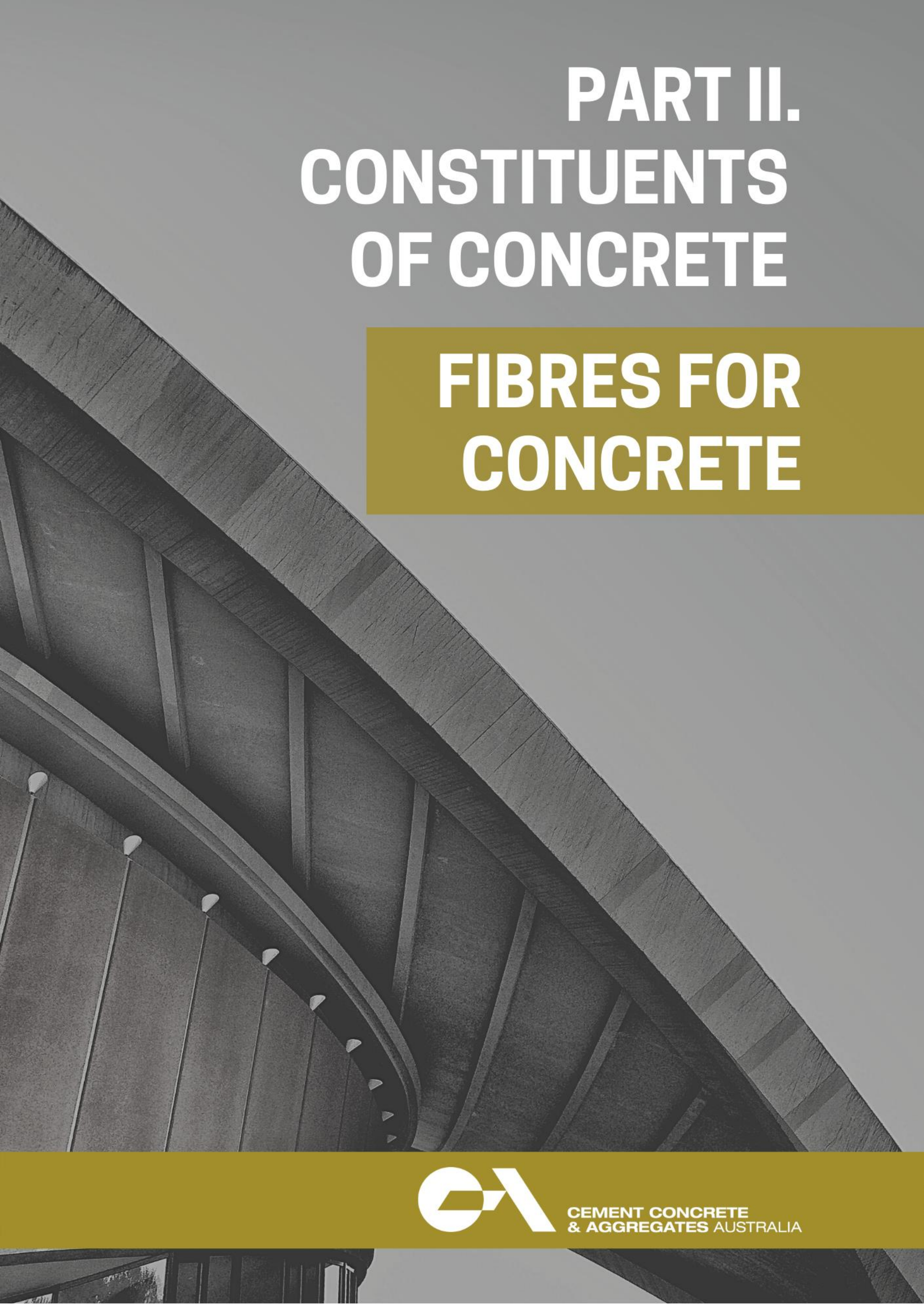

PART II. CONSTITUENTS OF CONCRETE

FIBRES FOR CONCRETE

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

CONTENTS

1. OUTLINE

Another form of reinforcement of concrete is available with the use of various types of fibres.

The more common forms of fibres currently available are discussed in this section but it must be noted that new forms of fibres, including variations from material used to manufacture the fibre, shape and size are being developed all the time.

The common broad material types used in fibres are discussed in this section including steel, various types of synthetic, glass, carbon and some natural fibres. Each of these materials will enhance concrete properties in various ways that are briefly discussed.

