Tensile strength testing of thin spray-on liner products (TSLs) and shotcrete

by H. Yilmaz*

Synopsis

Tensile strength testing has been one of the most common physical property testing methods of thin spray-on liner (TSL) products worldwide. However, the variety of products tested has been insufficient for comparison purposes. Specimen preparation procedures and test parameters such as curing time and loading rate are not reported well. Comprehensive tensile strength testing on 20 TSL products and one plain shotcrete brand was performed over 28 days of curing period. Detailed information on the test procedures with particular attention on the important aspects during sample preparation and test execution are provided. As expected, the tensile strength increases with increasing curing period. The test results make the categorization and comparison of liner products possible.

Keywords

Thin spray-on liner, TSL, tensile strength test, TSL tensile strength, shotcrete tensile strength, tensile strength category, curing period, repeatability index.

Introduction

Tensile strength testing has been one of the most common physical property testing methods of TSL products by a number of researchers and manufacturers worldwide. However, the number of publications on the subject has been limited.

The American Society for Testing and Materials (ASTM) has a tensile test standard designed to determine the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell (dog-bone) shaped test specimens. 'ASTM D638-Standard Test Method for Tensile Properties of Plastics' can be adapted to the testing of TSLs after some modifications. This test standard was originally designed for the plastic materials and not for measuring the tensile strength of TSLs.

Researchers such as Tannant *et al.* (1999), Archibald (2001), and Spearing and Gelson (2002) made reference to ASTM D638 (1998) and performed tensile tests on TSLs. The loading rate and specimen dimensions mentioned in the standard were used. The number of tests was adequate; on the other hand, only a few TSL products were available for testing. Tests were normally done at 7 days of curing, and Tannant *et al.* (1999) and Archibald (2001) recommended that in order to effectively assess material physical property behaviour, consistent and suitable interval times for testing must be established.

Modifications of ASTM D638

The suggested loading rates of 5 to 50 mm/minute in the ASTM D638 (1998) standard are intended for thin plastic sheets and cannot be applied to TSLs. Most TSLs have limited deformation range and failure occurs in less than 1 mm of deformation. The use of 5 mm/minute loading rate would imply that the testing would be completed in 12 seconds, which fall short of the minimum test duration recommendation of 30 seconds (Ozturk and Tannant, 2010). The testing should ideally be completed in 3 minutes. Therefore, the loading rate should be flexible in such a way that the failure is achieved within the recommended time limit, whether the rigid or yielding TSLs are tested.

Preparation of specimens by a process of stamping using specially prepared die cutting moulds (Tannant *et al.*, 1999; Archibald, 2001) is suitable for plastic materials and not for cementitious TSLs. The alternative process of machining is time consuming, very difficult, and can damage the weak cementitious specimens of brittle nature. The machining operation is also a significant cost addition to the specimen preparation. As a substitute, a much simpler method of preparing the samples by making use of moulds made of perspex can be used. The TSL mixture is poured into the

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 Paper received Jul. 2010; revised paper received Sep. 2010.

mould and the specimens are easily taken out after the setting of TSL without any damage to the specimens. In addition, moulding process ensures excellent thickness control on the prepared specimens.

The following sections outline the details of the tensile strength testing of TSLs. The testing is done to provide assistance in the comparison of various TSL products. Important aspects during sample preparation and test execution are pointed out. The test results are also presented and discussed.

Tensile strength test considerations

The general purpose of the test is to determine the tensile strength of a TSL material or shotcrete. Tannant *et al.* (1999) stated that the rate at which a membrane cures in the mining environment may dictate how soon people can resume work in a given heading or stope. It is further stated that tests to measure the gain in tensile strength versus age, under temperature and humidity conditions representative of the underground environment, may be required. Therefore, the curing period is selected to be the main parameter for the tensile strength testing.

The specimen preparation and testing requires caution due to the small thickness of the specimen. Rough handling and misalignment of the testing machine can easily damage the specimen before the actual strength is obtained. Therefore, this section will discuss a few other sensitive issues that need to be taken into account in the procedures of the tensile strength testing.

In situ loading mechanism

The cracks may form due to highly stressed ground, stress relieved ground, blasting, seismicity, etc. Crack dilations and outward movements along cracks play an important role in tensioning TSL, as seen in Figure 1. Crack dilations may be experienced at many locations in a mine such as pillars, bullnose (sharp corner) positions, hangingwall or roof where excessive sagging occurs.

When a crack joins with an adjacent one or pre-existing weakness planes, wedges or blocks would be formed. Depending on the orientation of cracks and the shear strength characteristics of the weakness planes, the rock blocks may have a potential to become loose and drop out, especially from the roof and sidewalls of the excavation. Then, TSL would experience tension following the bond failure and plastic yield.

Specimen dimensions

TSL

The shape and dimensions of an ASTM D638 (1998) Type I test specimen (Figure 2) are suitable for testing rigid TSLs. The shape and dimensions of a Type IV specimen mentioned in the same standard are thought to be more suitable for testing TSLs with high elongation capacities. A Type IV specimen, as seen in Figure 2, is smaller and most of the deformation would take place at the narrow section (only 33 mm long). Therefore the failure would be possible before the extension limit of the testing machine is reached. However, the use of a Type IV specimen was not needed during the testing programme since none of the TSL materials used exhibited high yield capacity.

The thickness of the TSL specimens is determined by taking the field applications as a reference. This thickness is generally accepted to be around 5 mm.

Shotcrete

Shotcrete dog-bone dimensions are, similarly, chosen to reflect the *in situ* applied thickness and an average thickness of 50 mm is selected (Figure 3). The width of the narrow section of the sample is also kept at 50 mm and the remaining dimensions were increased by a factor of 2 as compared to the Type I specimen for TSLs.

