Tunnelling into a Sustainable Future – Methods and Technologies – Johansson et al (Eds)

Re-evaluating restrained shrinkage tests for sustainable sprayed concrete tunnel linings

Z. Xu
WSP, Queensland, Australia

L. Hanžič
Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia

H. Asche
Aurecon, Queensland, Australia

J. Karlovšek
The University of Queensland, Queensland, Australia

ABSTRACT: The demand for tunnelling and underground construction is steadily increasing, alongside growing considerations for carbon emission reduction in tunnelling projects. Using sprayed concrete as a prominent ground support mechanism for the sequential excavation method is also undergoing low-carbon transition with improved resource efficiency. Enhancing the durability of sprayed concrete linings for structural support and water tightness is essential, particularly when used as a permanent lining, replacing conventional cast in-situ concrete for a design life exceeding 100 years. As sprayed concrete is a time-dependent material used in a time-dependent tunnelling environment, restrained shrinkage cracking in tunnel linings is a recognised issue, especially in mined tunnels in shallow or hard-rock ground with minimal ground movement. The susceptibility of sprayed concrete to restrained shrinkage cracking poses challenges to low-carbon transition, impacting the efficacy and longevity of tunnel linings. Excessive crack widths in tunnel projects often lead to non-conformances, requiring time-consuming repairs and affecting project delivery. However, current design methods for permanent sprayed concrete linings inadequately consider the effects of restrained shrinkage, particularly with sprayed concrete containing reinforcement fibres and accelerators. This paper examines the features that should be included in the restrained shrinkage test for tunnel lining applications, and proposes an improvement in detecting crack initiation and determining the optimal number of measurement points form when multiple cracks form with a finite element analysis. The analysis results showed the possibility of detecting the onset of cracking and crack location with multiple measurement points by interpreting the response of each measurement point.

1 INTRODUCTION

The increasing demand for tunnelling and underground construction is accompanied by a rising focus on reducing carbon emissions in these projects. Sprayed concrete, also known as shotcrete, a fundamental ground support element in the sequential excavation method, is also adapting to lower-carbon approaches with better resource efficiency. Ensuring the durability of sprayed concrete linings for structural stability and watertightness is crucial, especially when used as permanent linings instead of traditional cast-in-situ concrete, with a required lifespan of over 100 years.

Like conventional concrete, sprayed concrete used in tunnelling also experiences shrinkage due to internal and external moisture loss. Unlike ordinary cast concrete, sprayed concrete

DOI: 10.1201/9781003559047-66

applications feature several vital differences that impact the shrinkage. Firstly, sprayed concrete has a higher cement content (more shrinkage potential) and a smaller proportion of aggregates with reduced maximum grain size (less resistance to shrinkage) to achieve a suitable pumpability and sprayability of sprayed concrete (Australian Shotcrete Society, 2020). Additionally, adding a set accelerator helps achieve a fast setting for early strength gains and overhead placement. Nevertheless, the products from the accelerator reaction (ettringite) have a higher potential for shrinkage cracking (Zhang and Glasser, 2000). As hydration occurs in an already stiffened paste, higher porosity develops in sprayed concrete, which makes sprayed concrete more susceptible to moisture loss (Paglia et al., 2003). Furthermore, sprayed concrete is placed onto the substrate in relatively thin layers without formwork, resulting in a large exposed surface-to-volume ratio and a significant moisture loss due to evaporation.

Restrained shrinkage cracking of sprayed concrete tunnel lining is a well-known problem, particularly in shallow or hard-rock tunnels with limited ground movement. While shrinkage in ground-supporting sprayed concrete can be beneficial when ground movement compresses the lining (Von Rabcewicz, 1964), it becomes problematic in shallow, hard-rock tunnels like those in Sydney, where long-term shrinkage has the potential to reverse the reaction force in the lining from initial compression to overall tension (Mueller, 2014, Clark et al., 2017). Although adding macro reinforcement fibres helps bridge cracks and limit shrinkage strain, typical fibre dosages (moderate) may not control crack widths below 0.2 mm (American Concrete Institute, 2018). This vulnerability to cracking presents challenges to low-carbon strategies, potentially compromising the performance and durability of tunnel linings. Large crack widths often result in non-compliance, leading to costly repairs and delays in project timelines.