There are no current Australian Standards covering the specification of the fibre itself and so there is a reliance on reference to international standards. AS 3600 and AS 5100.5 do reference some aspects of the use of fibres in concrete but their scope is limited at present.

2. FIBRE TYPES AND SPECIFICATION

2.1 GENERAL

The history of the use of fibres to provide benefits to mortars or concrete dates back about 3,500 years with earliest use of various natural fibres to reinforce mud bricks in the Middle East. Asbestos fibres have been used in fibre/cement products for the last 100 years and cellulose fibres for the last 60 or more years. In the last 50 years steel fibres, synthetic fibres, carbon fibres, natural fibres and glass fibres have been used to improve concrete properties.

The properties of concrete that are being enhanced, to varying degrees, by different types of fibre include:

- Improved concrete plastic state cracking performance;
- Improved tensile or flexural strength or post cracking strength performance;
- Improved impact strength or toughness of a concrete structure;
- Cracking control by improved post-cracking ductility;
- Improved concrete durability in certain environments.

Most of these reasons for using fibres have already been discussed in Part I of this Guide and will not be covered in this section. This section will cover the types of fibres most commonly used in Australian concrete and where possible provide guidance on their specification for use in concrete.

2.2 STEEL FIBRES

Steel fibres are commonly described by Shape, Aspect Ratio, Length and Tensile Strength.

The aspect ratio of a fibre is defined as the length of the fibre divided by the average cross section diameter of the fibre.

Each fibre shape and length will have a maximum volume of fibre that can be added per cubic metre of concrete. In the case of steel fibres used in concrete containing normal quantities of coarse aggregate in the mix design, it is rare that steel fibre dose rate can exceed 1% by volume (approximately 80 kg per m^3). This is largely as a result of the effect of interference between fibres and coarse aggregate in the concrete mix and its impact on concrete mix workability. The typical doses of steel fibres range from 0.3% to 1% of the concrete volume. Higher doses of fibres may be used in some specialised concrete with little or no coarse aggregate.

Typical Properties of Steel Fibres

The steel fibre tensile strength, aspect ratio, length, shape and dose rate in the concrete mix all impact on the final hardened properties of concrete that contains these fibres as noted in Part I of this Guide. These and other properties of steel fibres are discussed in the following.

Tensile Strength and Elastic Modulus of Steel Fibres

Steel fibre tensile strength typically ranges between 800 MPa and 2,000 MPa. Each fibre type and source have their own design tensile strength. Measurement of steel fibre tensile strength is generally carried out in accordance with Euro or ASTM standards (e.g. ASTM A820 or EN 14889-1).

The elastic modulus of steel fibres is normally reported as approximately 200 GPa as per other normal forms of steel reinforcement. The failure strain of steel fibres varies with type of steel fibre but generally ranges from 3% to 5% extension.

Common Shapes and Aspect Ratios of Steel Fibres

There are many different shapes and aspect ratios associated with steel fibres. As a general rule it is rare for a steel fibre to have an aspect ratio greater than 80 where the dose rate of fibres is as high as 1% by volume of concrete but for lower dose rates the higher aspect ratios may be used. The commonly used steel fibres have aspect ratios between 30 and 80.

Some common shapes of steel fibres are indicated in **Figure 7.1**.

Specification of Steel Fibres

ASTM A820 or EN 14889-1 can be used to specify steel fibres.

ASTM A820 identifies five basic types of steel fibres based on their manufacture method:

- Type I, cold-drawn wire;
- Type II, cut sheet;
- Type III, melt-extracted;
- Type IV, mill cut;
- Type V, modified cold-drawn wire.

Each type of fibre can be either straight or deformed.

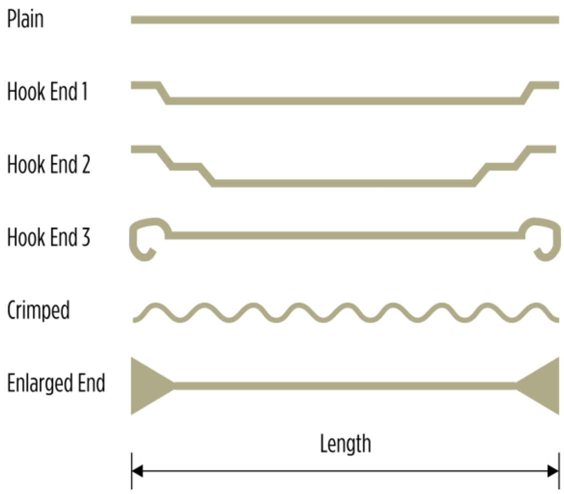

Figure 7.1 – Some Common Steel Fibre Shapes

Using this standard for steel fibres requires the fibres to be assessed for:

- Tensile strength (average tensile strength to exceed 345 MPa);
- Allowable variation in fibre dimensions and resulting aspect ratio;
- Bending test (fibres bent around a 3.2 mm pin to an angle of 90^{o} must not break in more than 10% of fibres in the sample).

