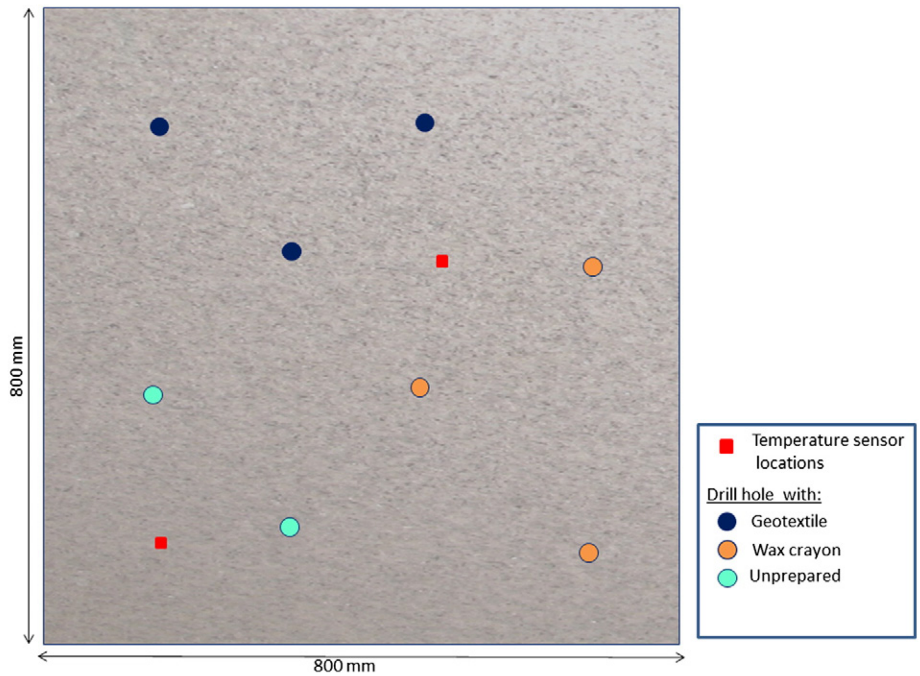

Fig. 1. Plan view of the test panels with temperature sensor locations and drill hole location with different type of preparation (see the legend).

perimeter of the opening. The affected rock often named Excavation Disturbed Zone (EDZ) is characterized by reduction of rock mechanical properties and increase in hydraulic properties, due to an increased frequency of new as well as propagated pre-existing fractures. This part of the rock mass is therefore also more sensitive to freezing and thawing conditions since free water during freezing may widen and propagate the fractures within this zone which finally may lead to detachment and fallouts of pieces or blocks of rock from the host rock mass.

The problem with ice is of a greater concern when it occurs in the interface between the rock and the shotcrete since this can cause fallout of both materials (Andrén, 2009). The interface between rock and shotcrete is often weaker than both the rock and the shotcrete. During the freezing period, cracking in rock and shotcrete may occur due to development of ice pressure in the interface that can reduce the overall strength and stiffness of the rock support. This ultimately creates favorable conditions for fallouts of shotcrete and rock.

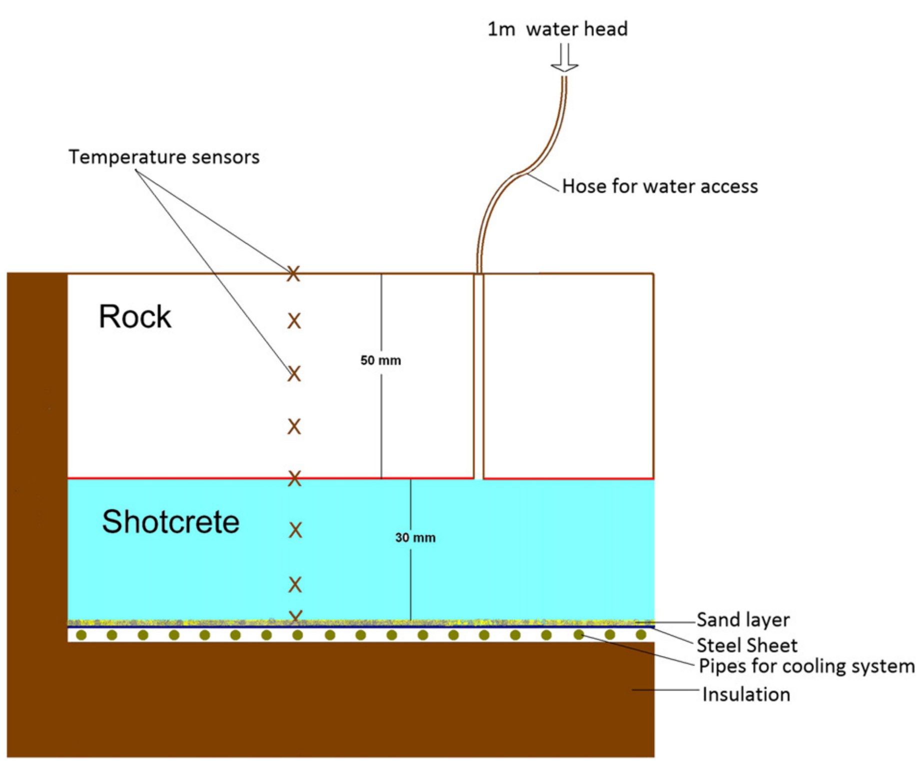

Fig. 2. Simplified sketch of the vertical section of the freeze-thaw lab experiment.