This paper aims to discuss the features that a suitable restrained shrinkage test for tunnel lining applications should possess. Included in the paper is an analysis, using the finite element method to explain proposed improvements in the detection of crack initiation when multiple cracks form.

2 FACTORS NOT TAKEN INTO ACCOUNT IN CURRENT SHRINKAGE TESTS

The current standardised free shrinkage test methods used in practice focus on unrestrained drying shrinkage (European Committee for Standardization, 2019, Standards Australia, 2015b, ASTM International, 2024), and do not account for the restraint conditions present in tunnel linings, which omit significant differences and variance between in-place sprayed concrete and concrete as supplied before being sprayed. The following subsections discuss the crucial factors not considered in currently adopted shrinkage tests.

2.1 *Early age shrinkage*

In concrete design standards or guidelines, such as AS3600:2018 (Standards Australia, 2018) and Eurocode 2 (European Committee for Standardization, 2004), the final basic drying shrinkage prediction is calibrated with drying shrinkage test results.

However, some standardised free drying shrinkage tests (e.g. AS1012.13 (Standards Australia, 2015b) and ASTM C157 (ASTM International, 2024)) are specifically designed to remove the effects of early age shrinkage (e.g. autogenous shrinkage) by providing wet curing to specimens at an early age to eliminate the impact of autogenous shrinkage. However, drying shrinkage of the sprayed concrete starts almost as soon as placement finishes due to the lack of formwork and wet curing. Thus, the drying shrinkage test data alone cannot provide a realistic indication of shrinkage.

2.2 *Spraying technique and equipment performance*

Spraying is the most distinct feature of sprayed concrete compared to conventional concrete. The compaction of sprayed concrete is achieved by the impact of concrete on the substrate. Namely, the concrete is pneumatically accelerated through the nozzle of the spray gun, and its kinetic energy is converted into internal energy upon the impact. The workmanship of nozzlemen and the equipment performance are unpredictable factors in sprayed concrete application, which are the causes of pulsation, rebound and insufficient compaction.

Pulsation is caused by the different cohesion and pumpability between sprayed concrete and accelerator, resulting from poor equipment performance. Consequently, the flow of the concrete in the hose and nozzle experiences high fluctuation while the flow rate of liquid from the accelerator remains constant. Pulsations result in the layering of sprayed concrete with overdosing of the accelerator, causing lower strength and higher porosity.

Rebound is the aggregate, sand, and cement that rebound off the receiving surface during spraying. Because the larger aggregate is more prone to rebound (Armelin and Banthia, 1998), the primary component of the rebound is the largest aggregate pieces. As a result, the aggregate content of in-place sprayed concrete is lower than that of the concrete supplied, and fewer aggregate particles are available as restraining components for shrinkage. Rebound is affected by spray techniques such as distance from the nozzle to the receiving face, nozzle motion, and spray angle (Australian Shotcrete Society, 2020). Similarly, the spraying techniques highly affect the compaction of sprayed concrete on substrates.

2.3 *Effect of set accelerators*

The primary effect of an alkali-free set accelerator added to concrete is the fast formation of ettringite (Gelardi et al., 2016, DiNoia and Sandberg, 2004). Whereas the formation of ettringite in mature concrete is harmful (e.g. sulphate attack), a controlled formation of ettringite in concrete at an early age is beneficial for the Portland cement system (e.g. early strength development) (Neville, 2002, Barger et al., 2001). Due to a large amount of bonded water, ettringite is unstable in a dry environment. Galan et al. (2016) claim that ettringite-rich cement paste is more sensitive to drying than ordinary Portland cement paste. Also, the faster the setting time, the lower the strength of accelerated cement paste specimens, as they did not consolidate properly (Reyes et al., 2013), reducing the resistance to restrained shrinkage.

