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Creep behaviour investigation of a thin spray-on liner

D. Guner, H. Ozturk*

Mining Engineering Department, Middle East Technical University (METU), Ankara, Turkey

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ABSTRACT

Thin spray-on liner (TSL) is a fast-setting multi component polymeric material applied on a rock surface with a thickness of 2–5 mm. TSLs are primarily used as an areal support element in a support system that also incorporates rock bolts. Different laboratory and field tests were performed to understand the support performance of the TSL for underground design. The research described in this paper presents laboratory studies of the tensile creep behaviour of a cement based TSL for the first time in the literature. For this purpose, "dogbone" tensile/tensile creep test samples were prepared under laboratory conditions with different curing times (1, 7, and 14 days) and were tested under 23 ± 2 °C laboratory conditions according to the ASTM standards. A range of dead weights (80%, 60%, 40%, and 20% of the tensile strength) was applied until the rupture of the specimens. The time-dependent behaviour of a TSL was presented for different constant load and curing time conditions. Moreover, creep rupture envelopes were constructed to estimate the tensile failure time of the TSL for a given loading condition. If the tensile stress acting on the TSL is known, the effective permanent support time of the TSL can be estimated by the derived equations. It was observed that during the creep tests, if TSL is sustained under more than 60% of its ultimate tensile strength, it fails within 24 h. The tested TSL is highly sensitive to creep deformation and design engineers should be aware that creep might cause serious problems in the application of TSLs. As a practical guide, it is proposed that for the 7 day or older aged TSLs, 15–20% of the tensile strength and for 1-day or younger aged TSLs, 30–35% of the tensile strength should be taken as a tensile strength design parameter.

1. Introduction

Rock reinforcement elements are primarily utilized for preventing the movement of the rock mass or larger rock blocks, whereas surface supports, capable of preventing small block size instabilities, are more favorable for containment purposes. They have also been referred to as areal supports that cover an area of roof and walls. Wire mesh, straps, grids, thick layer sprayed material (mortar and shotcrete), and Thin Spray-on Liners (TSLs) are considered as areal support elements.[1–3]

Sprayed areal supports start acting as active support elements even for relative rock movements of a few millimeters. Therefore, they can reinforce the rock mass at early stages before the excavation convergence reaches large displacement values on the ground reaction curve. Steel wire mesh, straps, and grids are definitely passive support elements and require substantial displacement to act as an active support element. While shotcrete or reinforced shotcrete provide much higher support resistance than TSLs, where squeezing problem is severe, TSLs may provide better support over the full range of rock deformations.[4] Contrary to the traditional brittle bolt and shotcrete supports, the high plastic behaviour of TSLs lead to the distribution of the loads on larger lining area. When used in conjunction with wire mesh, the liner achieves a high load-carrying capacity, equivalent to or exceeding the strength of the reinforced shotcrete. Being different than shotcrete, which yields suddenly in shear or tension, polyurethane/polyurea or cement based TSLs can deform together with the rock and even when the rock has failed and started to displace and become "loose", they still give supporting action. Another important component of the support function is a TSL's ability to deform yet carry the load like a suspension bridge.[5]

Despite the significant properties and operational benefits of TSLs, the vast majority of the industry still doubts the long term performance of this relatively new material. This is mainly based on the challenges in defining quantitative measures of TSL. Researchers have studied the support mechanism of TSLs using numerical and analytical methods, and laboratory studies. A detailed literature review on this can be found at Guner and Ozturk.[6] Different laboratory and field tests have been performed for the last two decades to understand the structural effectiveness of the TSLs for underground support. Laboratory studies measuring the mechanical properties of TSL available in the literature are presented in Fig. 1. Only direct tensile and adhesion strength tests

* Corresponding author.
E-mail address: ozhasan@metu.edu.tr (H. Ozturk).

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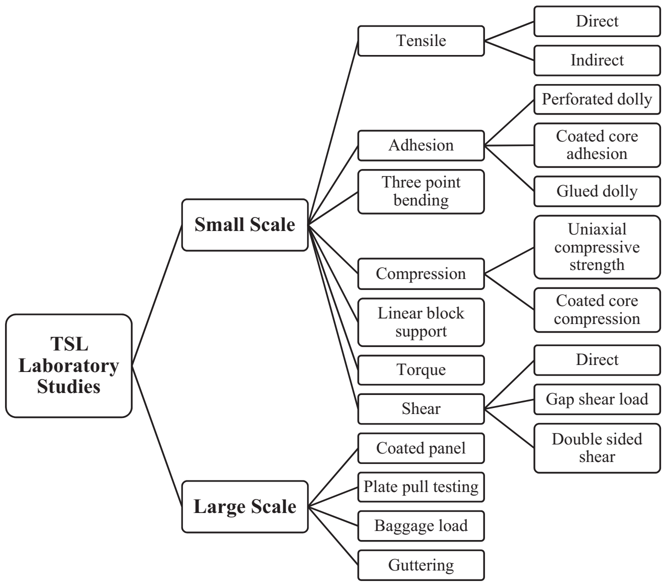

Fig. 1. Schematic Description of Laboratory TSL Experiments in Literature.

gained wide acceptance among TSL researchers.

