"Concrete Reinforcement for a Sustainable Future".

Tunnelling With BarChip Macro Synthetic Fibre Concrete Reinforcement

www.barchip.com

BarChip Inc.
The Synthetic Fibre Experts


“Make The Change
To A Better
Reinforcement
System”

BarChip Inc. has a simple vision – revolutionise the world of concrete reinforcement.

For over 100 years the technology behind concrete reinforcement has barely changed.

It's expensive.

It suffers from corrosion.

It's time consuming and labour intensive.

It's dangerous to install.

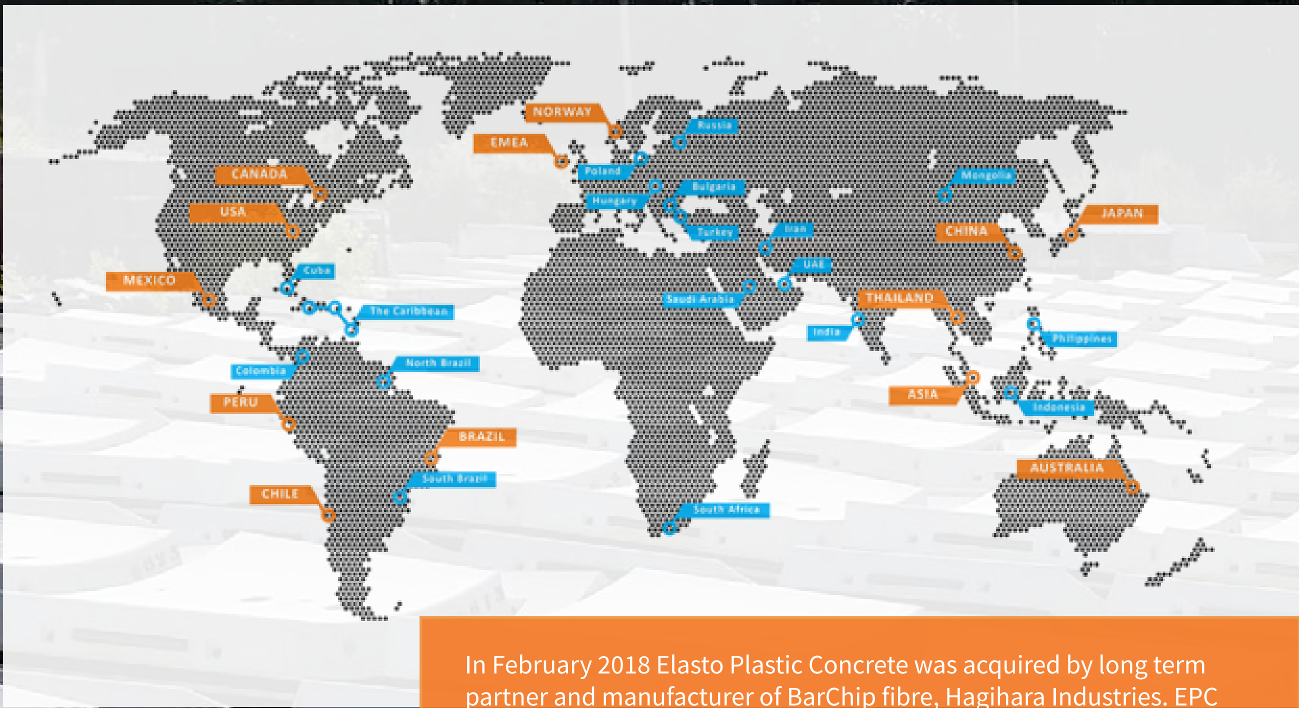
Our BarChip synthetic fibre concrete reinforcement is cheaper, tougher, safer, longer lasting and more environmental friendly than any known reinforcement system.

The time of expensive, high maintenance steel reinforcement is over. Join thousands of companies already using the macro synthetic fibre concrete reinforcement system and make the change to a better reinforcement today.

BarChip®
Synthetic Reinforcing Fibre

Replacing Steel Reinforcement in Concrete.

About BarChip Inc.



In February 2018 Elasto Plastic Concrete was acquired by long term partner and manufacturer of BarChip fibre, Hagihara Industries. EPC was subsequently rebranded BarChip Inc. in July 2018.

BarChip Inc. combines the world class plastics technology capabilities of Hagihara Industries and the industry leading concrete technology expertise of EPC under one roof.

BarChip Inc.'s Yoshiaki Hagihara;

"We believe that we must always continue to evolve, to become a valuable company for the sake of society and mankind. Through the economic, engineering performance and environmental benefits delivered by BarChip reinforcement, we can increase our positive impact on society. BarChip has been built on the promise of high performance, manufacturing quality and above all customer service. BarChip Inc. will continue to uphold these values."