2.4 *Curing of sprayed concrete*

The final quality of sprayed concrete depends on how sprayed concrete is cured. Concrete cured in an environment with low humidity is not likely to achieve the same strength and durability as wet-cured concrete. Due to the inapplicability of standard curing methods, sprayed concrete is often not appropriately cured on site, and the drying of sprayed concrete starts immediately after placement finishes. Drying can be aggravated in the area near the ventilation ducts for forced ventilation. The wet-curing process in the standardised drying shrinkage determination method masks the drying shrinkage at an early age.

2.5 *Restraint condition*

The standardised free shrinkage tests, such as AS1012.13 (Standards Australia, 2015b), ASTM C157 (ASTM International, 2024) and BS EN 12390-16 (European Committee for Standardization, 2019), do not consider the condition of restraint, and often, the free drying shrinkage test is the only shrinkage test done during the mix design for the design shrinkage strain calculation. However, the interaction between shrinkage potential and restraints governs the cracking potential of the sprayed concrete tunnel linings.

Currently, standardised ring tests such as ASTM C1581 (ASTM International, 2018) and AASHTO T334 (AAOSHT, 2008) adopt a small-size instrumented steel ring, and thin wall annulus shape concrete specimens with circumferential drying for the evaluation of the cracking potential of concrete under restrained. The stress of the concrete ring test is also an analogue to the stress in a pressurised pipe (Moon and Weiss, 2006). Comparably, the induced circumferential stress caused by restrained shrinkage of the sprayed concrete lining fully bonded to the substrate before cracking is analogous to the hoop stress in a pressurised pipe (Reid and Bernard, 2020). Thus, the ring test becomes a potential test method for sprayed concrete. However, their small specimen size may not represent sprayed concrete accurately.

2.6 *Effect of fibres*

Reinforcement fibres are added to the sprayed concrete mix to enhance tensile strength and toughness with crack-bridging and energy absorption. Sprayed concrete used in Australian tunnels is often reinforced by steel fibres (Australian Shotcrete Society, 2020). The standardised free shrinkage test has no fibre addition, and the effects of fibres in shrinkage are not considered.

Different types of reinforcement fibres perform differently in the pre-cracking and post-cracking stages. The optimisation of the reinforcement fibres used in sprayed concrete has been focusing on extending the softening part during the crack opening stage instead of the pre-cracking stage, and the designed fibre allows fibre elongation or slip instead of fracture. However, this also facilitates the crack localisation as such design avoids fibres being loaded to the ultimate strength. Therefore, considering the reinforcement fibres is critical to studying restrained shrinkage cracking of sprayed concrete lining. The test methods for evaluating cracking of sprayed concrete (e.g. ASTM 1550 (ASTM International, 2012) are useful for estimating the toughness of fibre-reinforced sprayed concrete (FRS) when crack width is greater than 0.2mm. A test method with an emphasis on studying cracking resistance with smaller crack widths is more beneficial for crack width control. Should this test become widespread, it is hoped that it will become a catalyst for the development of fibres to achieve better crack width control in sprayed concrete tunnel linings.

2.7 *Specimen size*

The specimen size in standardised shrinkage tests is too small to warrant the production of representative sprayed concrete specimens. For example, AS1012.8.4 (Standards Australia, 2015a) and ASTM C157 (ASTM International, 2024) utilises prims with dimensions of 75 × 75 × 280 mm and 75 × 75 × 285 mm, respectively. In FRS, the distribution and orientation of the fibres influence the mechanical performance, especially crack-bridging and energy absorption (Kaufmann et al., 2013). Spraying concrete at high velocity to a small mould may force a significant part of the fibres in the ring specimen to align in the circumferential direction, which is not representative of the random distribution of the actual fibre-reinforced sprayed concrete application.