The increase in the size of the shotcrete specimen is necessary firstly due to the reason that shotcrete contains aggregates that may be larger than the 5 mm thickness of the Type I specimen. Secondly, the fibre length for the fibre reinforced shotcrete can be as much as 50 mm, which

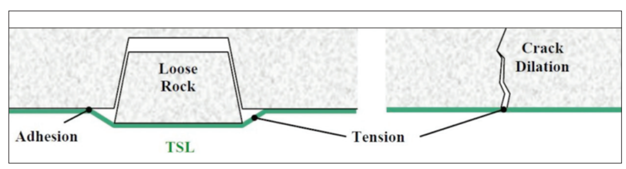

Figure 1—*In situ* loading mechanism of TSL relevant to tensile strength testing

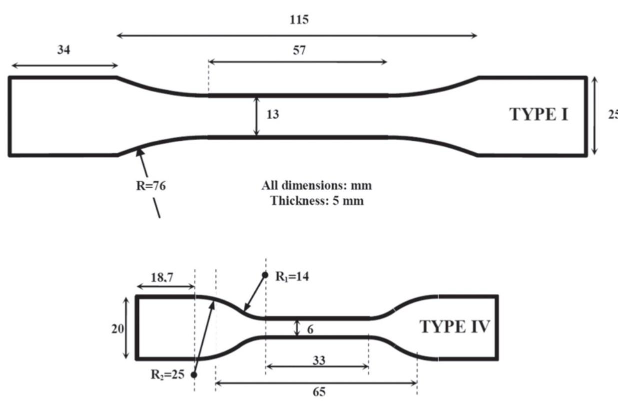

Figure 2—Type I and Type IV specimen shapes and dimensions of ASTM D638

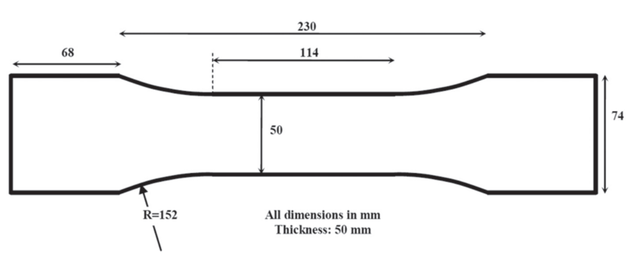

Figure 3—The shape and dimensions of dog-bone specimen for shotcrete testing

exceeds the width of the narrow section on the dog-bone specimen. During the specimen preparation process these fibres would be forced to fit into the narrow section, therefore making, their orientation along the long axis of the dog-bone specimen. In practice, of course, fibres are randomly orientated and the prepared specimen should simulate the actual shotcrete texture as much as possible.

Thickness control

The uniformity on the thickness of the dog-bone specimen is important for uniform stress distribution. Uneven shape at the grip positions may cause premature failure due to high stress concentrations during clamping of the specimen. A flat perspex glass is laser cut with the desired contours of the finished specimens. Specimen thickness is governed by the depth of the perspex. Pouring of the prepared TSL mixture into the perspex mould and then levelling, done with the help of a spatula against the surface of perspex mould, greatly ensures uniform thickness on the specimen.

Eccentric loading

Eccentric loading is the consequence of the difference between the direction of pull and the axis of the specimen, as illustrated in Figure 4. Eccentricity may also take place along the direction that is perpendicular to the plane of the specimen. The rigid attachment of the devices, used for gripping the specimen ends, to the loading machine is the primary reason for eccentric loading. Therefore the ends of the specimen should have the freedom to move and self-align with the direction of the pull. Universal joints or steel rope attachments could be used to impart freedom to the specimen ends in an attempt to prevent eccentric loading.

Loading rate

The loading in tensile strength testing is done under load control mode. The initial rate of loading is 2.5 N/s up to 100 N (40 seconds) and then tensioning at a constant loading rate of 5 N/s up to failure. The initial stage of loading may be skipped for stronger TSLs for which the failure would take place between 2 and 3 minutes. The loading rate for shotcrete should be doubled due to the increased specimen dimensions in the narrow section that necessitate a higher load for failure.

Specimen failure

The tensile loading of the dog-bone specimen induces the highest stresses in the narrow section in the middle as shown in Figure 5. The failure should take place anywhere in this part of the specimen for testing to be valid. The failure of TSL material occurs either due to tension or tear mechanism.

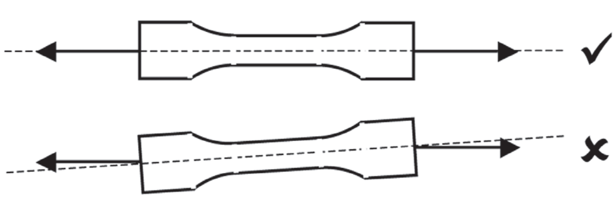

Figure 4—The importance of alignment between the specimen axis and pull direction

Excessive tightening of grips could cause weakening of the grip positions and then eventual premature failure during testing. Weak tightening, on the other hand, would result in the slipping of the grips. The balance on the correct amount of gripping would be acquired after some experience.

Description of tensile strength test sample preparation, apparatus, and testing procedures

TSLs from 17 local and international manufacturers were collected. Table I summarizes the manufacturers and 35 of their products that were made available for the testing programme. TSLs vary in composition and most of the products are cement-polymer based with the exception of three products which are polyurethane based. Manufacturers usually offer a number of products and some of their products are under continuous development. A few of the TSLs listed have no established brand names as they were at the research and development stage at the time. Only 21 of the 35 products are included in the analysis. The results of the remaining TSLs, which were mainly used during the initial trials and the development of the test set-up and procedures, were influenced by the ongoing modifications. Therefore these TSLs are not included in the analysis. The product names are not revealed in the results and discussion section in order to preserve confidentiality.