Our **Services**

BarChip is a solutions provider, not just a fibre supplier.

Design Support

Ensuring Correct Standards
Specification Requirements
Determining Performance Requirements
Structural Design
Finite Element Analysis
Design Manuals

Mix Design Support

Aggregate Proportioning
Additive and Admixture Selection
Batching Process Support
Batching Audits
Guidance on Slump and Workability Adjustments for FRC

Application Support

EFNARC Nozzleman Certification
Nozzleman Review
Equipment Review
Process Review
Guidance on Finishing Techniques

Quality Control

Equipment Review
Sampling
Testing Programs
Process Review
Analysis of Test Results

BarChip Inc.
The Synthetic Fibre Experts

www.barchip.com

What is BarChip Synthetic Fibre?






BarChip synthetic fibre is a high performance polypropylene fibre used as structural reinforcement in concrete and shotcrete.

The BarChip reinforcement system works by distributing hundreds of thousands of high tensile strength fibres throughout the entire concrete mix, each one stronger than steel and bonded to the cement matrix. They reinforce every part of the concrete structure, front to back and top to bottom, leaving no vulnerable unreinforced concrete cover

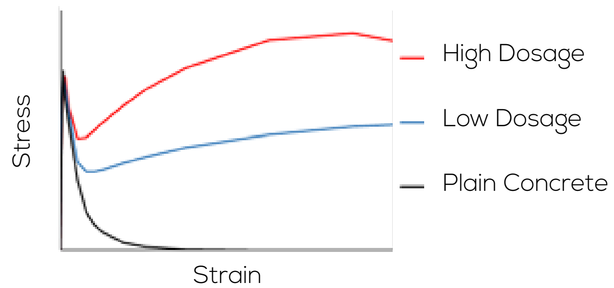
The BarChip reinforcement system is engaged at the exact point it's needed, reducing the onset of micro cracking, preventing crack propagation and minimising crack widths. The end result is a concrete structure that is more durable, more ductile and faster to produce.

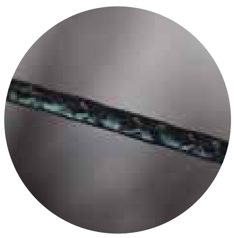
The latest advances in polymer technology, engineering design and manufacturing techniques have been incorporated into BarChip synthetic fibres to deliver a concrete reinforcement that is unequalled in usability, durability and service performance.

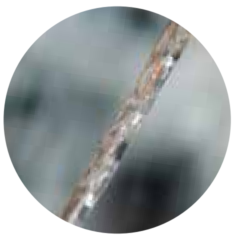
BarChip Fibre Benefits

- Redistributes load - increased ductility / toughness
- Eliminates corrosion - long term durability
- Reduces maintenance costs and rehabilitation closures
- Eliminates set-up of steel mesh
- Up to 70% reduction in carbon footprint compared to steel
- Safer and lighter to handle than steel
- Reduces wear on concrete pumps and hoses
- Reduces development cycle times
- Is UV stabilised to resist solar deterioration
- Comes in weather proof packaging on multi-stack UPVC pallets

BarChip synthetic fibre increases the post crack flexural capacity of concrete and can be used to replace steel reinforcement in concrete.







Product Features (see PDS and SDS at www.barchip.com for more details)

Characteristic	BarChip 48	BarChip 54	BarChip 60	BarChip R65	Standard
Fibre Class II	For structural use in concrete, mortar and grout				EN 14889-2
Tensile Strength	640 MPa	640 MPa	640 MPa	640 MPa	JIS L 1013/ISO 2062
Young's Modulus	12 GPa	12 GPa	12 GPa	12 GPa	JIS L 1013/ISO 2062
Anchorage	Continuous Embossing				
Base Material	Virgin Polypropylene			Virgin and Recycled Polypropylene	
Alkali Resistance	Excellent				
Length	48 mm	54 mm	60 mm	65 mm	
Fibres per kg	59,520	37,040	33,330	26,990	
Reinforcing Length	2,857 m/kg	2,000 m/kg	2,000 m/kg	1,754 m/kg	
CE Certification	0120 - GB10/79678				
ISO 9001:2008 Certification	JKT0402914				

BarChip Applications

BarChip synthetic fibre reinforcement is used as the primary reinforcement in nearly every type of concrete application. Each one of our BarChip fibres is designed for a specific concrete application, ensuring you get the highest possible performance at the lowest possible dose rate.

BarChip synthetic fibre has been safely used to reinforce over 130 road, rail and utility tunnels.