Moreover, for the ring test, the crack width in the restrained rings depends on the size of the restrained ring and the degree of restraint, which influences the expected performance in the field. Specifically, longer specimens, like slabs in the field with lengths ranging from 3 m to 6 m, experience larger crack openings than smaller specimens (Raoufi et al., 2010). In contrast, the small specimens in the ring test, such as ASTM C1581 (ASTM International, 2018), correspond to a slab of about 1 m long.

Moreover, standardised tests for sprayed concrete, such as ASTM C1550 (ASTM International, 2012), favour large specimens produced by spraying concrete into large moulds, thus reducing the defects and inconsistencies caused by limited spraying angles, rebound and inadequate compaction. Thus, a large ring test that enables spraying and data acquisition from an early age is needed for the assessment of FRS cracking due to restrained drying shrinkage cracking.

2.8 *Multiple crack formation*

Macro fibres added into the sprayed concrete mix bridge the developing cracks and resist their propagation, effectively reducing the shrinkage strain and restricting crack growth. Ideally, to slow down the crack propagation, it is considered beneficial if multiple subcritical cracks form and prevent one crack from propagating through the whole thickness of the structure or widening the crack.

ASTM C1581 (ASTM International, 2018) and AASHTO T334 ((AAOSHT, 2008) utilise thin concrete specimens with circumferential drying, and the cracking potential of concrete is evaluated with the net time-to-cracking (by using the age of cracking of one single crack) and average stress rate, based on publication by See et al. (2003). Age at cracking is defined as the age when a sudden decrease in strain of the steel ring occurs in current standards for ring test (ASTM International, 2018). The sudden decrease of strain only occurs when the crack propagates through the whole thickness of the concrete.

However, if a ring test is conducted on thicker concrete rings, the net time-to-cracking may be prolonged, especially when reinforcement fibres are added to specimens. It does not affect the age of cracking in ring tests with small concrete rings, whereas the prolonged duration of crack propagation in larger concrete rings potentially creates a lag between the actual crack initiation and the time when a through-crack forms.

Moreover, multiple crack formations may occur in thicker ring specimens of fibre-reinforced concrete, and a sudden decrease in strain may not occur. Thus, the stress rate method in ASTM C1581 (ASTM International, 2018) may not be applicable.

In summary, the practical test method of restrained shrinkage for sprayed concrete applications should have the following features:

- The mould is sprayable, requiring sufficient mould surface for spraying and including the effect of accelerator addition, workmanship and equipment;
- The measurement can start from an early age;
- The mould can be stored in the actual curing environment;
- The restraint condition should be comparable to the tunnel environment;
- The duration of the test should be practical and
- Analysis should accommodate potential multiple crack formation.

3 MULTIPLE CRACK FORMATION AND DETECTION OF CRACK INITIATION

From the discussion above, it is evident that a larger and sprayable ring test is required to study restrained shrinkage cracking in tunnel linings. Xu et al. (2024) conducted a large, restrained shrinkage ring test with cast concrete (Figure 1 (a)). In this large ring test, the instrumented steel ring's inner radius (R_{IS}) and the outer radius (R_{OS}) are 545 mm and 600 mm, respectively. The outer radius of the concrete ring (R_{OC}) is 800 mm, resulting in a concrete ring thickness of 200 mm. Three measurement points (MPs) are located on the inner circumference of the steel ring with a 120° angle between the adjacent MPs (Figure 1 (b)). Each MP was calibrated before the ring test, which enables revealing a more accurate response of each MP during crack initiation to crack propagation. The drying of the specimens was enabled at the top and bottom surfaces of the concrete ring to minimise the differential shrinkage in the radial direction. The instrumentation on the steel ring was adapted for long test durations with temperature compensation by arranging strain gauges in a full Wheatstone bridge configuration in each MP and thermocouples for temperature measurement. Multiple crack formation was observed, and micro-cracks occurred before the significant drop of strain was detected (Xu et al., 2024). It shows the need for a method to deal with multiple crack formation in ring tests.