Figure 5—Failure location for valid tensile strength testing

Table I

TSL products tested

Manufacturer	TSL product name
BASF	Mayco super lining, BASF white TSL
Carbontech	A-Seal, V-Seal
Cementation LP	Superseal
CHC	CHC TSL
Chryso	Chryso TSL
Concor	D21H, Standard (version 1 and 2)
Geo-Mining	Geo-Mining TSL
Guyric pipe company	GPC polyurethane TSL
Hydroflex Pty Ltd	Diamondguard
MBT (Degussa)	Masterseal 845A
Minova SA	Capcem KT grey and white, Tekflex, Raplok
Nico Du Rand consultants (NDRC)	Super lining (version 1, 2 and 3)
NS consultancy	Ultraskin
Precrete	Rockliner A, F2, T1, 916, D50
Pumachem CC	Conseal
SA Mining Eng. Supplies	Tunnelguard (2005, 2007, 2009 versions), TGNC, TGNT, TGC
TAL	TAL TSL

(a) (b) (c)

Figure 6—Steps in the preparation of dog-bone specimens. (a) mould set-up (b) pouring of TSL (c) levelling of TSL

Shotcrete was also included in the testing programme. Only one of the commercially available and most commonly used plain shotcrete brands was selected. The shotcrete curing had to be done properly in order to ensure that strength gain was not sacrificed. Water spray was applied daily on the shotcrete in an attempt to provide favourable conditions during the curing process.

Sample preparation

The preparation of specimens is the most important stage of any testing method. The procedures followed during sample preparation are described in detail as follows:

- ➤ Preparation of the perspex mould (Figure 6a)
  - Type I specimen dimensions, as stated in Figure 2, are laser cut on a 5 mm transparent Perspex sheet. Five specimens are included on each Perspex sheet.
  - Apply a suitable releasing agent (machine oil, grease or any commercially available mould release agent) on the Perspex mould to avoid the sticking of TSL on the Perspex. The application of releasing agent should not be excessive to prevent interference with the composition of TSL.
  - Arrange a flat surface or a table for setting the perspex mould. In case of irregularities on the surface of the table, 8 or 10 mm thick plain perspex sheets may be used as the base.
  - Place transparency or plastic sheets on the flat surface. The TSL specimens are easily removed from plastic sheets due to their flexibility.
  - Set and secure the perspex mould on the flat surface so that the mould does not move during the pouring of TSL mixture.
- ➤ Mix the TSL according to manufacturer's recommended mix ratio with the help of a kitchen food mixer (Kenwood Chef). The shear rate during mixing is one of the most important variables affecting the rheological properties of fresh Portland cement pastes (Helmuth, 1980). The rheology of TSLs would also be influenced if they are mixed for different periods of time and speed. To eliminate the possible differences, all the TSL products were mixed at speed setting 1 on the mixer for approximately 2 minutes. However, the influence of mixing speed and duration on the rheological properties of TSLs requires further research and therefore kept outside the scope of this paper.
- ➤ Pouring of the TSL (Figure 6b)
  - Pour the TSL mixture into the cavities on the perspex mould carefully.
  - Viscous TSLs are difficult to pour therefore they should be taken from the TSL container and applied on the mould by a spatula.
  - Clear the excessive spills away using the spatula.
  - Place another plastic sheet on top of the perspex mould. Swipe the spatula on the plastic sheet against the mould in an attempt to level and to ensure uniform thickness of the TSL specimens (Figure 6c).
  - Any excess amount of TSL and air bubbles is driven out at the levelling stage. However, seldom incorporation of air bubbles at the failure location during testing is taken into account in the calculation of tensile strength by subtracting the bubble area from the failure area
- ➤ Removal of the specimens from the perspex mould
  - Wait until the TSL mixture sets.
  - Remove the plastic sheet on the top and bottom of the perspex mould.
  - Take the dog-bone specimens out of the perspex mould. It is very important that the perspex mould is made up of detachable pieces to minimize the damage to the specimens. (Figure 6a).
  - Clean the unwanted extensions on the contour the specimen. These extensions are thin and easily broken with fingers without damaging the specimen. Scraping with a spatula leaves a good finish on the final contour of the specimen.

All the specimens are prepared at a time to conform to 5 specimens for each curing time.

Test set-up and execution

Due to the unavailability of a tensile load frame, the set-up illustrated in Figure 7 is designed for the use in compressive testing machines. The set-up for shotcrete testing is proportionately bigger.

The specimens cure until the predetermined curing period is completed under normal laboratory conditions. Five samples are randomly selected out of the complete set of specimens. The specimen is placed in the bottom grip, as shown in Figure 7, and tightened while one visually observes

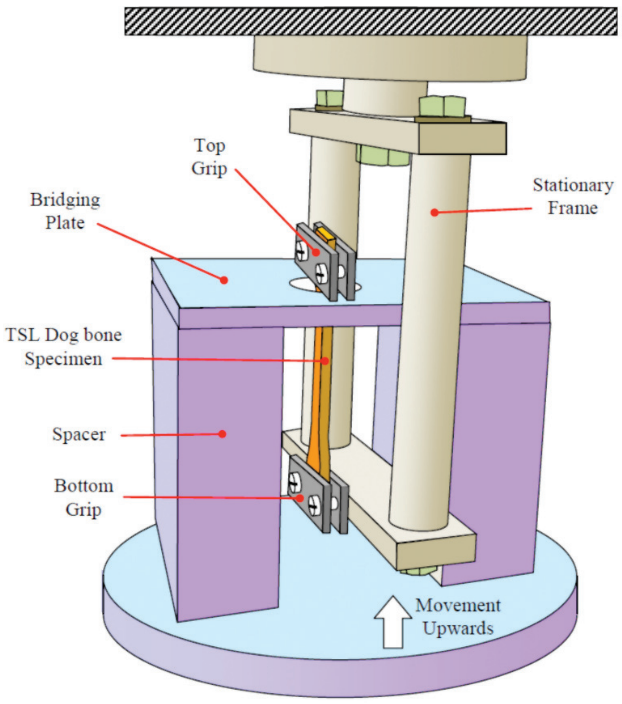

Figure 7—Configuration of the tensile strength test assembly to be used in compressive machines

the alignment of the long axis of the specimen with the direction of the pull. Then, the top grip is attached and tightened carefully. Since the bottom grip is fixed, tightening of the top grip should be done in a manner so as not to impose small deflections on the specimen. Otherwise, weak TSL specimens would be damaged due to compressive or buckling forces.