BarChip Synthetic Fibre Delivers Results:

- **50%** Increase in Precast Production Speeds
- **25%** Increase in Sprayed Concrete Application Speed
- **40%** Reduction in Precast Concrete Costs
- **60%** Reduction in Equipment Maintenance
- **100%** Reduction in Corrosion
- **80%** Reduction in Fibre Handling Costs
- **50%** Increase in Daily Floor Completion Rates
- **70%** Reduction in Carbon Footprint

BarChip Inc.
The Synthetic Fibre Experts

BarChip
Synthetic Reinforcing Fibre

Safely Supporting Over 5,000 km of Sprayed Concrete Ground Support, Including;

Atlantic Subsea Tunnel, Norway
Caldecott 4th Bore, USA
Helsinki Metro West, Finland
Cheves Hydro Power, Peru
North Strathfield Rail Underpass, Australia

The Only Synthetic Fibre To Completely Replace Steel Reinforcement in Precast Segmental Tunnel Linings. Projects include;

Malaga High Speed Rail, Spain
Harefield to Southall Gas Pipeline, UK
São Paulo Metro Line 5, Brazil
Santona Laredo Subfluvial Tunnel, Spain

Replaces Steel Reinforcement in Cast In-Situ Tunnel Linings, including;

Oliola Water Tunnel, Spain
El Regajal High Speed Rail, Spain
Legacy Way Road Tunnel, Australia
Euclid Creek Storage Tunnel, USA

Increasing the Durability and Performance of Concrete Track Slab, including;

Docklands Light Rail, UK
Szeged Electrified Tramway, Hungary
Bukit Berapit, Malaysia
Shinkansen, Japan

Best Practice For Testing Fibre Reinforced Concrete

Testing Fibre Reinforced Concrete

The cross-sectional failure mode of a typical beam test with a single crack does not reflect the behaviour in a shotcrete lining, but is suitable for most civil concrete structures.

The performance of fibre reinforced concrete ***is generally determined with a simply supported beam test***, such as

- ASTM C1609
- EN 14651

Simply supported beam tests are typical for applications such as precast tunnel segments, cast in-situ linings and rail track slabs.

1. The beam test yields a stress-strain relationship for a small deformation range and provides data for service considerations.
2. The beam test is statically determinate and provides basic values for design.
3. The beam test produces a single crack which develops and eventually leads to failure due to strain localisation.
4. The failure mode of a beam test is a cross-sectional failure.

A beam test is a low deformation test (up to 4 mm central displacement) and thus, does not provide information for larger displacements that can be found in sprayed concrete linings.

Testing Fibre Reinforced Shotcrete

A panel test is the most suitable test for sprayed concrete as it is statically indeterminate, allows for multiple cracking and most accurately represents a shotcrete lining

The performance of fibre reinforced shotcrete ***should always be measured using a panel test***. Recognised tests are;

Continuously Supported Panel:

- EFNARC
- SIA 162/6
- NB7
- EN 14488-5

Round Determinate Panel:

- ASTM C1550

Toughness, or energy absorption capacity, is the first and most basic requirement for fibre reinforced shotcrete in order to provide sufficient performance data at larger deformations. For sprayed concrete linings, a panel test which measures energy absorption is the more relevant test method to represent the working and failure mechanism of a fibre reinforced shotcrete lining.

Panel tests are statically indeterminate (hyperstatic), just as the lining itself is, allowing stress redistribution and multiple cracking and thus, represent the structural behaviour of the fibre reinforced shotcrete lining significantly better than a simply supported beam.

Panel tests have a significantly lower variability than beam tests because a much larger cumulative crack length develops. As such the meaningfulness and the reliability of panel testing is much higher and requires fewer specimens per set to yield reliable results.

For more information, download BarChip Technical Note:
Best Practice for Testing Fibre Reinforced Shotcrete

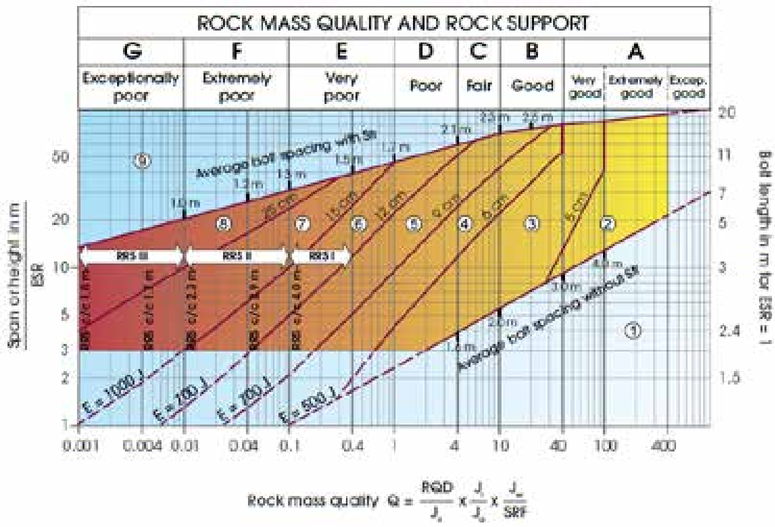
BarChip Inc.
The Synthetic Fibre Experts

