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STEEL FIBRE REINFORCED CONCRETE QUALITY CONTROL – EXAMPLES FROM OVERSEAS STANDARDS AND CODES

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SUMMARY

Although NZS3101 allows Engineers to design with SFRC – it gives limited guidance relating to quality control of SFRC.

This paper will present practical specification guidelines for engineers to ensure that the **correct fibre**, at the **correct dosage** is used in the concrete and **dispersed uniformly**.

Recent developments in fibre quality control and specification will also be discussed, including the inclusion of SFRC design and QC into the Australian Concrete Structures Standard, AS3600: (2018).

Introduction

The market for Steel Fibre Reinforced Concrete (SFRC) is well developed. SFRC has found wide-spread use in a range of applications, including industrial floor slabs and pavements, precast, shotcrete, structural foundations, tunnel linings and more. This market development is underpinned by several decades of research and publications covering design, construction and quality control methods for SFRC (Ross, 2009).

SFRC adoption has been motivated by its well-established benefits. SFRC can provide a faster, safer, more affordable and more sustainable construction method for reinforced concrete elements.

As with all new construction techniques, these benefits can only be realised if there is a comprehensive set of controls around the design and manufacture of SFRC, ensuring that SFRC concrete elements meet the performance required by the design engineer.

In the 2006 revision, NZS3101 adopted recommendations from RILEM TC 162-TDF covering design of SFRC. Appendix A to C5 of NZS3101 covers the determination of SFRC performance from material test data, and how these material characteristics can predict material behaviour for structural design of moment and shear resistance in ULS and/or SLS.

Regarding the source of SFRC material properties used in designs, NZS3101 states:

"The properties of the fibre, such as its aspect ratio, ultimate tensile strength and end anchorage have a significant influence on the performance of the fibre reinforced concrete. Different fibre properties will result in different fibre dose rates to meet specific design

properties. Designs must be based on the test data supplied by the fibre manufacturer, or confirmed by tests."

This opens the opportunity for engineers to specify SFRC by performance or prescriptive specifications. In a performance specification, the designer would state the minimum residual flexural tensile strength required. NZS3101 contains specific guidance on specification of SFRC on a performance basis by specifying "Strength classes", whereby the SFRC supplier is responsible for ensuring the minimum characteristic $f_{R,1k}$ and $f_{R,4k}$ values are achieved. The SFRC design in this case is based on the concrete supplier's material testing to determine a specific steel fibre type and dosage which meets the performance required, in a specific mix design.

Prescriptive specifications of SFRC performance will state a fibre type and dosage which must be used in concrete supplied to the project. This fibre/dosage should be determined by the fibre manufacturer based on material testing, using the same concrete compressive strength used for the project. This will typically result in a more conservative level of performance as there is no opportunity for optimisation of the whole-mix performance. Furthermore, the steel fibre manufacturer has no control over the concrete mix design or its performance, so are likely to take a conservative approach that ensures performance requirements are achieved.

In both performance and prescriptive SFRC specifications – the properties and performance of the in-situ concrete, with respect to post-cracking performance provided by steel fibres, is determined by:

(1) Concrete construction methodology (Placing, compaction, curing etc)
(2) Concrete achieving the specified compressive strength
(3) The specific fibre being used
(4) The specified fibre having consistent properties/performance
(5) The correct dosage of fibre being batched
(6) The fibre being homogenously dispersed throughout the concrete

A generalised version of the SFRC design, production and construction process is shown in Figure 1. Also shown are stages of this process which can be performed in accordance with NZS 3101, NZS 3104 and NZS3109.

Of these six factors listed above influencing in-situ SFRC performance, (1) is covered by NZS3109, as normal concrete construction methodologies are typically suitable for SFRC, and (2) is covered by NZS3104, which specifies quality control requirements for ready-mix concrete production. No current NZ standard specifically addresses quality control requirements for SFRC (points (3) to (6))

In the absence of codified SFRC quality control, specifying engineers have either relied on their own specifications, recommendations from fibre suppliers or good practice being followed by the concrete supplier.