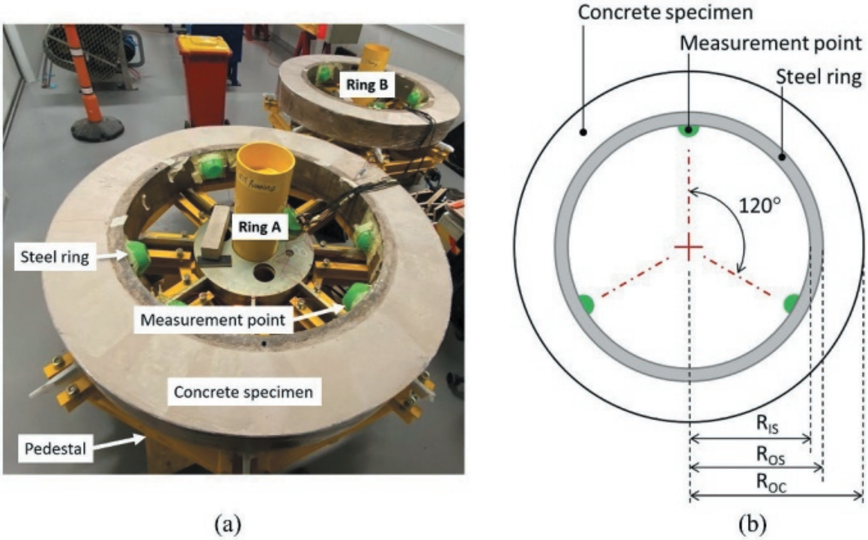


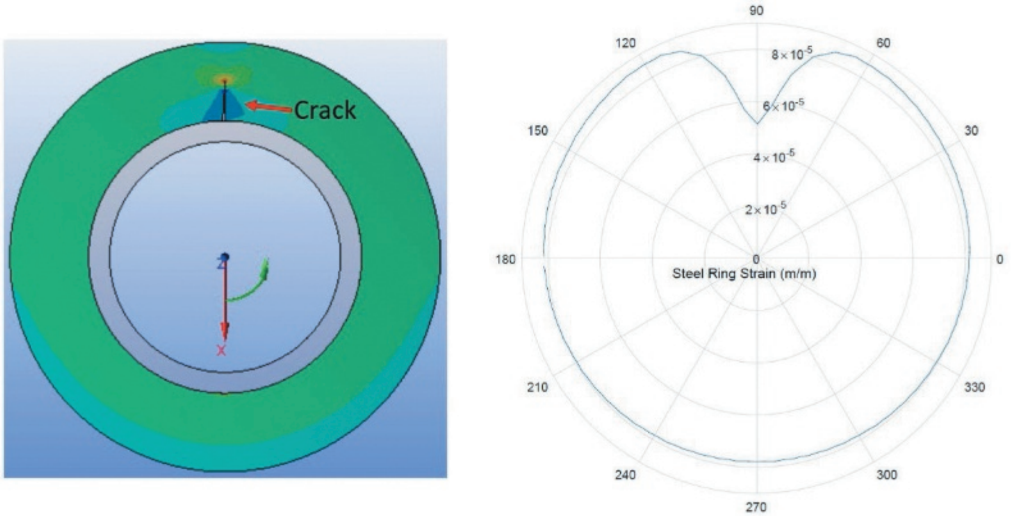
Figure 1. Restrained shrinkage test using large instrumented steel rings and concrete specimens. (a) Experiment setup; (b) locations of measurement points (MPa) (Xu et al., 2024).