Design of Fibre Reinforced Shotcrete and Concrete

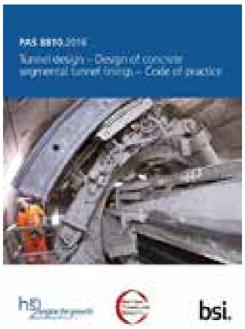
The design of fibre reinforced shotcrete linings is largely based on energy absorption capacity in ultimate limit state (ULS) obtained from panel test results. Multiple bodies have developed guidelines or standards for the use of fibre reinforced shotcrete;

- EFNARC
- NB7
- EN 14487
- EN 14488
- ACI 506.1R
- Shotcreting in Australia 2nd Edition

Internationally the most common design approach is based on the Q-System developed and expanded upon by Barton and co-workers over many years.



Permanent support recommendations based on Q-values and span/ESR with correlating energy absorption requirements as based on panel testing.



2016 saw the release of multiple guidance documents for the design of fibre reinforced segmental tunnel linings.

- ITA's ITAtech Guidance for Precast Fibre Reinforced Concrete Segments Vol 1 Design Aspects
- ITA's WG 2 Twenty years of FRC Tunnel Segment Practice: Lessons learnt and proposed Design Procedure
- BSI's PAS 8810 Tunnel Design – Design of Concrete Segmental Tunnel Linings – Code of Practice

The performance specifications in these design guidance documents are based on beam testing.

Commonly, N-M interaction diagrams are used to analyse the moment capacity of fibre reinforced concrete linings.

For special cases BarChip's experienced team can provide detailed finite element analysis (FEA) for our synthetic fibre reinforced segments, which prove performance over the entire life of the structure.

FE Analysis of the Harefield to Southall gas transfer tunnel.

BarChip
Synthetic Reinforcing Fibre

Are You Meeting Your Low-Carbon Economy Targets?

The European commission on climate action has set in place a low carbon economy road map that suggests;

- By 2050, the EU should cut greenhouse gas emissions to 80% below 1990 levels
- Milestones to achieve this are 40 % emissions cuts by 2030 and 60% by 2040
- All sectors need to contribute

BarChip Synthetic Fibres Reduce Your Carbon Footprint.

Carbon Case Study - Permanent Sprayed Concrete Lining

Research has shown that SFRS cannot be expected to achieve a service life of 120 years in aggressive environments (Nordström 2016). To achieve this service life significant rehabilitation works need to be performed which would greatly increase the carbon footprint of the project. BarChip has analysed this carbon footprint for a nominal 8.5 m wide by 6.5 m high 50 km tunnel.

Steel Fibre kg CO_2e	Rehabilitation Concrete 2 x 25% (kg CO_2e)*	Rehabilitation Steel 2 x 25% (kg CO_2 e)*	Total CO_2 over 120yrs (kg CO_2e)
6,973,670	22,422,881	3,486,834	32,883,385

BarChip Fibre kg CO_2e	Rehabilitation Concrete	Rehabilitation Steel	Total BarChip (kg CO_2e)	**Total Carbon Saving (kg CO_2e)**
1,414,022.40	Not Required	Not Required	1,414,022.40	**31,469,363**

*Research by Nordström (2016), E., 2016. "Evaluation after 17 years with field exposures of cracked steel fibre reinforced shotcrete". Rock Engineering Research Foundation, BeFo Rapport 153 Stockholm, ISSN 1104-1773 (in Swedish)

A savings potential of **31,469,363 kg** of embodied carbon exists over 50 km of tunnelling works, simply by switching to BarChip synthetic fibre reinforcement. That's equivalent to;

6,647

Passenger cars driven for one year.

9,987

Tonnes of waste recycled instead of land filled.

4,647

Homes electricity use for one year.

72,858

Barrels of oil consumed.

815,565

Tree seedlings grown for 10 years

251

Acres of forests preserved from conversion to cropland for one year

BarChip Synthetic Reinforcing Fibre

How much carbon would you save by choosing BarChip synthetic fibre reinforcement?