As SFRC becomes more widely used throughout NZ, particularly in structural applications, it is crucial that SFRC production is quality controlled to ensure in-situ performance.

This paper will present practical specification guidelines for engineers to ensure that the **correct fibre**, at the **correct dosage** is used in the concrete and **dispersed uniformly**. Methods of specification from international codes, standards and guidelines will be presented. Particular attention will be given to the new AS3600 concrete structures standard, to determine if the SFRC quality control scheme may be an appropriate model for NZ to follow.

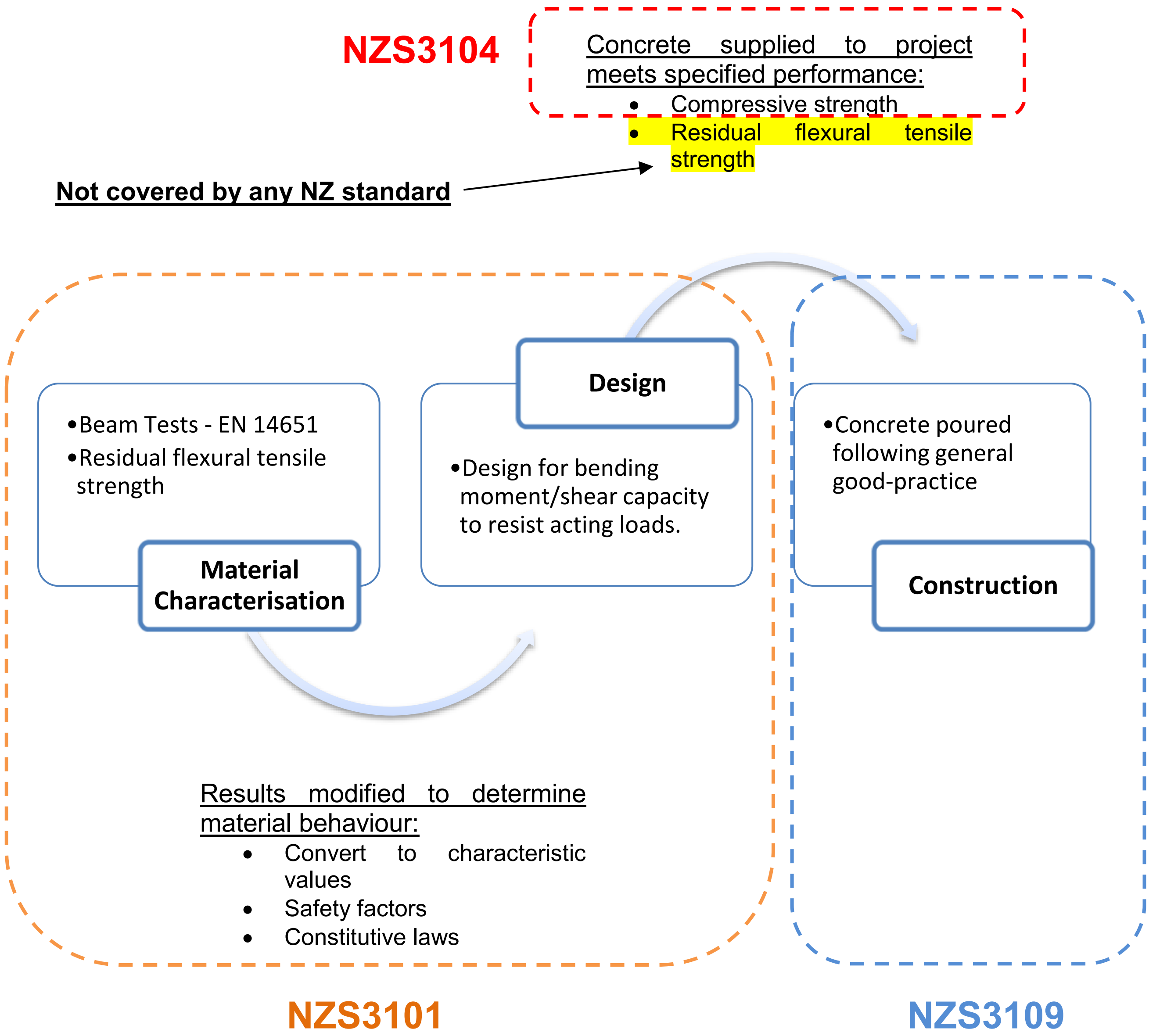


Figure 1 – SFRC design, production and construction process as covered by NZ Standards.