EN 14889-1 *'Fibres for concrete, Part 1: Steel fibres - Definitions, specifications and conformity'* classifies steel fibres into five groups in a similar manner as ASTM A820. In the case of EN 14889-1 it has the following groups:

- Group I – Cold-drawn wire;
- Group II – Cut sheet;
- Group III– Melt extracted;
- Group IV – Shaved cold drawn wire;
- Group V – Milled from blocks.

For each group there are further characterisations by properties such as:

- Cross-section: Round, flat, crescent etc.;
- Deformations: Straight, wavy, end hook etc.;
- Length: ....19-60 mm;
- Aspect Ratio (length/diameter): 30-100;

- Tensile strength..........345-1,700 N/mm^2;
- Young´s modulus................205 kN/mm^2.

The properties of the fibres covered by EN 14889-1 include a requirement for the fibre supplier to advise the dose rate of fibres in kg/m^3 to achieve a residual flexural strength of 1.5 MPa at CMOD = 0.5 mm and/or a residual flexural strength of 1 MPa at CMOD = 3.5 mm when tested on a standard concrete mixture in accordance with the standard beam test (EN 14651 *'Test Method for Metallic Fibre Concrete - Measuring the Flexural Tensile Strength'*).

The CMOD or 'crack mouth opening displacement' has been mentioned previously in Part I of the Guide.

2.3 SYNTHETIC FIBRES

In Part I of the Guide it was noted that there are a number of materials used in producing fibres. There is also a large variety of dimensions and forms of synthetic fibres.

The key specifications for synthetic fibres used in concrete are:

- ASTM C1116 – *Standard Specification for Fiber -Reinforced Concrete;*
- EN 14889-2 – *Fibres for concrete, Part 2: Polymer fibres - Definitions, specifications and conformity.*

ASTM C1116 has relatively little range in definition/specification for synthetic fibres and relies on the impact of fibres on the properties of concrete containing a specific fibre. The classification for synthetic fibres is 'Type III – Synthetic Fiber Reinforced Concrete'. Properties of the fibre that are of concern are:

- Impact of concrete and admixtures on long term deterioration of the fibres (impact of moisture and alkalis in concrete);
- Impact of fibres on concrete consistency and water requirement;
- Impact of fibres on air entrainment of concrete;
- Impact of fibres on flexural tensile strength of the concrete tested in accordance with ASTM C1609.

The ASTM C1116 standard does note that fibres composed of polypropylene, polyethylene or nylon have demonstrated a suitable degree of durability in concrete.

EN 14889-2 provides more detail regarding the specification of the fibres themselves and identifies three general polymer (synthetic) fibre categories:

- Class 1a – Micro fibres – Monofilament with diameter less than 0.30 mm;
- Class 1b – Micro fibres – Fibrillated with diameter less than 0.30 mm;
- Class 2 – Macro fibres – Diameter greater than 0.30 mm.

EN 14889-2 defines 'polymer' as being composed of any of the following general synthetic materials or combinations of these:

- Polypropylene;
- Polyethylene;
- Polyester;
- Nylon;
- Polyvinyl alcohol (PVA);
- Poly-acrylic;
- Aramids.

EN 14889-2 also provides guidance on compliance of all classes of polymer fibres. The following set of properties can be specified:

- Class;
- Polymer type;
- Fibre shape and Aspect Ratio;
- Fibre length;
- Equivalent diameter of fibre;
- Linear density (of mono filament yarn) or density;
- Fibre shape;
- Tensile strength of fibre (largely Class 2);
- Tenacity class of fibre (Class 1a and 1b only);
- Modulus of elasticity of fibres.
- Melting point and point of ignition of fibres;
- Effect of fibre on consistency of concrete;
- Effect of fibre on strength of concrete.