“Environmentally Friendly Concrete Reinforcement”

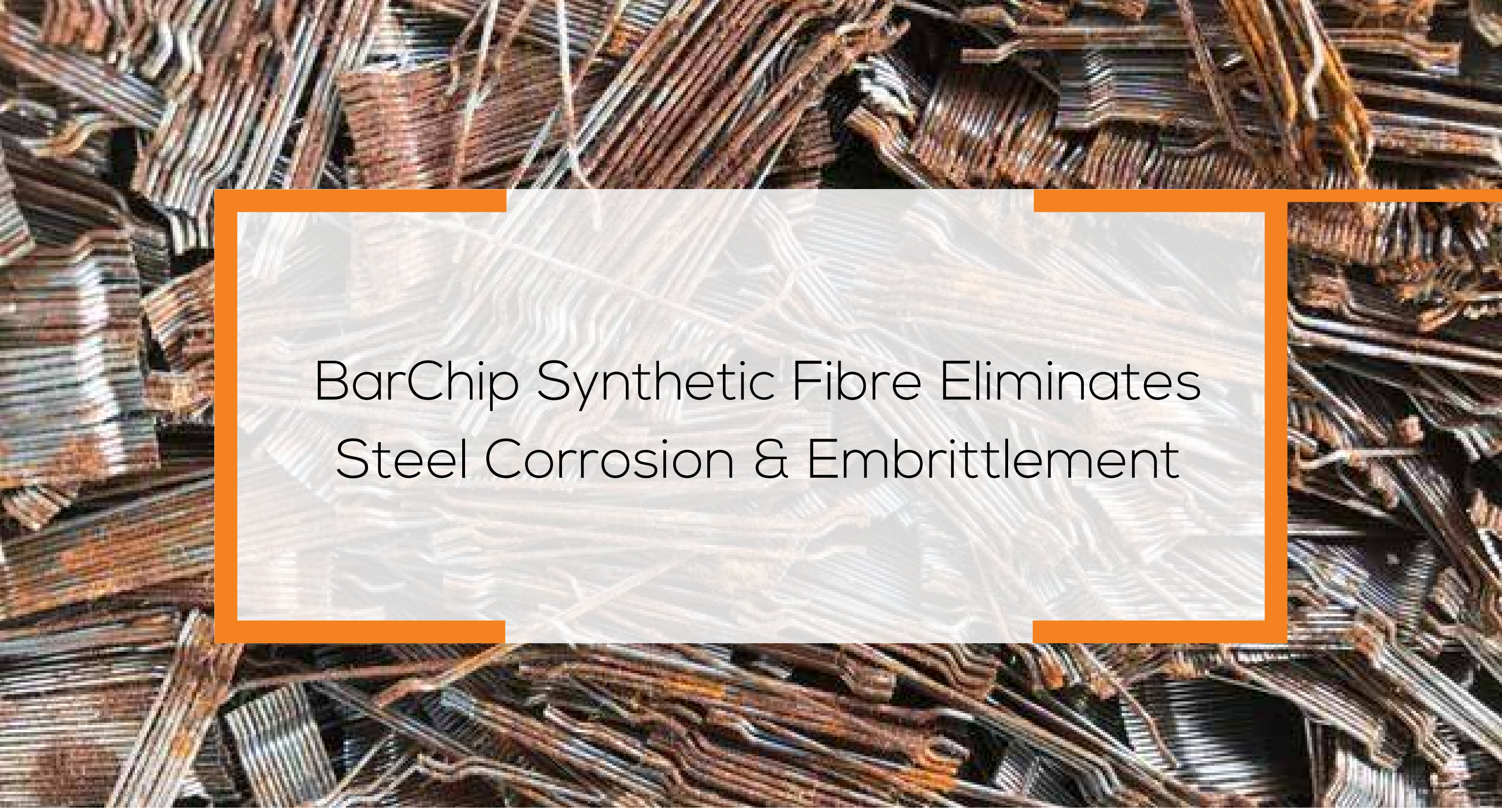
BarChip Inc.