Calculations

The calculation of stress takes the original cross-sectional area of the narrow section into account. The tensile strength (σ_t) can be calculated using Equation [1].

$$\sigma_t = \frac{F}{A} \quad (\mathrm{Pa}) \qquad [1]$$

where F = load at failure in N
A = original cross-sectional area of the specimen (in m^2) at the narrow section.

The area can be calculated before the test or after the test (for rigid TSLs) by measuring the width and the thickness of the specimen at the expected failure zone.

Results and analysis

Typical load-displacement behaviours of plain and polypropylene fibre reinforced TSLs can be seen in Figure 8. Plain TSLs do not exhibit the post failure behaviour due to the destructive nature of tensile strength testing. On the other hand, fibre reinforced TSLs yield and offer a significant advantage in terms of energy absorption capacity in spite of the lower ultimate strength level.

Summary graphs of tensile strength against the full curing period are provided in Appendix I for all of the TSL brands and shotcrete. The averages of tensile strengths at each curing time are indicated as red markers on the graphs. The best fit curves with their correlation coefficients (R^2) and the equations are also provided. The scales of the graphs are kept the same for easy comparison. Figure 9 shows the best fit curves depicting the tensile strength development over the curing period for shotcrete and 20 letter coded TSL products.

Tensile strength, in general, tends to increase with the increasing curing period. Product R (polyurethane type) displays an exceptional behaviour in that tensile strength marginally decreases. This is partly due to the lack of number of tests required at the curing periods (see the graph for TSL R in Appendix I). The strength improvement for the low strength TSL products and shotcrete is negligible.

The tensile strength, taking the strength development over 28 days into account, is categorized and illustrated in Figure 10. The tensile strength of shotcrete is one of the lowest (0.68 MPa at 26 days); therefore, shotcrete is positioned in the weak tensile strength category.

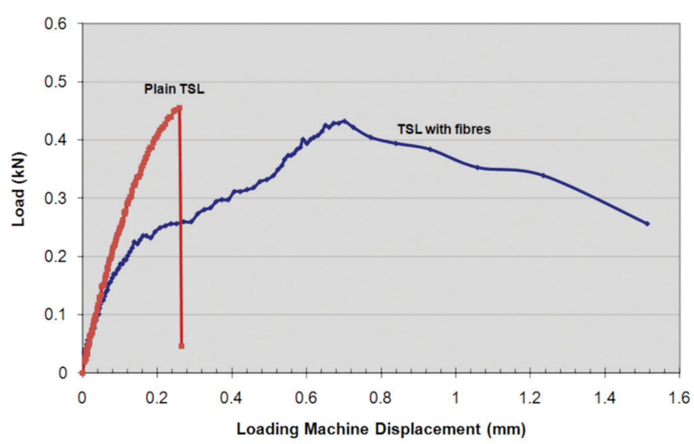

Figure 8—A typical example of the load-displacement behaviour during material tensile strength testing for plain and fibre reinforced TSLs

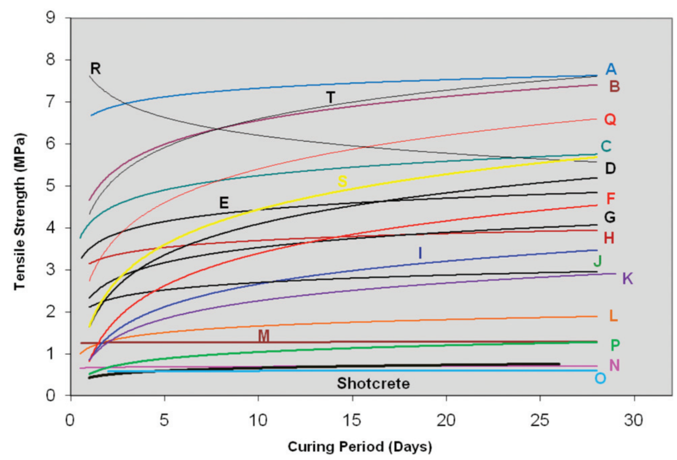

Figure 9—Tensile strength results for shotcrete and TSL products

The tensile strength equations, correlation coefficients (R^2) and strength ranking for all products are listed in Table II. 52.4% of the liner products displays strong and very strong tensile strength behaviour. The correlation coefficients tend to decrease with decreasing tensile strength. The products M, N and O in the weak tensile strength category, in fact, have zero correlation coefficients.

Polyurethane products A and R also present lower correlation coefficients. However, the general trend with R^2 values point to the strength improvement over the duration of 28 days.

Detailed statistics on the test results in terms of mean strengths, standard deviations and coefficient of variations (CV) corresponding with each testing day are summarized in Appendix II for all the tensile strength tests. Strong and very strong materials generally have lower CVs than the weak and medium strength TSLs. Standard deviations, on the other hand, demonstrate the opposite behaviour in that strong and very strong materials have higher standard deviations than the weak and medium strength TSLs. Standard deviations are also found to increase for the weaker TSLs as the curing period increases. There is no definite trend in the spread of CV over the testing period. Some materials (A, D, E, F, G, H, J, K, N, Q, S and T) show decreasing CV, while the remaining ones show increasing CV over 28 days.

Repeatability

The repeatability index (RI) for the tensile strength testing is calculated using Equation [2] (Yilmaz, 2007).

$$RI = \frac{\sum CV\%}{N} \qquad [2]$$

where

$\Sigma CV\%$: is the sum of coefficient of variation percentages at each curing time for all tests, and

N: is the total number of curing times.

The total number of curing times at which testing took place is 103. The RI value is calculated as 17.1 for tensile strength testing. This indicates that tensile strength testing is more repeatable compared to the shear bond strength testing done by Yilmaz (2007) where RI is 20.5.