For crack width control in tunnel linings, detecting the age of macro crack initiation rather than the age of a through crack is more beneficial. With more accurate individual strain gauge responses, detecting the onset of cracking is possible. A finite element analysis was conducted in ANSYS with ring test geometry of R_{OC} = 280 mm, R_{OS} = 130 mm, R_{IS} = 110 mm and h =75 mm to explore the responses of different strain gauge arrangements. A crack with a length of 30 mm and crack width of 1 mm was introduced to the concrete ring, initiating from the inner circumference of the concrete ring (Figure 2 (a)). The thickness of the steel ring is set to 10 mm to have higher deformations, resulting in higher steel ring strain readings. A fictitious temperature field was used to simulate the shrinkage of concrete. The free shrinkage of 200 με is assigned to the concrete with a coefficient of thermal expansion of 10×10^{-6} °C^{-1} and change of temperature ΔT = 20 °C. The elastic modulus of steel and concrete are 200 GPa and 30 GPa, respectively, while Poisson's ratio of the steel and concrete are 0.3 and 0.2.

Figure 2 (b) shows the strain distribution of the steel ring in a polar coordinate system with a crack at 90°. It is noted that near the cracked area, the circumferential strain of the steel ring is much lower than the rest of the ring.

The strain concentration from the crack shows the potential to detect crack formation by interpreting multiple strain gauge measurements. Figure 2 shows individual strains with two, three, four and six strain gauges on the steel ring, which are 180°, 120°, 90° and 60° away from each other, respectively. The horizontal axis represents the angular distance ($\Delta\theta$ in polar coordinates). Also, the strain distribution exhibits symmetry along the centerline of the crack. Partly due to this symmetrical distribution of the strain of the steel ring, when only two strain gauges are installed (180° apart), the reading of both gauges becomes identical at some crack locations, which makes the crack formation unnoticeable.

In contrast, at least two strain measurements show noticeable differences when more than three strain gauges are installed on the steel ring. Compared to the FE result with the data of the large ring test by Xu et al. (2024), the trend of the strain change between MPs with different angular distances matches the experimental data. For example, MP1 and MP3 have almost the same angular distance to the macro crack (final through crack), and their strain data are highly comparable before and during crack propagation. The MPs located closer to the crack showed a more significant decrease in strain than those positioned further away.



(a) (b)

Figure 2. Ring test with a crack initiated from the steel-concrete interface. (a) Geometry of ring test and location of crack; (b) Steel ring strain in a polar coordinate system with the crack at 90°.

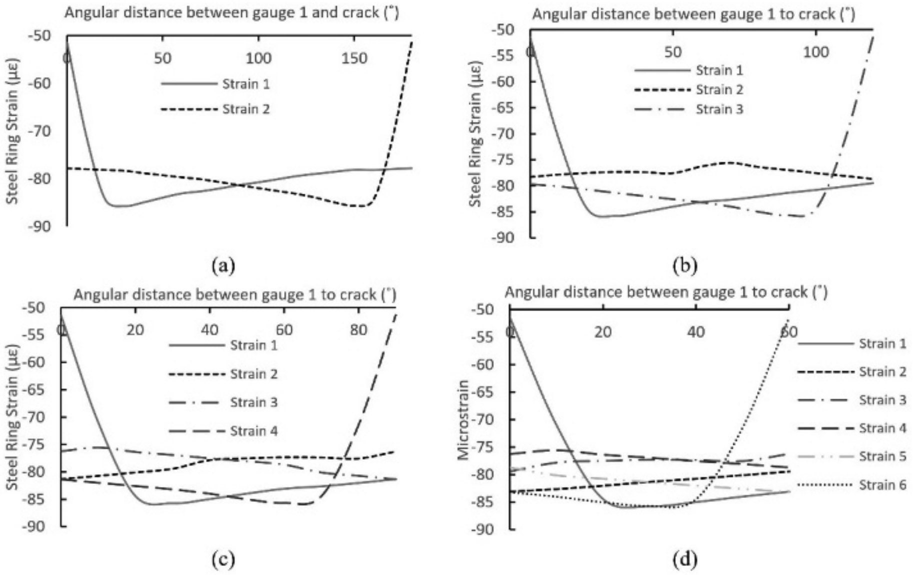


Figure 3. Steel ring strain regarding angular distance to crack with (a) two strain gauges, (b) three strain gauges, (c) four strain gauges, and (d) six strain gauges. Strain gauge 1 aligns with the crack.