The Synthetic Fibre Experts

BarChip
Synthetic Reinforcing Fibre

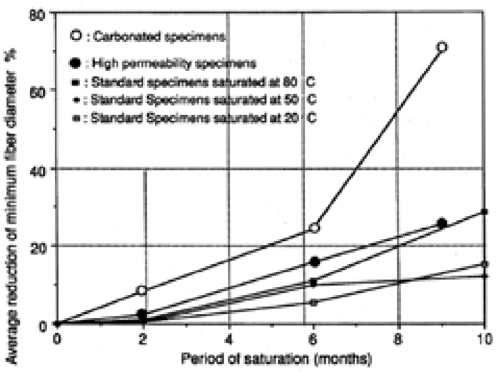
When Performance Matters, Choose BarChip

www.barchip.com

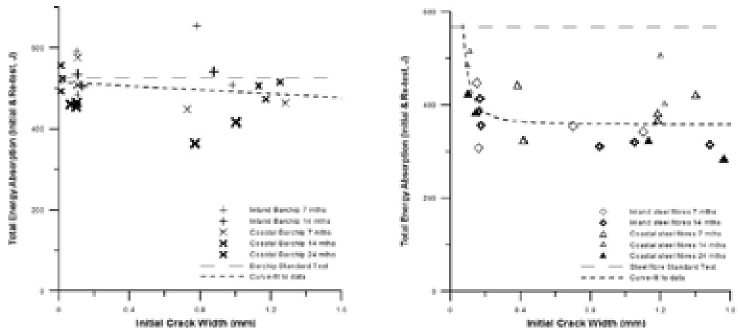


BarChip Synthetic Fibre Eliminates Steel Corrosion & Embrittlement

Corrosion in steel fibre reinforced concrete leads to a loss of fibre cross section, which causes a rapid loss of post crack performance.

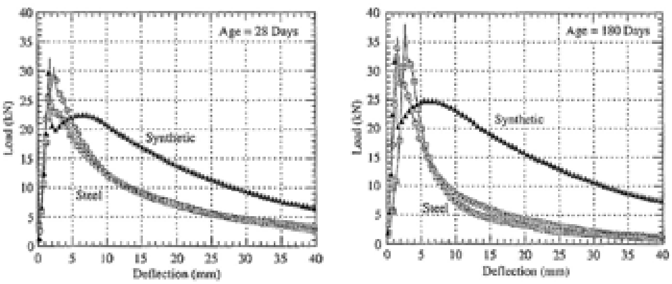


Relationship between the average reduction of minimum fibre diameter and saturation period for the flexural specimens (Kosa and Naaman, 1990).

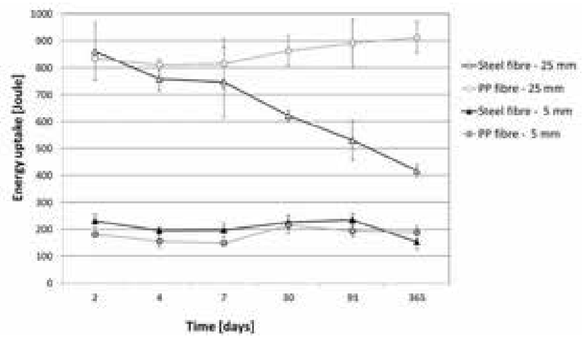


Post crack performance of BarChip macro synthetic fibre reinforced shotcrete is not affected by exposure or corrosion, however steel fibre reinforced shotcrete suffers a substantial loss in performance after just 7 months (Bernard, 2004).

Late age strength gain in concrete results in a brittle, snapping failure of steel fibre, a process known as embrittlement.



DiNoia and Rieder (2004) – "As age increases from 7 to 180 days, the drop-off in load bearing capacity as a function of deflection occurs more rapidly with increasing age… At 180 days, the drop-off in load bearing capacity is very dramatic (for steel fibre reinforced shotcrete)".



Energy uptake up to 5mm and 25mm displacement vs. time (Bjontegaard et al., 2014)

References can be found in BarChip Technical Note: [*Durability and Long Term Performance of Fibre Reinforced Concrete.*]

Durability of Fibre Reinforced Concrete - The Facts

Over 40 years of published research supports a simple fact;

"...it is not realistic to expect a service life of 100 years...in aggressive environments with steel fibre" (Nordström 2016).

1. High quality polypropylene macro synthetic fibres, such as BarChip, do not suffer from the effects of corrosion and maintain performance regardless of known exposure conditions, even in large crack widths;
2. Uncracked steel fibre reinforced concrete specimens are largely unaffected by corrosion, however once cracks are formed, performance deterioration as a result of corrosion is rapid;
3. Steel fibre corrosion results in a loss of fibre diameter at the crack opening. The rate and amount of corrosion increases as the crack width increases;
4. Crack widths greater than 0.10 mm lead to significant rates of deterioration of steel fibre as a result of corrosion, because the crack width affects the time of corrosion initiation;
5. Corrosion of steel fibre reinforcement results in a significant change of the failure mode, changing from a ductile pull out failure to a brittle snapping failure, causing rapid loss of toughness. This is referred to as ***corrosion induced brittle failure***;
6. Embrittlement of steel fibre reinforced concrete occurs due to late-age strength gain, causing the bond between the concrete matrix and the fibre to exceed the fibres' tensile strength, changing the failure mechanism from a ductile pull out to a brittle failure caused by rupturing of the fibres. This is referred to as ***embrittlement induced failure***;
7. Embrittlement has been shown to occur as early as 30 days of age and in concrete with nominal strength as low as 40 MPa, and has been shown to reduce post-crack performance by as much as ***50%***;
8. High quality macro synthetic fibres, such as BarChip, are not affected by late age concrete strength gain. In contrast they show improved performance with age and strength gain. However, one study indicates that low quality synthetic fibres may be affected by embrittlement effects;
9. BarChip fibres can be used as an alternative to steel reinforcements with significant associated benefits such as improved durability, reduced costs and increased sustainability.