Testing for these properties are generally specified using a relevant EN or ISO standard test method.

Typical Properties of Synthetic Fibres

Each type and class of synthetic fibre will have its own characteristic properties, and these may vary a little between different suppliers. The EN 14889-2 standard requires the supplier to verify compliance to the Standard as required for each fibre class as a degree of control over specified properties. For testing of fibres in concrete a standard concrete mixture is used in accordance with EN 14845-1. The testing of the effect of fibres on the standard concrete properties are carried out in accordance with EN 14845-2.

Some typical properties of fibres of differing types are provided in **Table 7.1**.

Table 7.1 – Typical Synthetic Fibre Properties (Class based on EN 14889-2)

Fibre Type & Class	Density (gm/cm^3)	Diameter (mm)	Elastic Modulus (GPa)	Tensile Strength (MPa)
Polypropylene – Class 1a	0.90 – 0.91	0.015 – 0.100	2 – 5	150 – 400
Polypropylene – Class 1b	0.90 – 0.91	0.030 – 0.100	4 – 5	300 – 500
Polyolefin – Class 2	0.91 – 0.97	0.8 – 1.1	5 – 14	470 – 690
Polyethylene HD – Class 2	0.96	0.9	5	200
Polyethylene HD – Class 1a	0.96	0.020 – 0.050	10 – 30	>400
PVA – Class 1a	1.30	0.003 – 0.015	12 – 40	700 – 1,500
Nylon – Class 1a	1.15	0.009 – 0.200	2 – 4	170 – 690
Aramid – Class 1a	1.20 – 1.45	0.010 – 0.015	70 – 130	2,900 – 3,500

The required synthetic fibre properties will vary between the various classes of fibre and this is discussed in regard to critical properties for its likely end use in the following.

Specified Properties for Class 1a Synthetic Fibres

Smaller diameter Monofilaments are most likely specified for use in structures where some of the following properties of concrete are expected to be improved:

- Reduced permeability;
- Increased impact resistance;
- Some reduction of spalling of concrete in a fire;
- Reduction in concrete plastic cracking.

The properties that may be more critical for specification of these fibres will most likely include:

- Fibre type and Class;
- Fibre length;
- Equivalent diameter of fibre;
- Tensile strength of fibre;
- Effect on consistency of plastic concrete at specified dosage.

Depending on the fibre use the fibre may also need to be assessed for the following:

- Plastic shrinkage reduction (e.g. to ASTM C1579);
- Assessment of specified dosage for reduction in spalling of concrete under fire testing using a specified concrete mix

(e.g. EN 1363-1, EN 1363-2 or ASTM E119);

- Testing of the permeability or impact resistance of concrete using test methods relevant to the end use of the concrete.

Specified Properties for Class 1b Synthetic Fibres

Smaller diameter fibrillated fibres are most likely specified for use in structures where some of the following properties of concrete are expected to be improved:

- Reduced permeability;
- Increased impact resistance;
- Reduction in concrete plastic cracking.

The properties that may be more critical for specification of these fibres will most likely include:

- Fibre type and Class;
- Fibre length;
- Equivalent diameter of fibre;
- Tensile strength of fibre;
- Effect on consistency of plastic concrete at specified dosage.

Other properties may be assessed as required and as noted for Class 1a fibres.

Specified Properties for Class 2 Synthetic Fibres

Macro synthetic fibres are most likely specified for use in structures where some of the following properties of concrete are expected to be improved:

- Improved residual tensile strength of hardened concrete;
- Increased impact resistance;
- Improved cracking control in pavements.

The properties that may be more critical for specification of these fibres will most likely include:

- Fibre type and Class;
- Fibre length;
- Equivalent diameter of fibre;
- Fibre shape and Aspect Ratio;
- Tensile strength of fibre;
- Effect on consistency of plastic concrete at specified dosage;
- Effect on strength of a standard concrete at CMOD = 0.5 mm and = 3.5 mm in accordance with EN 14889-2 or average residual strength (ASTM C1399), flexural toughness (ASTM C1609) and Flexural toughness factor (ASTM C1609) all carried out using the specified concrete mix.

Other properties may be assessed as required.

2.4 OTHER FIBRE TYPES

There are a number of other fibre types that either have more common use in specific concrete mixtures or are less commonly used. Examples of these include the following:

- Alkali resistant glass fibres;
- Basalt fibres;
- Carbon fibres;
- Asbestos fibres;
- Cellulose fibres ;
- Other 'natural' fibres.

