

Tensile-Creep Test Specimen Preparation Practices of Surface Support Liners

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Abstract. Ground support has always been considered as a challenging issue in all underground operations. Many forms of support systems and supporting techniques are available in the mining/tunnelling industry. In the last two decades, a new polymer based material, Thin Spray-on Liner (TSL), has attained a place in the market as an alternative to the current areal ground support systems. Although TSL provides numerous merits and has different application purposes, the knowledge on mechanical properties and performance of this material is still limited. In laboratory studies, since tensile rupture is the most commonly observed failure mechanism in field applications, researchers have generally studied the tensile testing of TSLs with modification of American Society for Testing and Materials (ASTM) D-638 standards. For tensile creep testing, specimen preparation process also follows the ASTM standards. Two different specimen dimension types (Type I, Type IV) are widely preferred in TSL tensile testing that conform to the related standards. Moreover, molding and die cutting are commonly used specimen preparation techniques. In literature, there is a great variability of test results due to the difference in specimen preparation techniques and practices. In this study, a ductile TSL product was tested in order to investigate the effect of both specimen preparation techniques and specimen dimensions under 7-day curing time. As a result, ultimate tensile strength, tensile yield strength, tensile modulus, and elongation at break values were obtained for 4 different test series. It is concluded that Type IV specimens have higher strength values compared to Type I specimens and moulded specimens have lower results than that of prepared by using die cutter. Moreover, specimens prepared by molding techniques have scattered test results. Type IV specimens prepared by die cutter technique are suggested for preparation of tensile test and Type I specimens prepared by die cutter technique should be preferred for tensile creep tests.

1. Introduction

Underground operations have high occupational-work accident rates compared to other engineering related projects. Therefore, ground support has a primary importance for maintaining a safe working environment and sustaining the advance rate in underground mines, roadways, tunnels and other excavations. Different supporting systems are developed to meet the demands of the industry. Although wire mesh and shotcrete combination is one of the most commonly used support systems since the 1970s, the mechanical and operational properties can only be improved to a certain extend. Researchers started to develop new technology material supported by private companies to produce new material with better mechanical, operational, and logistic properties than shotcrete. In accordance with this purpose, Thin Spray-On Liner (TSL) is engineered with the simultaneous studies performed in Canada and South Africa at the beginning of the 1990s. TSLs are generally cement, latex, polymer-



based, either reactive or non-reactive, fast curing multi component thin coating surface support and sealing materials that are sprayed to the rock surface at a layer of few millimetre thickness. They usually consist of liquid-liquid, powder-liquid, or water-powder components, mixed just before or during the field applications.

TSL provides a level of reinforcement to the rock mass, retaining and holding functions. These functions might have achieved through high tensile strengths of the liner itself, and a strong adhesive bond between the rock and the liner [1]. Moreover, a high degree of elongation capability of the TSLs allows to distribute the demand loads over a greater lining area, unlike point-anchor bolts or conventional shotcrete.

In underground openings, the cracks may form due to highly stressed ground, stress relieved ground, blasting, seismicity, etc. When a crack contacts with adjacent or pre-existing weakness planes, wedges or blocks would be formed. Crack dilations and outward movements along cracks play an important role in tensioning TSL. Researchers and manufacturers conducted various types of laboratory and in-situ studies to understand the properties and support mechanisms of TSLs in detail. Based on previous studies in this field, tensile and adhesion tests have major importance in laboratory studies to understand support mechanisms and to make a quantitative classification among available products.

In previous tensile test studies, researchers referred to ASTM D638 since there is no accepted standard for TSLs [2]. This standard was originally published for determination of the tensile properties of unreinforced and reinforced plastics with defined test conditions. As TSLs are generally polymer based products, this testing methodology can easily be adopted. According to this standard, Type I and Type IV test specimen geometries are suitable for TSL testing and specimen preparation by machining operations, moulding, or die cutting technique are suggested. Generally, Type I specimens are preferred among TSL researchers, Type IV specimens can also be selected especially for testing of higher elongation capacity specimens. Moreover, TSL researchers agreed on the concept that the creep properties of TSLs are important design parameters and creep might be a serious problem due to the polymer ingredients [3,4]. Recently, new studies were conducted on the time-dependent tensile creep behaviour of TSLs [5]. Test specimens for tensile creep measurements should be either Type I or Type IV as specified in ASTM D638 test methodology.

The purpose of this study was to quantify the effects of specimen geometry and specimen preparation technique on tensile mechanical properties of TSL. Laboratory tests were conducted for a ductile TSL product under 7-day curing time and ambient conditions. For this purpose, die cutters and molds for Type I and Type IV specimen geometries were prepared. As a result of this study; ultimate tensile strength, tensile yield strength, tensile modulus, and elongation at break values were obtained for 4 different test series.