Cracking in concrete leads to a loss in fibre diameter due to corrosion. A 30% loss can occur in as little as 10 months, resulting in a 50% decrease in performance.

BarChip synthetic fibres will never suffer from the effects of corrosion.

The effects of embrittlement on long term performance can be even more severe than corrosion.

For more information, download BarChip Technical Note: [Durability and Long Term Performance of Fibre Reinforced Concrete.]

BarChip
Synthetic Reinforcing Fibre

BarChip Synthetic Fibre Reinforced Shotcrete

Delivers Many Safety Advantages

Beyond Just Rock Fall and Rock Burst Risk Reduction

Rock bursts and rock falls have always been the most challenging safety hazard in underground mining operations, often resulting in the most serious consequences. Layout, regional support, exclusion zones, remote equipment and specified working procedures are all methods used to lower risks on site, however adequate ground support is still the most effective in-situ method for controlling the risk of rock fall.

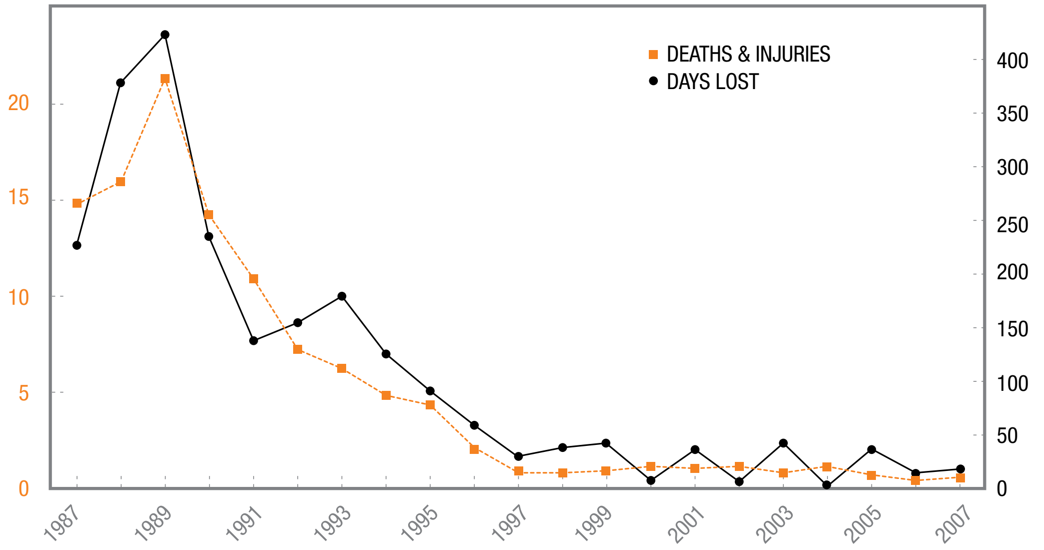
Fibre reinforced shotcrete is widely recognised as the most effective means of rock support due to it's speed of delivery, economy, safety and durability. The graph below shows the reduction in fatalities, injuries and working days lost on site in Australia since fibre reinforced shotcrete was introduced in the early 1990's.