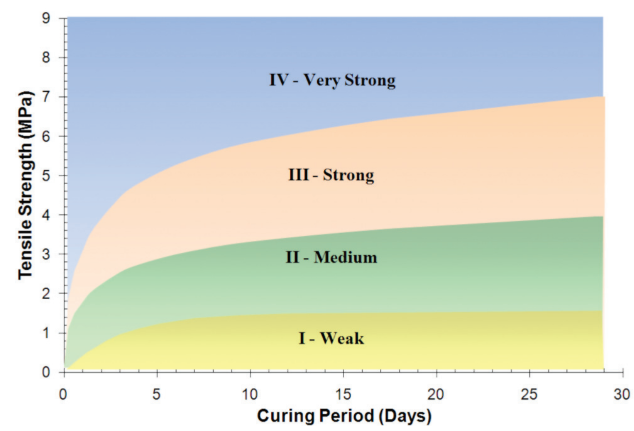

Figure 10—Tensile strength categories

Table II

Tensile strength equation, correlation coefficients and ranking according to 28-day strength

TSL	Tensile strength equation	R^2	Rank	Strength category
TSL A	$0.30\ln(x) + 6.63$	0.20	1	IV—Very strong
TSL T	$0.98\ln(x) + 4.32$	0.81	2	
TSL B	$0.85\ln(x) + 4.74$	0.40	3	
TSL R	$-0.52\ln(x) + 7.93$	0.15	4	III—Strong
TSL Q	$1.16\ln(x) + 2.73$	0.84	5	
TSL C	$0.50\ln(x) + 4.11$	0.32	6	
TSL S	$1.21\ln(x) + 1.62$	0.77	7	
TSL D	$1.06\ln(x) + 1.65$	0.93	8	
TSL F	$1.12\ln(x) + 0.82$	0.90	9	
TSL E	$0.44\ln(x) + 3.37$	0.38	10	
TSL G	$0.54\ln(x) + 2.34$	0.41	11	
TSL I	$0.78\ln(x) + 0.86$	0.91	12	II—Medium
TSL K	$0.62\ln(x) + 0.84$	0.67	13	
TSL H	$0.30\ln(x) + 3.07$	0.07	14	
TSL J	$0.28\ln(x) + 2.08$	0.15	15	
TSL L	$0.22\ln(x) + 1.15$	0.32	16	
TSL M	$0.00\ln(x) + 1.27$	0.00	17	I—Weak
TSL P	$0.23\ln(x) + 0.51$	0.70	18	
TSL N	$0.00\ln(x) + 0.68$	0.00	19	
Shotcrete	$0.10\ln(x) + 0.42$	0.35	20	
TSL O	$0.01\ln(x) + 0.57$	0.00	21	

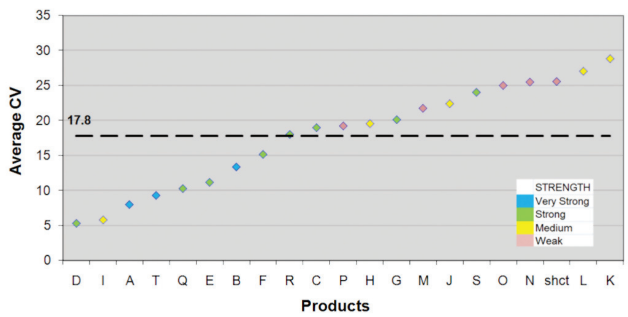

Figure 11—Distribution of average CV for tensile strength testing

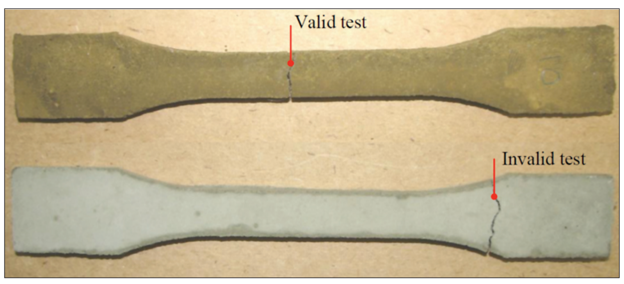

Figure 12—Valid and invalid tensile strength testing based on the position of failure

The distribution of the average CV for all of the tensile strength tests is shown in Figure 11. The grand average for the tensile strength testing method is 17.8. The data presented in Figure 11, indicate a lower average CV for TSLs in the high strength categories. One can, therefore, say that tensile strength testing is more stable and repeatable for stronger TSLs.

Failure mode

The failure of material occurs either due to tension or to tear mechanism. The location of failure should be in the narrow section of the specimen for valid testing. Figure 12 shows an example of both valid and invalid tensile strength testing. The strong TSL materials characteristically do not suffer from test invalidity due to the failure position of the specimen.

Invalid testing due to failure position may result from:

- ➤ The failure of weak TSL material due to the clamping forces
- ➤ Uneven shape and thickness of the specimen at the clamping position
- ➤ Air bubbles outside the narrow section.

The problem of test rejection can be alleviated by careful specimen preparation and clamping at the time of testing.

Conclusions and recommendations

A few modifications to the preparation of the specimens and test execution had to be done for the ASTM D638 (1998) standard to be applicable to TSLs and shotcrete.

The derivation of acceptable test results highly depends on the proper preparation of the specimens. The modifications adapted during the specimen preparation aimed to simplify and ease the specimen preparation process. Special attention was given to moulding procedures to ensure uniform specimen thickness and dimensions, and not to induce damage on the specimens.

Tensile strength testing is applicable ton shotcrete after increasing the size of the dog-bone specimen to suit the shotcrete's structural composition and applied field thickness. The tensile strength of shotcrete (plain) was measured to be 0.72 MPa at 8 days and found to compare well with the values found in the literature. Lacerda and Rispin (2002) stated that shotcrete tensile strength was less than 1 MPa at 12 hours, whereas Hahn and Holmgren (1979) quoted 0.5 to 1.0 MPa at 7 days.