Steel fibre performance and quality

The performance of a given steel fibre at a specified dosage is determined by the physical properties of the steel fibre, primarily aspect ratio (length/diameter, see figure 2 below), fibre tensile strength and fibre shape.

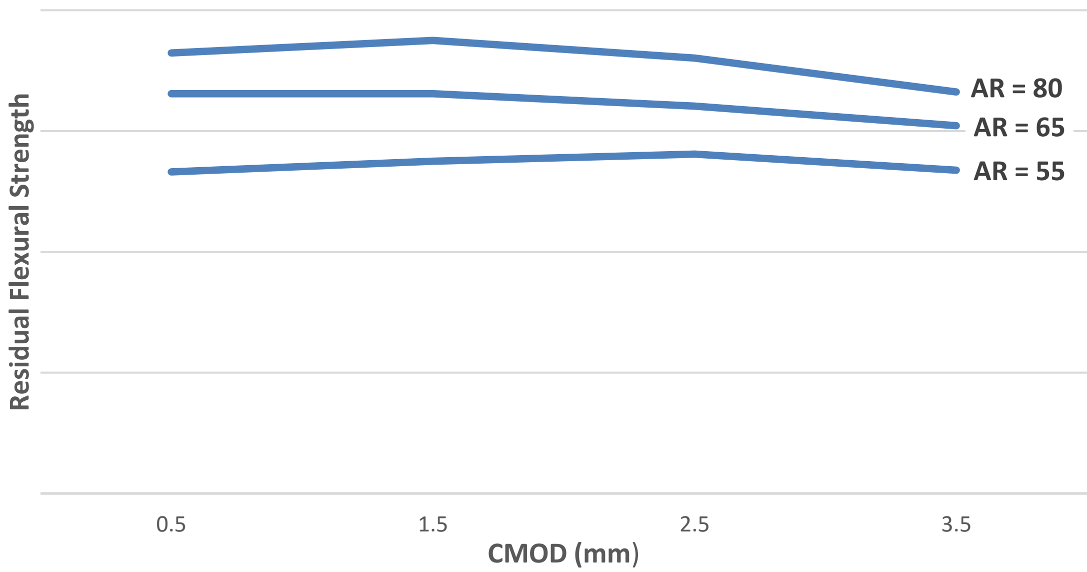


Figure 2 – Influence of fibre Aspect Ratio (AR = length/width) on post-crack performance with constant fibre length and dosage.

If fibres are to provide a consistent and reliable level of performance, these fibre properties must be consistent. Manufacture of fibres in accordance with a suitable performance manufacturing standard ensures this is the case, as it does for most other construction materials such as concrete, steel and wood.

Current standards which include specified tolerance for steel fibre properties are:

- EN 14889 – 1: (2006)
- ASTM A820: (2011)
- ISO 13270: (2013)