2. Previous studies

Most of the researchers have selected tensile test methodology as a primary TSL characterization test [6]. In addition to tensile strength of TSLs, other material properties related with tensile failure such as the tensile modulus, elongation capacity, or elongation at break can also be found in the scope of this test methodology.

TSL tensile test was firstly conducted by Tannant et al. [7]. They used the Standard Test Method for Tensile Properties of Plastics (ASTM D638, 1998) for the test set up and testing progress. This ASTM standard was taken as basis in almost all following studies. In 2001, Archibald carried out tensile tests for 4 different TSL products by measuring the displacement change during tests [8]. As a result of this study; tensile strength, elongation capacity, and modulus of deformation for 4 different liners having different thickness range were presented. It was suggested that at least 10 specimens should be tested

for each material and tests should be conducted at the end of the 7th curing day [8]. The most detailed tensile test study was performed by Yilmaz, 2010. In this study, the effect of curing time on tensile strength parameter for 20 different available TSL products was investigated and categorized into 4 different groups namely, weak, medium, strong, and very strong based on their tensile strengths [9]. Figure 1. shows the test set-ups of some previous studies.

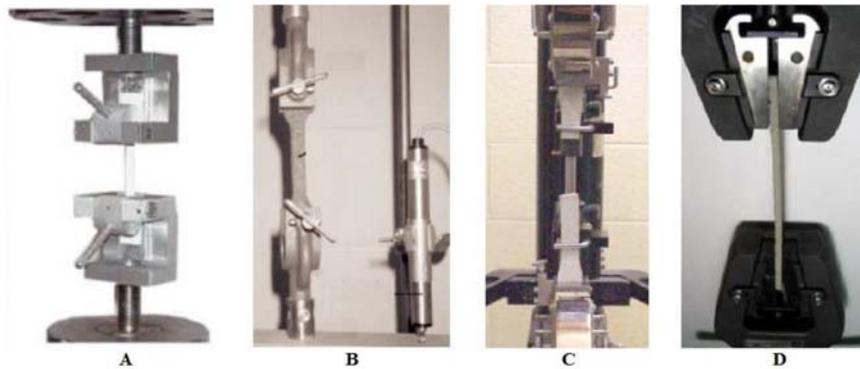


Figure 1. Previous Test Setups and Specimens

(A: Archibald, [8], B: Tannant et. al, [7], C: Spearing and Gelson [10], D: Ozturk, [11])

3. Laboratory studies

The laboratory tests were conducted with a reactive TSL. Due to confidentiality, the TSL product and company name are not disclosed in this study. The liner has two components; the liquid component is a stabilised resin latex and the powder-component is a hydraulically curing powder based on special cement, packaged in 20 kg bags. Components were mixed with 2:1 liquid-powder ratio. The tack free time of the product is measured as 30 minutes. Composition of the liner is not shared by the manufacturer. Liquid and powder components were mixed with an electric mixer at a 120 rpm for 5 minutes (Figure 2.A), then it was poured into a Plexiglass plate and molds with a 5 mm thick frame by using a spatula (Figure 2.B). After the molding process, the plate was vibrated to remove air bubbles.

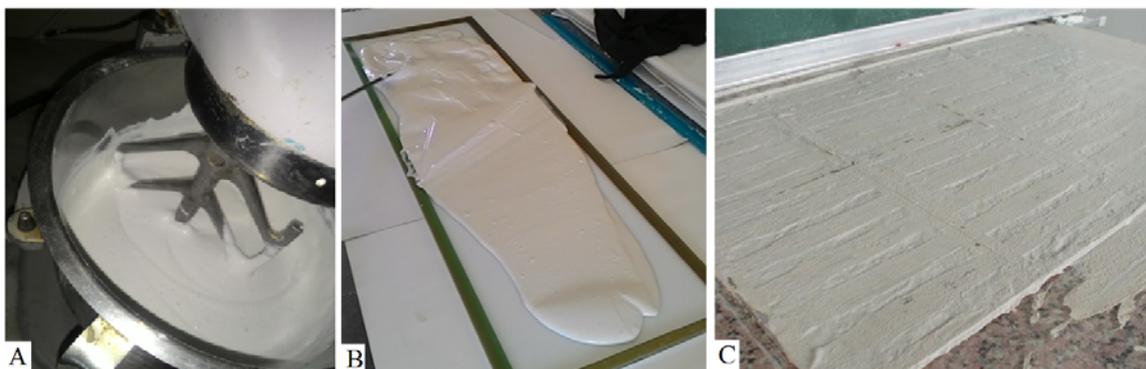


Figure 2. Mixing and Pouring of the Liner

The mixture was allowed to cure for 7 days at 25°C in the test chamber after being poured into the plate and molds. At the end of the curing period, 12 specimens were prepared by die cutter (Figure 3) and molding methods, for each geometry type.