Typical properties of some of these fibre types are provided in **Table 7.2**.

Specified Properties for Alkali Resistant Glass Fibres

Glass fibres for concrete have been developing over many years. In the late 1960's it was determined that the formulation of glass fibres needed to be modified to provide a high degree of alkali resistance to prevent the fibres from degrading in the highly alkaline environment of concrete or mortars. The original 'E-Glass' and 'A-Glass' fibre products are not suitable for use in concrete.

Glass fibres are more generally used in the pre-casting of specific types of light weight building and architectural elements in Australian construction.

The commonly specified properties of glass fibres for use in concrete include:

- Type of fibre (Alkali Resistant);
- Length of fibre ;
- Diameter of fibre;

- Density;
- Tensile Strength;
- Strain at failure.

There are no Australian standards providing guidance on glass fibres for use in concrete, but a useful document is provided by the National Precast Concrete Association of Australia *'A Recommended Practice: Design, Manufacture and Installation of Glass Reinforced Concrete (GRC)'*. In addition, there are international standards such as ACI 544.1R *'Report on Fibre Reinforced Concrete'* along with ASTM C1116, European Standard EN 15422 *'Precast concrete products – Specification of glass fibres for reinforcement of mortars and concretes'* and EN 1169.

Specified Properties for Carbon, Mineral-Based and Natural Fibres

This group of fibres are less commonly used in Australia and there are no Australian standards providing guidance on any of these.

It will depend on the expected properties of the concrete containing these fibres as to the critical properties of the fibres that will need to be assessed.

AC I544.1R *'Report on Fibre Reinforced Concrete'* provides useful information on the likely fibre properties and their use. Guidance on the properties of these fibres and their impact on concrete will need to be provided by the supplier on an individual basis.

Table 7.2 – Typical Properties of Some Other Fibre Types Used in Concrete

Fibre Type	Density (gm/cm^3)	Diameter (mm)	Elastic Modulus (GPa)	Tensile Strength (MPa)
A R Glass fibre	2.68 – 2.74	0.013 – 0.020	72 – 74	1,400 – 3,500
Basalt fibres	2.63 – 2.80	0.007 – 0.013	93 – 110	4,100 – 4,840
Carbon fibres	1.16 – 1.95	0.007 – 0.018	30 – 600	600 – 6,000
Asbestos fibres	2.55	0.0002 – 0.030	164	200 – 1,800
Cellulose fibres	1.5	0.020 – 0.120	10 – 50	300 – 1,000

3. REFERENCES

1) AS 3600 – *Concrete structures*
2) AS 5100.5 – *Australia Bridge design, Part 5: Concrete*
3) ACI 544.1R-96 – *Report on Fibre Reinforced Concrete* (American Concrete Institute)
4) ASTM A820-16 – *Standard Specification for Steel Fibers for Fiber-Reinforced Concrete*
5) ASTM C1116-10 – *Standard Specification for Fiber-Reinforced Concrete*
6) ASTM C1399-10 – *Standard Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete*
7) ASTM C1579-13 – *Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)*
8) ASTM C1609-19 – *Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)*
9) ASTM E119-19 – *Standard Test Methods for Fire Tests of Building Construction and Materials*
10) EN 1169 – 1999 – *Precast Concrete Products – General Rules for Factory Production Control of Glass-Fibre Reinforced Cement*
11) EN 1363-1 – 2012 – *Fire Resistance Tests Part 1: General Requirements*
12) EN 1363-2 – 1999 – *Fire Resistance Tests Part 2: Alternative and additional procedures*
13) EN 14845-1 – 2007 – *Test Methods for Fibres in Concrete Part 1: Reference Concretes*
14) EN 14845-2 – 2006 – *Test Methods for Fibres in Concrete Part 2: Effect on Concrete*
15) EN 14889-1 – 2007 – *Fibres for concrete, Part 1: Steel fibres - Definitions, specifications and conformity*
16) EN 14889-2 – 2007 – *Fibres for concrete, Part 2: Polymer fibres - Definitions, specifications and conformity*
17) EN 15422 – 2008 – *Precast Concrete Products – Specification of Glass Fibres for Reinforcement of Mortars and Concrete*
18) National Precast Concrete Association of Australia, *'A Recommended Practice: Design, Manufacture and Installation of Glass Reinforced Concrete (GRC)'* (NPCAA – 2006)

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