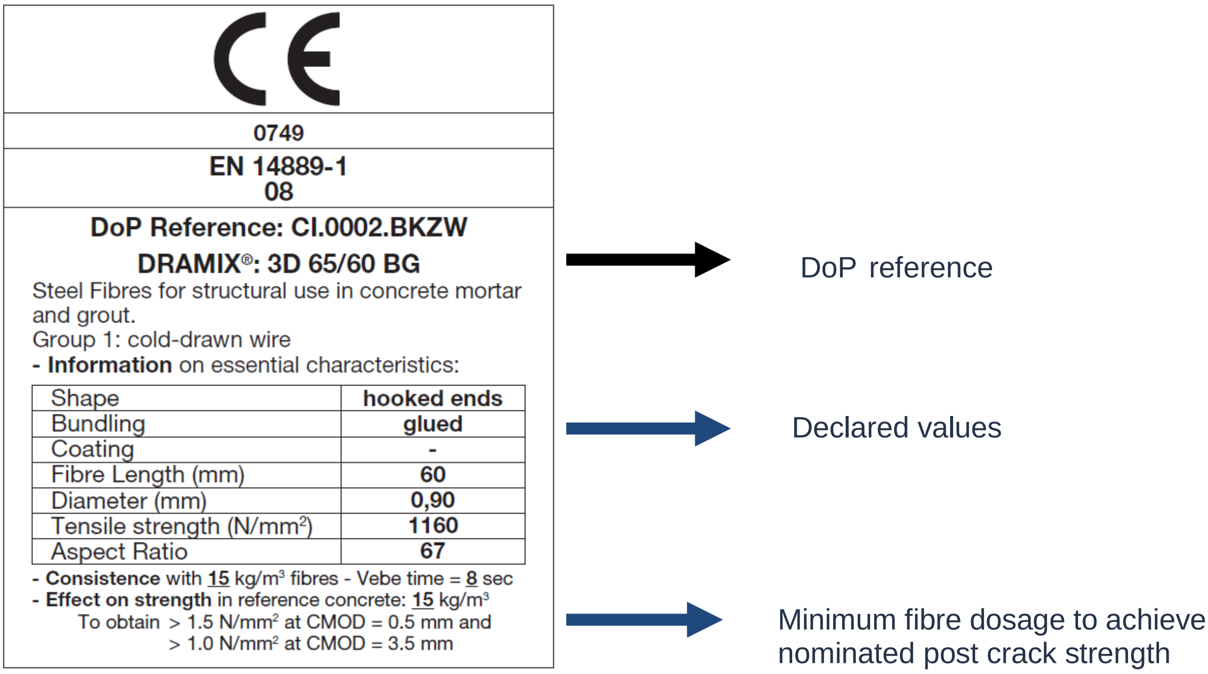
Tolerances for key properties are summarised in Table 1.

Table 1: Summary of tolerances from Steel Fibre manufacturing Standards.

Parameter	***EN 14889 - 1 / ISO 13270***	***ASTM A820***
Length	± 5%	± 10%
Diameter	± 5%	± 10%
Aspect Ratio	± 7.5%	± 15%
Tensile Strength	± 7.5%	None – Only minimum values
Effect on Consistence	Declared	Not Included
Effect on strength of Concrete	Declared	Not Included
Effect on air of Concrete	<2% increase (ISO Only)	Not Included

EN 14889-1 and ISO 13270 (Based on EN14889-1 with some additional requirements) are the only performance-based manufacturing standards for steel fibres and are referenced in the latest standards AS 5100 and AS3600. As with other performance-based manufacturing standards such as NZS3104 for Concrete, these standards specify test methods, test frequency and tolerances for fibre properties and performance. These standards require that any steel fibres for structural use (designated class 1 in EN 14889-1 and Class A in ISO 13270) have third-party monitoring of production and testing. Structural use fibres are designated as those intended to contribute to the load bearing capacity of the concrete element, such as those designed in accordance with NZS3101.

Fibres manufactured in accordance with EN 14889-1 should be labelled with a “CE marking”, which states the fibre properties and performance characteristics, as shown in Figure 3. This CE marking must be printed either on individual fibre bags or pallet labels, alongside package weight, date of manufacture and manufacturers name or trademark.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EN 14889-1
08

DoP Reference: CI.0002.BKZW

DRAMIX®: 3D 65/60 BG

Steel Fibres for structural use in concrete mortar and grout.
Group 1: cold-drawn wire
- **Information** on essential characteristics:

Shape	**hooked ends**
Bundling	**glued**
Coating	**-**
Fibre Length (mm)	**60**
Diameter (mm)	**0,90**
Tensile strength (N/mm²)	**1160**
Aspect Ratio	**67**

- **Consistence** with 15 kg/m³ fibres - Vebe time = 8 sec
- **Effect on strength** in reference concrete: 15 kg/m³
To obtain > 1.5 N/mm² at CMOD = 0.5 mm and
> 1.0 N/mm² at CMOD = 3.5 mm

Figure 3 – Example of CE Marking label with Declaration of Performance (DoP)

Although ASTM A820 specifies tolerances for some fibre properties, it does not include a rigorous performance-based system for production control, nor any requirements for third-party verification of claims made by fibre manufacturers. For this reason, concrete construction standards in Australia (AS3600 and AS5100) and Europe require all fibres used to comply with either EN 14889-1 or ISO 13270 (Ng & Htut, 2018).