Figure 3. Specimen Preparation by Die cutter

Dimensions of the newly prepared die cutters are presented in Figure 4. Specimen thickness is directly related with application thickness of the TSL. Since general application thickness is about 3-5 mm in field, researchers generally prepared 3-5 mm thick samples. In this study, 4 mm sample thickness is also selected.

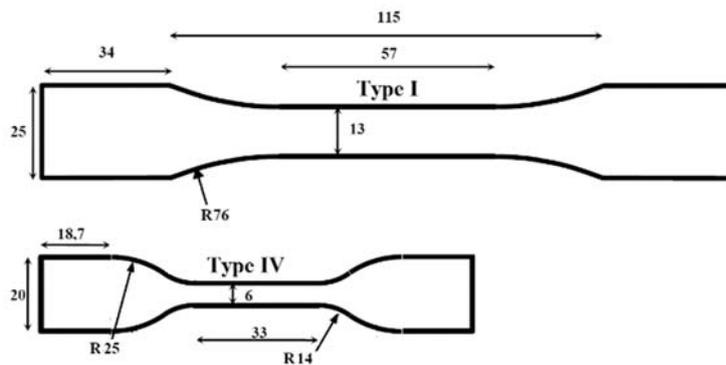


Figure 4. Type I and Type IV Specimen Geometries (in mm)

4. Test results

The tensile tests were conducted with a displacement rate of 6 mm/min, which is around the lower limit of the ASTM standard. During the tests; load, axial displacement, and time were recorded continuously. The test apparatus is shown in Figure 5. Due to the liquid component, dimensions of the molded specimens shrinks and bending might occur. Shrinkage is an inevitable problem for such samples. At the end of the 7-day curing time, 6% shrinkage was measured for specimens prepared by molding technique. Since die cutter was used at the end of the curing period, the shrinkage is not a problem for this sample preparation technique. It should be noted that each sample dimension was re-measured at the end of the curing time.

In this study, 4 different specimen sets were prepared. Test results are presented by abbreviations of each set. Set abbreviations are as follows;

- Type I geometry, specimens prepared by molding technique: **T-I-M**
- Type I geometry, specimens prepared by die cutting technique: **T-I-D**
- Type IV geometry, specimens prepared by molding technique: **T-IV-M**
- Type IV geometry, specimens prepared by die cutting technique: **T-IV-D**

As a result of the tensile test study, 4 important parameters were investigated;

- 1) Ultimate Tensile Strength (σ_t) in MPa
- 2) Yield Strength (σ_y) in MPa
- 3) Tensile modulus (E_t) in MPa
- 4) Elongation at break in %

Yield strength is defined as the minimum stress under which a material deforms permanently, whereas tensile strength describes the maximum stress that a material can handle before rupture. According to Guner and Ozturk (2017), in case applied constant load exceeds the elastic limit of the liner (yield strength), failure takes place within an hour. In field applications, loading conditions are irreversible which means that there is no possible way of unloading of TSL. Therefore, the yield strength of the TSL is as significant as ultimate tensile strength [5].

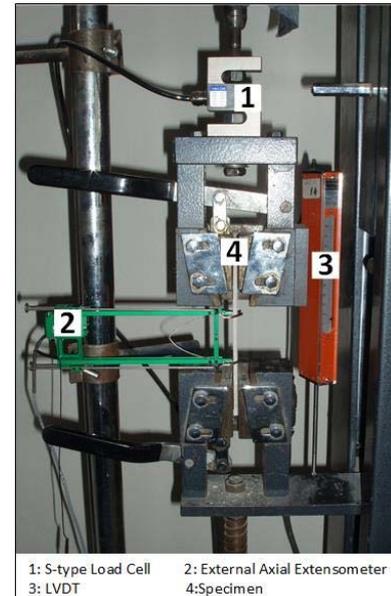


Figure 5. Tensile Test Set-

During the calculations, 48 stress-strain curves were plotted. Figure 6 shows the representative stress–strain curves of a sample representing four different test sets. Specimen photos before and after tests are presented in Figure 7.