The parameters necessary to establish standard testing methodology, such as the loading rate, dog-bone dimensions and thickness, number of tests, curing time, environmental conditions, etc. are emphasized. The testing should be performed at set values on these parameters to obtain comparable results. Curing time is chosen as the main parameter and testing is done over a period of 28 days. A sufficient amount of tensile strength testing was done on a variety of TSL products and shotcrete. The test results clearly show that the comparison of tensile strength for the liner products is possible. Additionally, the test results would make it possible to see whether TSLs would be a suitable alternative to shotcrete or not by simply comparing their tensile strengths. Strength improvement over the curing period was also noticeable on most products.

Acknowledgements

The manufacturers of products are thanked for their contribution in the test trials.

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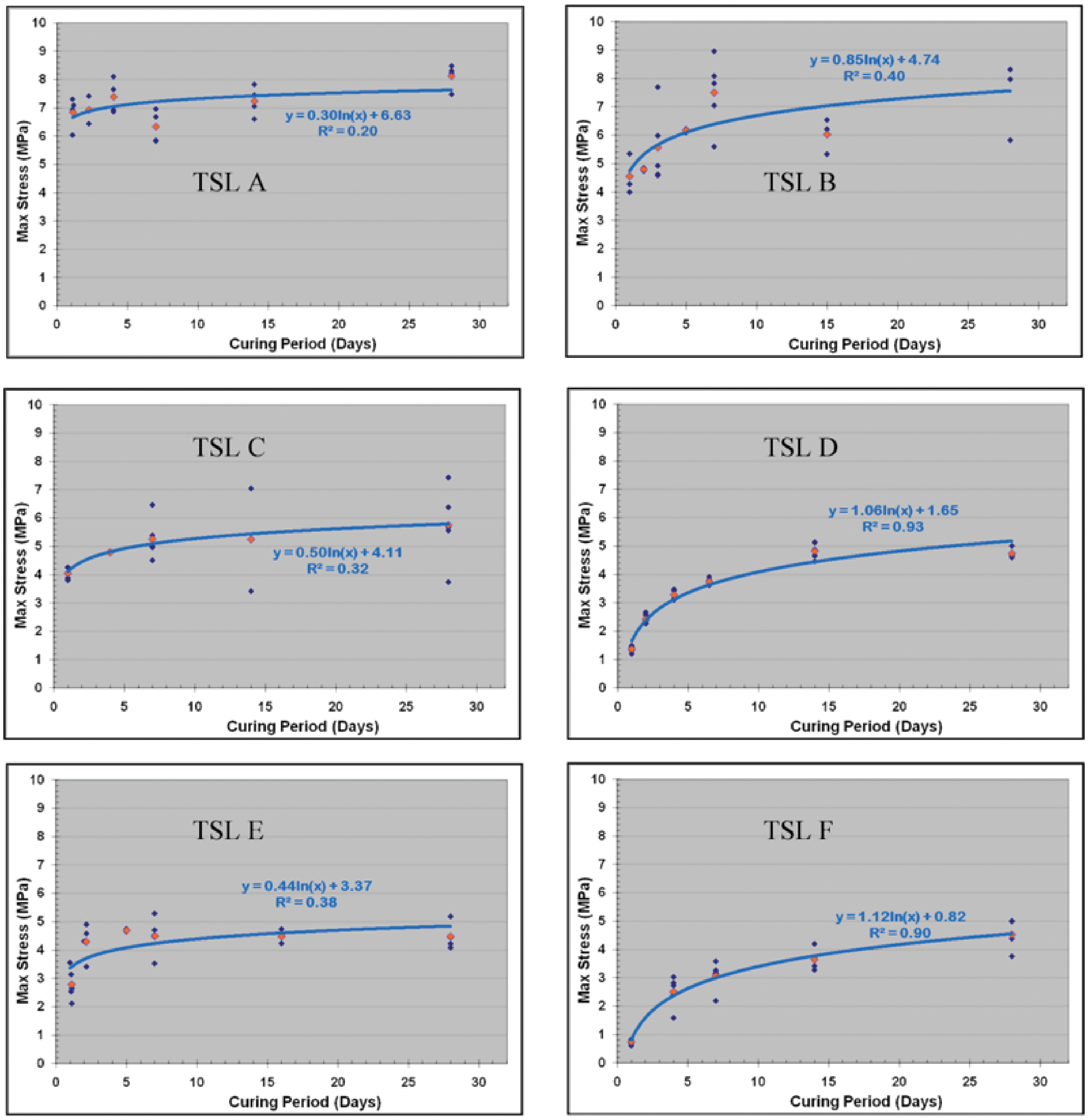
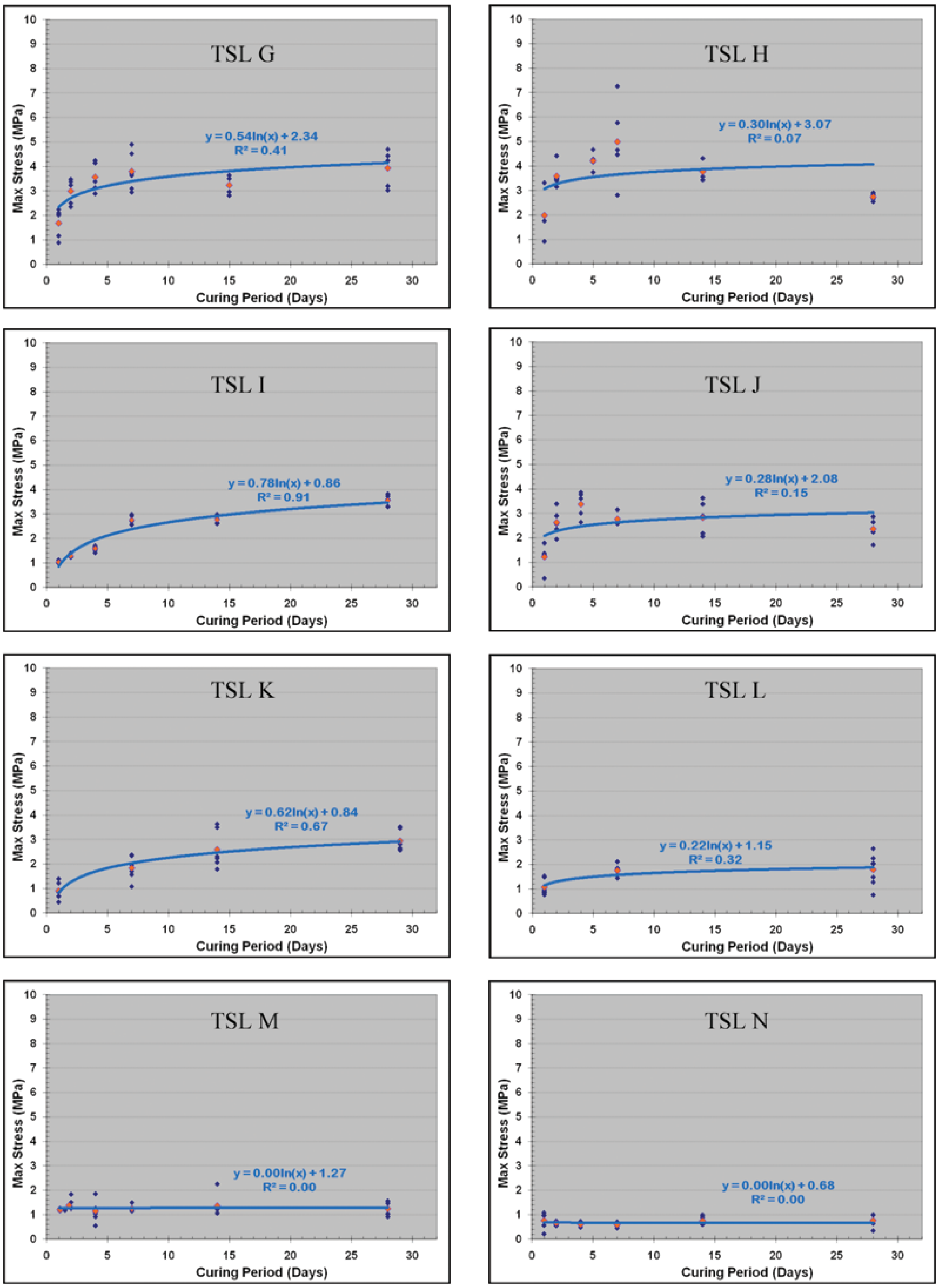
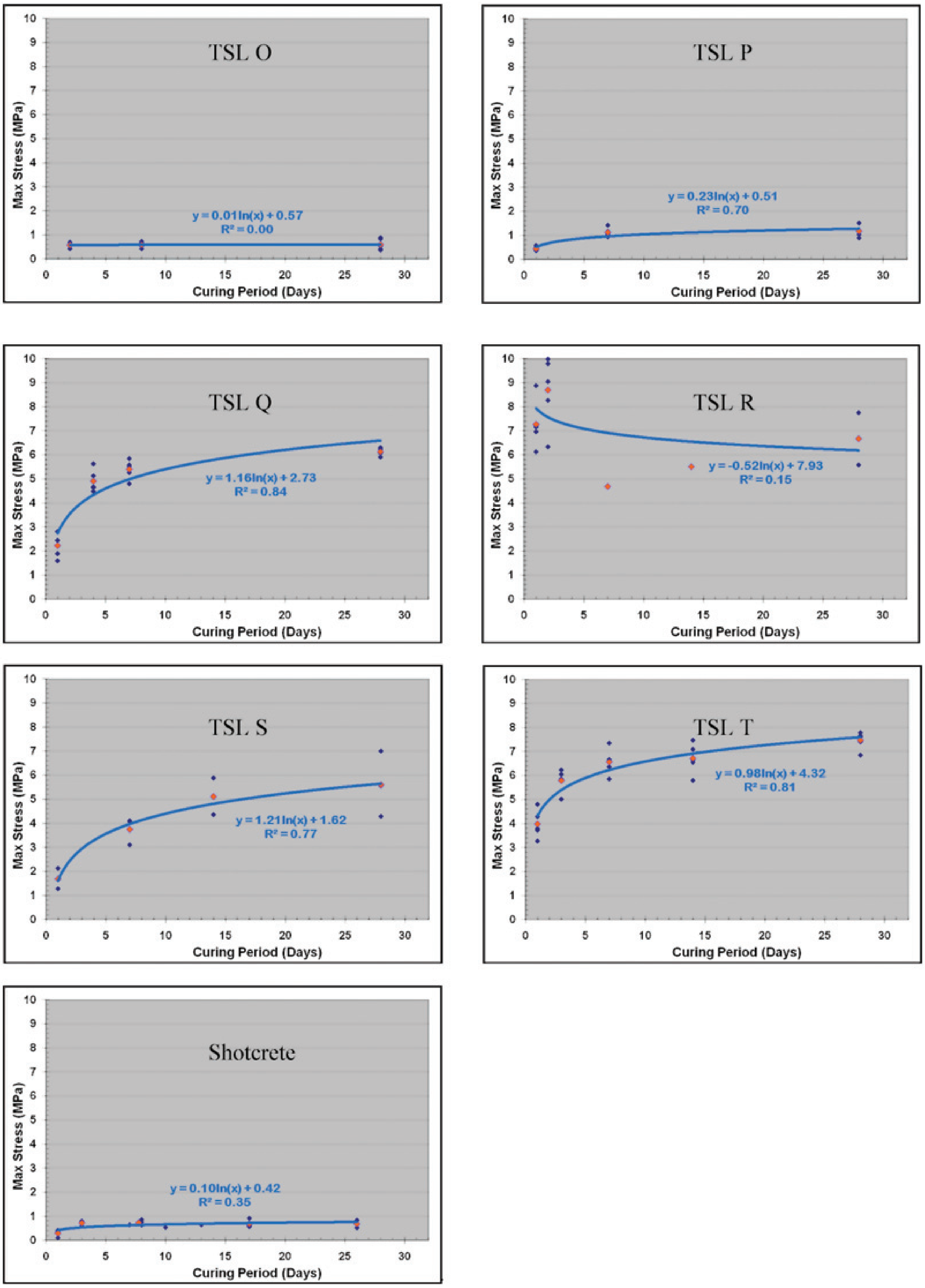
Appendix I