If engineers specify fibres which do not comply with either of these standards, there is no way to know if the performance of the SFRC will meet that required by the design.

<u>Specification</u>
Engineers need to be sure that the fibres used on their projects are providing a consistent level of performance, and that the fibres specified are delivered.

By specifying fibres manufactured in accordance with a performance-based manufacturing standard, consistent fibre performance will be achieved. Furthermore, reference to the fibre-specific CE-label and DoP ensuring the fibre specified by the engineer is used in SFRC production.

<u>Suggested specification clause</u>

- Fibres should be manufactured in accordance with EN14889-1, system 1 for structural use or, ISO13270 Class A.

- A Declaration of Performance (DoP) must be supplied to the project engineer or interested party and will be used to check against the CE label attached to delivered pallets of fibre.

Steel fibre dosage in concrete

Fibre "dosage" is simply the amount of fibre added to a volume of concrete in kg/m^3, with typical dosages specified in the range of 15-35kg/m^3.

Steel fibre dosage is directly related to the performance of SFRC as it determines the number of fibres bridging a crack, and therefore providing post-crack capacity. Figure 4 shows how varying the dosage of a given fibre influences residual flexural strengths, as measured by a three-point notched beam bending test such as EN 14651: (2005).

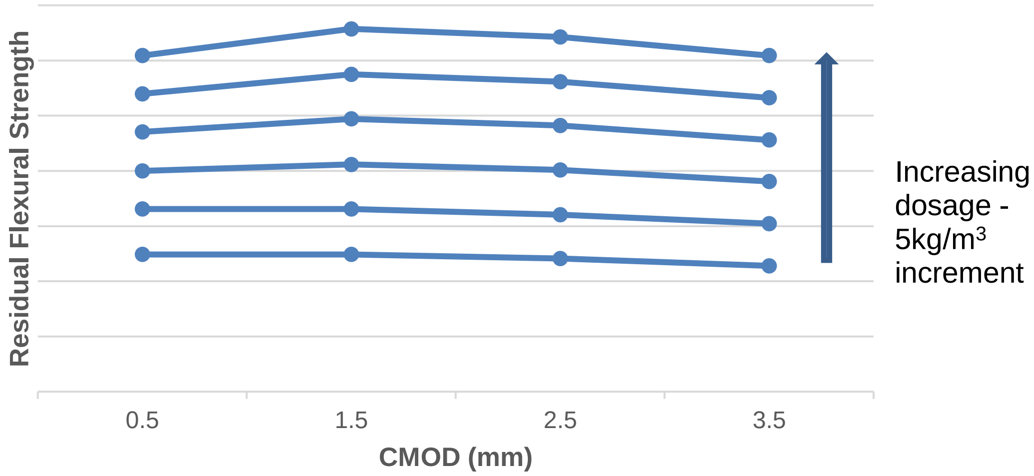

Figure 4 – Impact of steel fibre dosage on residual flexural strength

There are two main methods of steel fibre addition to fresh concrete; automatic dosing via specialist equipment, or the manual addition of fibres by hand.

<u>Auto Dosing</u>

Fibre dosing equipment for ready-mix concrete plants has been available since the early 90's and has since found widespread use throughout the industry (Incite AB , 2019).

These machines can be linked to the ready-mix plant's batching system, which can automatically dose each truck with the required weight of fibres, recording the dosage delivered to each truck either on the plant's batching records or a separate printout.

Figure 5 – Automatic fibre dosing equipment (Source: Incite AB)

Automatic dosing systems have found widespread use in Europe and Australia (Ross, 2009). This approach to dosing is most advantageous when installed in plants which produce high volumes of SFRC using the same type of fibre, as improved production efficiency can justify the high cost of installing the equipment. These plants are typically supplying precast plants, large infrastructure projects (particularly tunnels), and large industrial/warehouse developments.