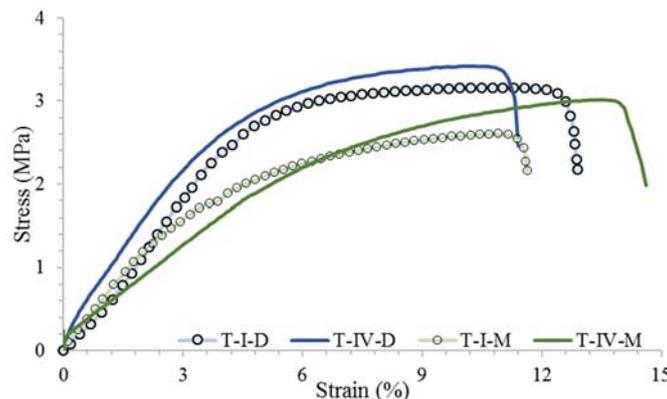


Figure 6. Representative Tensile Stress– Strain curves for Different Test Sets

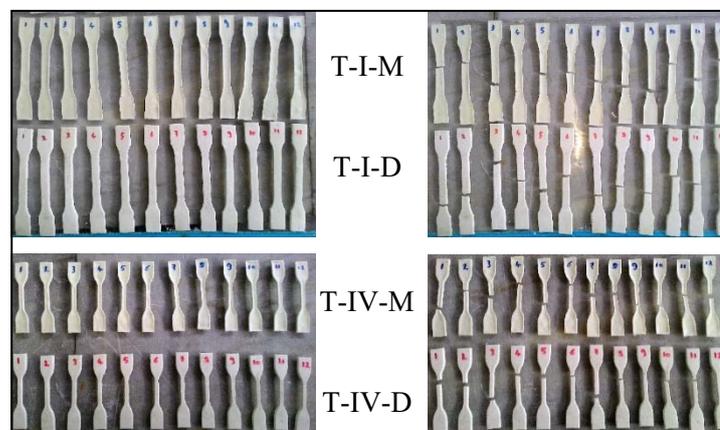


Figure 7. Specimen Photos Before and After Test Sets

As it can be seen from the stress-strain curves (Figure 6), T-IV-D specimens have the highest ultimate tensile and yield strength values, that is around 0.7 MPa greater than T-I-M specimens. Moreover, T-IV-M specimens have higher strain capability than other sets, this might lead to a decrease on the tensile modulus values. All obtained test results with the standard deviations are presented in Figure 8. All four test sets conform the minimum required ultimate tensile strength, tensile modulus and elongation at break values ($\sigma_t > 2$ MPa, $E_t > 20$ MPa, elongation at break $> 10\%$) stated in the general and special requirements of TSL document of the Experts for Specialised Construction and Concrete Systems (EFNARC) [12].