It can also be seen from Figure 3 that with more strain gauges, there is a higher chance of observing higher differences from the individual strain gauge readings due to the decreased angular distance between the MP and the crack. Therefore, more MPs mean a higher potential to detect the onset of cracking and crack location, which is especially important when visual observation on the surfaces of the concrete ring is not possible or when no sudden drop of steel ring strain occurs. With six MPs, the identified area of crack initiation can be limited to a 60° central angle if one of the MPs detects much higher changes in strain. The required number of MPs depends on the size of the concrete ring (R_{OS} & R_{OC}), and large concrete rings require more MPs to achieve a reasonable coverage of the concrete ring for each MP. For example, a 60° central angle corresponds to 0.63 m of the arc on the inner side of the concrete ring with $R_{OS} = 600$ mm.

However, numerous MPs in large ring tests using conventional electrical strain gauges require more instrumentation effort and more channels of data logger, which may not be practical and economical. More advanced strain measuring instruments, such as fibre optic strain gauges, may be more viable, as only one fibre-optic cable with multiple sensor points at small spacing needs to be installed.

4 CONCLUSION

The study of restrained shrinkage cracking in sprayed concrete tunnel linings highlights that standardised tests currently used in practice often do not accurately represent the conditions sprayed concrete faces in the field, especially regarding the interplay of shrinkage potential and restraint conditions. Factors such as the effects of set accelerators and fibre reinforcement must be considered in the test to understand the restrained shrinkage behaviour comprehensively.

Large-scale restrained shrinkage tests conducted recently showed the need to detect the onset of crack initiation when multiple crack formation occurs in ring tests. The analysis using the finite element method presented in this paper showed that with more MPs, there is a higher potential to detect the onset of cracking and crack location with a smaller angular distance between the crack and MPs. Moreover, a large concrete ring requires more MPs to achieve a reasonable coverage of the concrete ring for each MP. Ultimately, improved testing methodologies tailored to sprayed concrete applications will allow for better control of cracking and lead to more durable tunnel linings.

REFERENCES

AASHTO. 2008. AASHTO T334-08, Standard Method of Test for Estimating the Cracking Tendency of Concrete.

AMERICAN CONCRETE INSTITUTE. 2018. ACI PRC-544.4-18: Guide to Design with Fiber-Reinforced Concrete. Farmington Hills, MI, ACI.

Armelin, H. & Banthia, N. 1998. Mechanics of aggregate rebound in shotcrete—(Part I). *Matériaux et Construction*, 31, 91–98.

ASTM INTERNATIONAL. 2012. ASTM C1550-12a, Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel). West Conshohocken, PA.

ASTM INTERNATIONAL. 2018. ASTM C1581/C1581M-18a Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage. West Conshohocken, PA.

ASTM INTERNATIONAL. 2024. ASTM C157/C157M-24e1 Standard Test Method for Length Change of Hardened Hydraulic-Cement Motar and Concrete. West Conshohocken, PA.

AUSTRALIAN SHOTCRETE SOCIETY. 2020. Shotcreting in Australia: Recommended Practice. Third Edition ed. Sydney, Concrete Institute of Australia.

Barger, G., Bayles, J., Blair, B., Brown, D., Chen, H., Conway, T. & Hawkins, P. 2001. Ettringite Formation and the Performance of Concrete. *Portland Cement Association R&D, New York*, 1–16.