Currently there are very few concrete plants in NZ with automatic dosing equipment, due to the high cost of installation, difficulty of changing between fibre types and relatively low demand for SFRC. As the SFRC market and dosing equipment technology develops, they may become more widely used.

As with all concrete batching equipment, fibre dosing equipment must be regularly calibrated and properly maintained to ensure the required fibre content is delivered for each batch. This should be incorporated into the plants overall maintenance and calibration systems which ensure compliance with NZS3104.

<u>Manual Dosing</u>

The most common method of dosing steel fibres in New Zealand is by manually adding the steel fibre to the load of concrete at the batching plant. The total required weight of fibre required for the load is calculated based on the specified dosage, divided by the bag weight, then the required number of bags added to the truck. e.g. if a $6m^3$ load with a specified dosage of 20kg require 6 x 20kg bags or 12 x 10kg bags of fibre.

How the fibres are manually added to the concrete will be dependent on the type of fibre and the fibre mixing requirements.

<u>Specification</u>

With either dosing method, records must be kept, and provided to the engineer upon request, which show the amount of fibre added to each load of concrete. This is the same requirement as for any other component of ready-mix concrete, which must be accurately recorded on batch records.

By recording this information, if a fibre manufactured in accordance with EN14889-1, system 1 for structural use or, ISO13270 Class A, is used, a full record will exist of the fibre origin, including source steel used in the fibre manufacture.

<u>Suggested specification clause</u>

- Delivery dockets shall state fibre type and dosage as specified
- A record of the following shall be kept and provided to the specifying engineer upon request:
  - Each pour:
    - Pallet numbers + DoP reference for fibres used to supply the project
  - Each load:
    - Docket Number
    - Steel fibre type
    - Specified steel fibre dosage
    - Batched steel fibre dosage (as delivered by auto dosing machine, or # of bags added to the load)

Fibre dispersion in concrete

The final aspect of SFRC production quality control is ensuring that fibres are well-mixed throughout the concrete to ensure a homogenous distribution of fibre.

Mixing requirements

There are several methods for mixing steel fibre into concrete, with suitable methods determined by fibre type and concrete plant configuration (dry or wet batch).

Fibre can be batched with aggregate, by adding it to the aggregate weight hopper, directly to the conveyor belt, or added to the truck after batching of other components is complete.

When fibres are being manually dosed, fibres are typically tipped from their bags directly into the bowl, or onto a conveyor which feeds the fibre into the truck. It is generally accepted that addition of fibres into the truck after batching other components is the most effective method to minimise the risk of fibre balling.

Steel fibres are available in loose or collated (glued) form, as shown in Figure 6. Loose fibres are prone to balling, particularly when high aspect ratio (l/d) fibres are used. Specialised fibre blowers should be used to inject loose fibres directly into the truck bowl to minimise balling (Vitt, 2011).

Collated fibres are held together by a water-soluble glue, which breaks down upon introduction to wet concrete. As the glue breaks down it releases individual fibres form the bundle, assisting in achieving a homogenous dispersion of fibres and reduce balling.

Figure 6 – Loose and collated (glued) steel fibres (Source: Bekaert)

As with all other concrete constituents, adequate mixing of the concrete is required to ensure homogenous dispersion. NZS3104 specifies requirements for measuring mixer efficiency and mixing time for concrete that assures acceptable homogeneity is achieved.

In the case of SFRC, the dispersion of fibres within the concrete strongly influences its performance, therefore specifying engineers may specify additional quality control measures to determine the specific distribution of fibre within concrete delivered to their project. This shouldn't be required for slab on grade applications.

Fresh Concrete testing for distribution

The fibre content of fresh concrete can be determined by taking a sample of known volume, extracting and weighing the steel fibres within the sample, then calculating the dosage of fibre within the sample in kg/m^3. By taking samples from various points through a load of concrete, the distribution of fibres through that load can be assessed.