Researchers agreed upon creep properties of TSLs as an important design parameter.[7–9] Most of the research in this field focuses on determining ultimate tensile, shear and adhesion strength properties of TSLs. The time-dependent creep behaviour of TSLs is not investigated in literature to time.

In fact, the behaviour of TSLs under a constant load may be a serious problem and the creep properties might be important for the evaluation of long term performance. Further laboratory and field studies are required to understand the performance of polymer liners under sustained loading (rockfall) conditions.[10] During the field applications, TSLs are exposed to long term constant loads, including tensile and bonding forces primarily responsible for keeping the liner active. If the bonding forces decrease, debonding may occur and the liner might lose its holding function. If the adhesion between the TSL and the rock is strong, the liner is exposed to tensile stress. Moreover, if the liner exhibits a time-dependent elongation behaviour, the holding time becomes a function of both tensile and creep properties.

In order to better understand the elongation behaviour of TSLs, the creep behaviour of a cement-based TSL was investigated in this study. For this purpose, 1, 7, and 14-day cured dogbone TSL specimens were prepared according to the ASTM D-638 standard[11] and tested under 23 ± 2 °C laboratory conditions conforming a standard testing methodology.[12] Constant loads ranging from 20% to 80% of the ultimate tensile strength was applied until the rupture of the specimens. At the end of the laboratory studies, the time-dependent strain behaviour of the TSL was measured for different stress levels and curing time conditions. Creep rupture envelopes were constructed to estimate the tensile failure time of the TSL for a given loading condition. Finally, a worked out example was presented to estimate holding time of the TSL by considering two different scenarios; a regular tetrahedral block and a cubic block.

2. Creep on TSL

Engineering materials can exhibit a wide range of mechanical characteristics ranging from of a rigid solid to a viscous liquid depending on environmental and loading conditions. Due to the combination of these characteristics, polymers are usually referred to as time and temperature-dependent materials. This phenomenon is also known as creep.[13] Creep can be defined as the time-dependent permanent deformation that occurs under applied constant loads. For most materials, molecules and their bonds can stretch and move at elevated temperatures, thus materials will behave more ductile and the time-dependent material properties become more significant. Unlike many materials, polymers undergo creep even at room temperature and creep performance may become the primary design concern. Creep deformation depends on the stress, time, and temperature parameters and the creep curve is generally divided into three stages, primary (transient), secondary (steady-state), and tertiary (accelerating). In the primary stage, the strain rate, $d\varepsilon/dt$, is initially high and then decreases with time. After that, the material enters the secondary creep regime, in which the creep rate is constant and the slowest. Finally, the creep rate continually increases until the failure occurs (tertiary stage). Creep behaviour of various materials is commonly investigated in material engineering laboratory studies.

Polymers, metals, ceramics, and even some rocks show time-dependent material properties. Different creep test set-up and standards have been used depending on the exposed loading direction during field applications. Tensile, compressive, and flexural creep tests are widely performed in polymer engineering. In this study, a tensile creep test methodology for plastics[12] was followed throughout the laboratory studies since tensile failure is a commonly encountered failure mechanism in field application of TSLs (Fig. 2) that have a polymer content. Tensile creep test results can be used to estimate service life in field application, to compare different TSLs, and to characterize TSLs for long-term performance under constant loading conditions. TSL might behave similar to tensile creep conditions when applied on rock masses where discontinuities are present.

In blocky rock mass excavations, wedge blocks are formed by the intersection of three or more discontinuities. Unfavorable wedges with falling potential may be formed. Under the effect of gravity and other static and dynamic forces, back and wall wedges may either fall or slide out of their sockets. The geometry, strength characteristics, orientation, length of the planes, and stresses within the rock mass are the main factors that control the stability of formed wedges.[14,15] Rock bolts are widely used to prevent falling or sliding of wedge blocks. Since sprayed surface supports distribute the weight of the wedge in larger lining area, they can support small scale wedge blocks. TSLs can hold the blocks in their sockets as presented in Fig. 2.

For this kind of failure, the main concern of the TSL is the holding time. Since they behave as a time-dependent material, the holding behaviour is directly related to their creep properties. Due to blasting, rockburst, or earthquakes, wedges may form after the application of TSL. Therefore, the effect of curing time on creep properties is also another significant research subject. Creep properties of TSL have to be characterized by laboratory testing in accordance with related test standards.

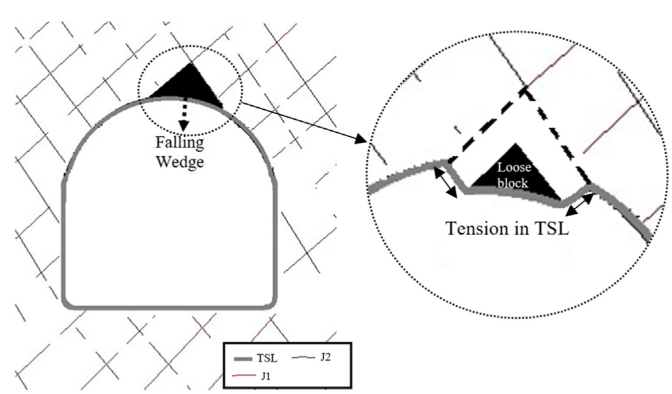

Fig. 2. Formed Wedge and Holding Function of TSL.