Clark, P., Burke, M. & Khatri, R. 2017. Durability of steel fibre reinforced shotcrete-A review of published technical papers, codes and standards. *16th Australasian Tunnelling Conference 2017*: *Challenging Underground Space: Bigger, Better, More.* Engineers Australia Barton, ACT.

Dinoia, T. & Sandberg, P. 2004. Alkali-free shotcrete accelerator interactions with cement and admixtures. *Shotcrete: More Engineering Developments*, 137–44.

EUROPEAN COMMITTEE FOR STANDARDIZATION. 2004. EN 1992-1-1: Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. Brussels, CEN.

EUROPEAN COMMITTEE FOR STANDARDIZATION. 2019. BS EN 12390-16:2019 Testing hardened concrete - Part 16: Determination of the shrinkage of concrete. Brussels, Belgium, CEN.

Gelardi, G., Mantellato, S., Marchon, D., Palacios, M., Eberhardt, A. & Flatt, R. 2016. Chemistry of chemical admixtures. *Science and Technology of Concrete Admixtures*. Elsevier.

Kaufmann, J., Frech, K., Schuetz, P. & Munch, B. 2013. Rebound and orientation of fibers in wet sprayed concrete applications. *Construction and Building Materials*, 49, 15–22.

Moon, J. H. & Weiss, J. 2006. Estimating residual stress in the restrained ring test under circumferential drying. *Cement and Concrete Composites*, 28, 486–496.

Mueller, A. 2014. Pacific highway upgrade from Tintenbar to Ewingsdale (T2E), St Helena Tunnel. *15th Australasian Tunnelling Conference 2014. Underground Space-Solutions for the Future.* Engineers Australia and Australasian Institute of Mining and Metallurgy ….

Neville, A. M. 2002. *Properties of concrete*, Prentice Hall, Parson Education: Harlow, England.

Paglia, C., Wombacher, F. & Böhni, H. 2003. The influence of alkali-free and alkaline shotcrete accelerators within cement systems: Influence of the temperature on the sulfate attack mechanisms and damage. *Cement and Concrete Research*, 33, 387–395.

Raoufi, K., Bernard, E. S. & Weiss, W. J. 2010. Shrinkage cracking behavior of fiber reinforced concrete: as assessed using the restrained ring test. *Journal of ASTM International*, 7, 1–15.

Reid, S. & Bernard, E. 2020. De-bonding of shotcrete linings at the substrate boundary. *Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art*. CRC Press.

Reyes, I.G., Cavalaro, S. H. P. & Alba, Á. J. R. 2013. Characterization and control of wet-mix sprayed concrete with accelerators.

See, H. T., Attiogbe, E. K. & Miltenberger, M. A. 2003. Shrinkage cracking characteristics of concrete using ring specimens. *Materials Journal*, 100, 239–245.

STANDARDS AUSTRALIA. 2015a. AS 1012.8.4:2015 Methods of testing concrete Method 8.4 Methods for making and curing concrete - Drying shrinkage specimens prepared in the field or in the laboratory.

STANDARDS AUSTRALIA. 2015b. AS 1012.13. 2015: Methods of Testing Concrete: Determination of the Drying Shrinkage of the Concrete Samples Prepared in the Field or in the Laboratory.

STANDARDS AUSTRALIA. 2018. AS 3600:2018 Concrete structures.

VON Rabcewicz, L. 1964. The new Austrian tunnelling method. *Water Power*, 16.

Xu, Z., Hanžič, L., Asche, H. & KarlovŠek, J. 2024. Large Ring Test for Evaluation of Restrained Shrinkage Cracking: Calibration and Experimental Trial. *Advances in Civil Engineering*, 6698625.

Zhang, L. & Glasser, F. 2000. Critical examination of drying damage to cement pastes. *Advances in cement research*, 12, 79–88.