EN 14721: (2005) outlines a test method for determining fibre content in fresh concrete, with a minimum sample size of 3L. Standard practice in New Zealand uses a larger sample size of >7L, an approach also adopted by AS 3600. Additional requirements/modifications made in AS 3600 are:

- Samples are taken from the first, middle and final third of the concrete batch during discharge
- Sample is taken in one continuous pour and directly from the discharge chute
- Fibre content of sample determined by wash-out, magnetic separation or validated automated dosage equipment.

Testing fibre distribution of fibres in fresh concrete, as described above, is a costly and time-consuming process typically taking 1-2 hours per batch tested. Therefore, engineers should in all cases avoid over-specification of such testing.

The required frequency of testing varies significantly between different specifications. The European standard for concrete production , EN 206: (2013), specifies SFRC fibre content must be determined at the same frequency as compressive strength tests are performed, which varies from 3 samples in $50m^3$ for initial testing, to 1 test in $400m^3$ for plants with a high level of production control.

AS3600 requires fibre distribution testing at the beginning of each day’s production and then at a frequency of 1 in $50m^3$ for manually dosed concrete, and 1 in $150m^3$ for automatically dosed concrete. This frequency is high, particularly for concrete with manually dosed fibre, and will add significant costs to SFRC production. One possible justification for this high testing rate may be the prevalence of on-site concrete testing in Australia, where most concrete testing is not performed at the production plant as it is in New Zealand.

Hardened Concrete testing for distribution

An alternative to determining the steel fibre distribution in fresh concrete is assessing fibre distribution within hardened concrete. EN 14721 specifies a method based on extracting 3 or more cores of volume >1L, which are then crushed to separate the fibres to determine dosage in kg/m^3.

This method has many drawbacks, including damage to the concrete element from core extraction, cost/difficulty of testing and poor accuracy, with up to 5% of fibres being lost in the testing process. Consequently, this method should be used as a last resort.

Automated methods

Development of automated systems for measuring steel fibre content and/or dispersion is ongoing. Currently there exists commercially available systems for measuring fibre distribution during concrete pours using a device attached to the concrete truck chute, as shown in Figure 7.

Figure 7 – Automated SFRC quality control device (Source: Bekaert)

This type of system is likely to become more widely used as technology improves. New standards for SFRC should make provision for their use in place of manual methods, as AS3600/5100 does.

<u>Specification</u>
If correct batching and mixing procedures are followed for SFRC, suitable to the specific fibre and plant configuration, fibres will be dispersed homogenously throughout the concrete. If concrete batching and mixing is done in accordance with NZS3104, and the recommendations of the steel fibre manufacturer are followed, then engineers can have confidence that in-situ SFRC performance will meet their design requirements.

In some cases, particularly where fibres are used to reduce or replace structural steel, engineers may also wish to specify testing to confirm the required fibre dosage and distribution is being achieved.

<u>Suggested specification clause</u>

- Concrete to be supplied by a Ready-Mix plant complying with the requirements of NZS3104:2003 and holding a current certificate of audit from the Concrete NZ Plant Classification Scheme
- Steel fibre to be added and mixed into concrete according to manufactures recommendations.
- Any loads which show signs of fibre balling or inconsistent fibre distribution shall be rejected.
- (Optional – For Structural Applications not slab on grade) Washout tests to be performed in accordance with AS3600:2018.

Conclusions

As SFRC becomes more widely used throughout NZ, particularly in structural applications, it is crucial that SFRC production is quality controlled to ensure in-situ performance. The current New Zealand Standards do not adequately cover the quality control required for the production of SFRC, to ensure that the residual flexural tensile strengths used by engineers in their designs are produced.

In the absence of a New Zealand codified SFRC quality control standard, specifying engineers have had to rely on overseas standards such as EN 206 and AS3600/5100. These standards require the fibres to comply with either EN 14889-1 or ISO 13270 to ensure consistence and they also include additional quality control steps to ensure distribution.

On-site fresh concrete fibre distribution testing may not be a practicable method of ensuring compliance and specifying NZS3104 is an interim measure to assures acceptable homogeneity is achieved but clearly there is a case for a compliance scheme based on fibre distribution testing at the plant, which is representative of all SFRC produced by that plant.

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