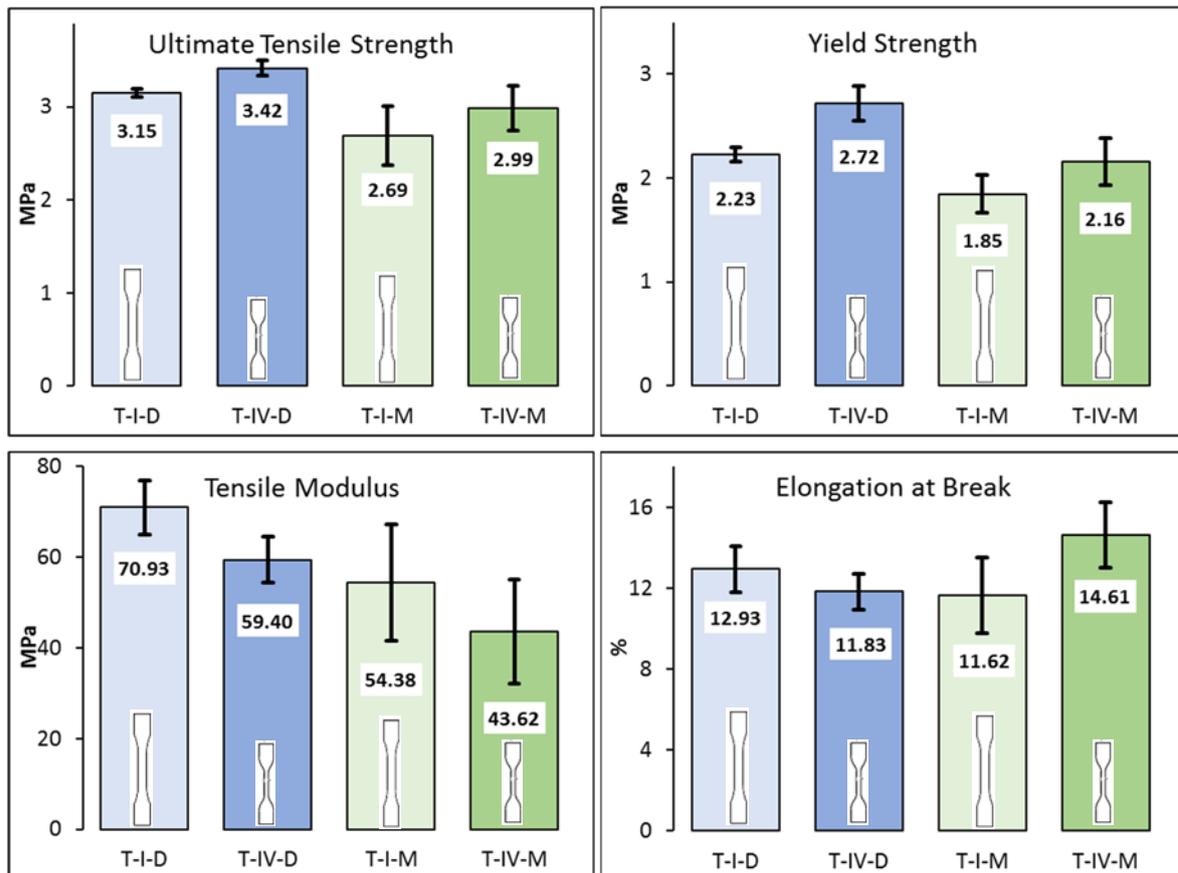


Figure 8. Ultimate Tensile Strength, Yield Strength, Tensile Modulus and Elongation at Break Results (error bars represent standard deviations)

Specimens prepared by die cutter have higher strength, tensile modulus values and small standard deviations between repetitive tests as seen in Figure 8. This result is attributed to the angular shape of the molds. Corners and the gauge section of the sample mold are not filled by the fresh TSL mixture naturally, therefore the mixture was carefully spread by a spatula. Large air bubbles were frequently observed. This might have had a negative impact on the test results. When preparing the sample by die cutter technique, the specimen can be cut from the desired region of the cured TSL plate.

Moreover, Type IV specimens have higher strength and tensile modulus values due to the small specimen dimensions. As the dimensions of the gauge section decreases, the possibility of lump or air bubble occurrence decreases. Table 1 presents the comparison of the tensile mechanical properties of the 4 test sets.

Table 1. Test Results Comparison

	% Change in			
	Ult. Tens Strength	Tensile Modulus	Elongation at break	Yield Strength
T-I-D vs T-I-M	+16.93	+30.43	+11.25	+20.77
T-IV-D vs T-IV-M	+14.50	+36.17	-19.02	+25.87
T-I-D vs T-IV-D	-7.88	+19.41	+9.31	-17.94
T-I-M vs T-IV-M	-9.79	+24.67	-20.44	-14.48

As a result of this study, specimens prepared by die cutter give more accurate results. In tensile testing, Type IV specimens prepared by die cutter was found as the most suitable specimen preparation technique. In tensile creep test study, since Type-IV specimens are not suggested in standards, Type I specimens prepared with die cutter is found to be a better choice.

5. Conclusions

In this study, a relatively ductile TSL product was tested under tensile loading. For this purpose, commonly used two different specimen dimension types (Type I, Type IV) were compared by their tensile test results according to the related standards. These specimens were prepared by molding and die cutting techniques as these are commonly used specimen preparation techniques. The effect of both specimen preparation techniques and specimen dimensions under 7-day curing time was investigated.

Main conclusions of this study are as follows:

- In sample preparation part, shrinkage of samples might occur due to different chemical compositions of TSLs. In field application, this problem may cause a decrease in the thickness of the liner.
- Die cutting technique is relatively easier to implement as a specimen preparation method due to its advantage in creating more homogenous, representative TSL specimens. In molding technique, corners and the gauge section of the Type IV samples do not get filled by the fresh TSL mixture naturally, large air bubbles were frequently observed.
- Specimens prepared by die cutter have higher ultimate tensile strength and yield strength values and also have small standard deviations between repetitive tests compared to molding technique.
- Specimen geometry also effects the tensile mechanical properties; Type-IV test specimens comparably smaller than Type I, have better strength properties and higher elongation capabilities.
- In tensile testing, Type IV specimens prepared by die cutter are observed as being more representative in laboratory scale studies.
- In tensile creep test studies, since Type-IV specimens are not suggested in standards, Type I specimens prepared with die cutter are recommended for laboratory scale tests.

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