Tensile strength test results




TSL G
y = 0.54ln(x) + 2.34
R² = 0.41
TSL H
y = 0.30ln(x) + 3.07
R² = 0.07
TSL I
y = 0.78ln(x) + 0.86
R² = 0.91
TSL J
y = 0.28ln(x) + 2.08
R² = 0.15
TSL K
y = 0.62ln(x) + 0.84
R² = 0.67
TSL L
y = 0.22ln(x) + 1.15
R² = 0.32
TSL M
y = 0.00ln(x) + 1.27
R² = 0.00
TSL N
y = 0.00ln(x) + 0.68
R² = 0.00
Max Stress (MPa)
Curing Period (Days)


TSL O
y = 0.01ln(x) + 0.57
R² = 0.00
TSL P
y = 0.23ln(x) + 0.51
R² = 0.70
TSL Q
y = 1.16ln(x) + 2.73
R² = 0.84
TSL R
y = -0.52ln(x) + 7.93
R² = 0.15
TSL S
y = 1.21ln(x) + 1.62
R² = 0.77
TSL T
y = 0.98ln(x) + 4.32
R² = 0.81
Shotcrete
y = 0.10ln(x) + 0.42
R² = 0.35
Max Stress (MPa)
Curing Period (Days)
0
5
10
15
20
25
30
1
2
3
4
6
7
8
9

Appendix II

Tensile strength test statistics

Mean (MPa)	Days	St dev (MPa)	CV (%)	Mean (MPa)	Days	St dev (MPa)	CV (%)	Mean (MPa)	Days	St dev (MPa)	CV (%)
TSL A				TSL B				TSL C			
6.85	1	0.6	8.1	4.64	1	0.47	10.14	4.05	1	0.2	5.2
6.93	2	0.7	9.9	5.57	3	1.32	23.70	4.79	4		
7.39	4	0.6	8.1	6.18	5	0.07	1.09	5.26	7	0.7	12.6
6.34	7	0.6	9.1	7.51	7	1.26	16.83	5.25	14	1.8	34.6
7.24	14	0.5	7.2	6.03	15	0.62	10.33	5.76	28	1.4	23.5
8.13	28	0.4	5.4	7.38	28	1.35	18.25				
TSL D				TSL E				TSL F			
1.37	1	0.12	8.5	2.79	1	0.56	20.0	0.74	1	0.09	12.3
2.42	2	0.16	6.7	4.29	2	0.64	14.9	2.51	4	0.56	22.4
3.29	4	0.16	5.0	4.69	5	0.07	1.5	3.07	7	0.52	17.0
3.75	7	0.10	2.8	4.50	7	0.64	14.2	3.65	14	0.41	11.1
4.83	14	0.27	5.7	4.48	16	0.25	5.6	4.53	28	0.59	13.1
4.75	28	0.14	3.0	4.48	28	0.49	10.9				
TSL G				TSL H				TSL I			
1.69	1	0.6	36.2	1.99	1	0.86	43.2	1.03	1	0.05	4.8
3.00	2	0.5	17.4	3.59	2	0.48	13.4	1.28	2	0.07	5.3
3.57	4	0.6	17.0	4.22	5	0.38	9.1	1.58	4	0.10	6.4
3.80	7	0.7	18.6	5.00	7	1.65	33.0	2.75	7	0.17	6.3
3.24	15	0.4	12.4	3.78	14	0.47	12.6	2.76	14	0.17	6.0
3.93	28	0.8	19.3	2.74	28	0.17	6.0	3.55	28	0.21	6.0
TSL J				TSL K				TSL L			
1.22	1	0.53	43.5	0.91	1	0.39	43.0	1.08	1	0.3	31.7
2.63	2	0.55	20.8	1.83	7	0.50	27.0	1.75	7	0.2	13.3
3.38	4	0.53	15.6	2.59	14	0.78	30.2	1.79	28	0.6	36.1
2.77	7	0.23	8.1	2.94	29	0.44	15.0				
2.83	14	0.70	24.7								
2.37	28	0.51	21.5								
TSL M				TSL N				Shotcrete			
1.21	1	0.08	6.4	0.76	1	0.4	48.0	0.29	1	0.1	46.6
1.39	2	0.25	17.8	0.65	2	0.1	12.8	0.71	3	0.1	12.6
1.15	4	0.39	34.1	0.60	4	0.1	15.3	0.72	8	0.1	14.9
1.25	7	0.13	10.4	0.59	7	0.1	18.8	0.68	17	0.1	21.1
1.37	14	0.50	36.4	0.75	14	0.2	20.6	0.68	26	0.2	32.5
1.25	28	0.31	25.2	0.77	28	0.3	37.4				
TSL O				TSL P				TSL Q			
0.58	2	0.10	17.6	0.45	1	0.09	21.0	2.23	1	0.49	21.8
0.59	8	0.12	21.1	1.13	7	0.19	16.9	4.91	4	0.47	9.6
0.60	28	0.22	36.4	1.18	28	0.23	19.9	5.40	7	0.39	7.3
								6.12	28	0.15	2.5
TSL R				TSL S				TSL T			
7.27	1	1.00	13.8	1.70	1	0.60	35.5	3.98	1	0.58	14.7
8.69	2	1.48	17.0	3.75	7	0.57	15.2	5.79	3	0.47	8.0
4.68	7			5.12	14	1.08	21.1	6.56	7	0.62	9.5
5.50	14			5.61	28	1.36	24.2	6.71	14	0.63	9.4
6.67	28	1.54	23.1					7.46	28	0.37	5.0

ΣCV% = 1763.5
N = 103 (total number of curing times)