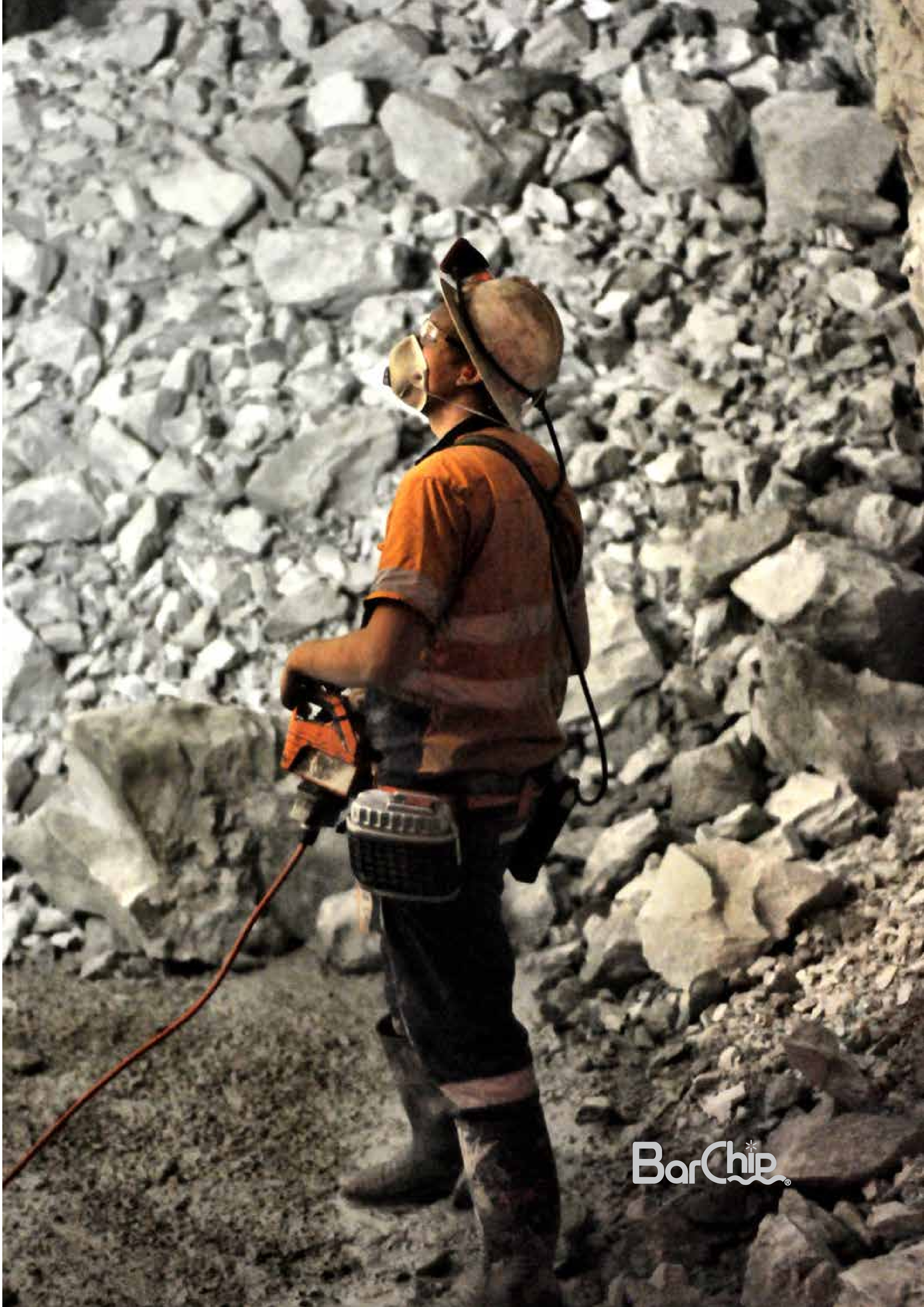
BarChip synthetic fibre reinforced shotcrete delivers many safety advantages beyond just rock fall and rock burst risk reduction.

BarChip fibre:

- Removes the need for workers to operate under unsupported ground
- Eliminates risk of failure due to corrosion or embrittlement
- Enables controlled movement
- Allows for large displacements in critical ground conditions
- Allows for visual inspection of problem areas
- Decreases the risk of equipment damage or injury from rebound
- Decreases the risk of injury from manual handling and placement of mesh
- Reduces the risk of spalling

*Measurements are per million hours worked





Both Steel and Synthetic FRC Structural Elements

Would Satisfy Serviceability Requirements

Found In Most Reinforced Concrete Structural Designs

Creep is a material property to deform permanently under sustained loads. It occurs as a result of long term exposure to levels of stress that are below the yield strength of the material.

Creep of FRC may occur when a cracked FRC section is subject to tensile stresses that are sustained for a significant amount of time. Macro synthetic FRC (MSFRC) generally exhibits larger tensile creep strain than steel FRC (SFRC) when subject to sustained tensile stresses, at least across narrow cracks in mature concrete *(Mackay & Trottier 2004)*.

Mackay J. & Trottier J.-F. 2004, state that;

“While cracked synthetic FRC can be expected to experience larger total creep deflections than cracked steel FRC, the difference is not large. For the bulk of FRC applications, synthetic FRC can be used to replace steel FRC with no adverse affects due to creep”. They further state that, “test data seems to indicate that both steel and synthetic FRC specimens would satisfy serviceability requirements found in most reinforced concrete structural designs”.

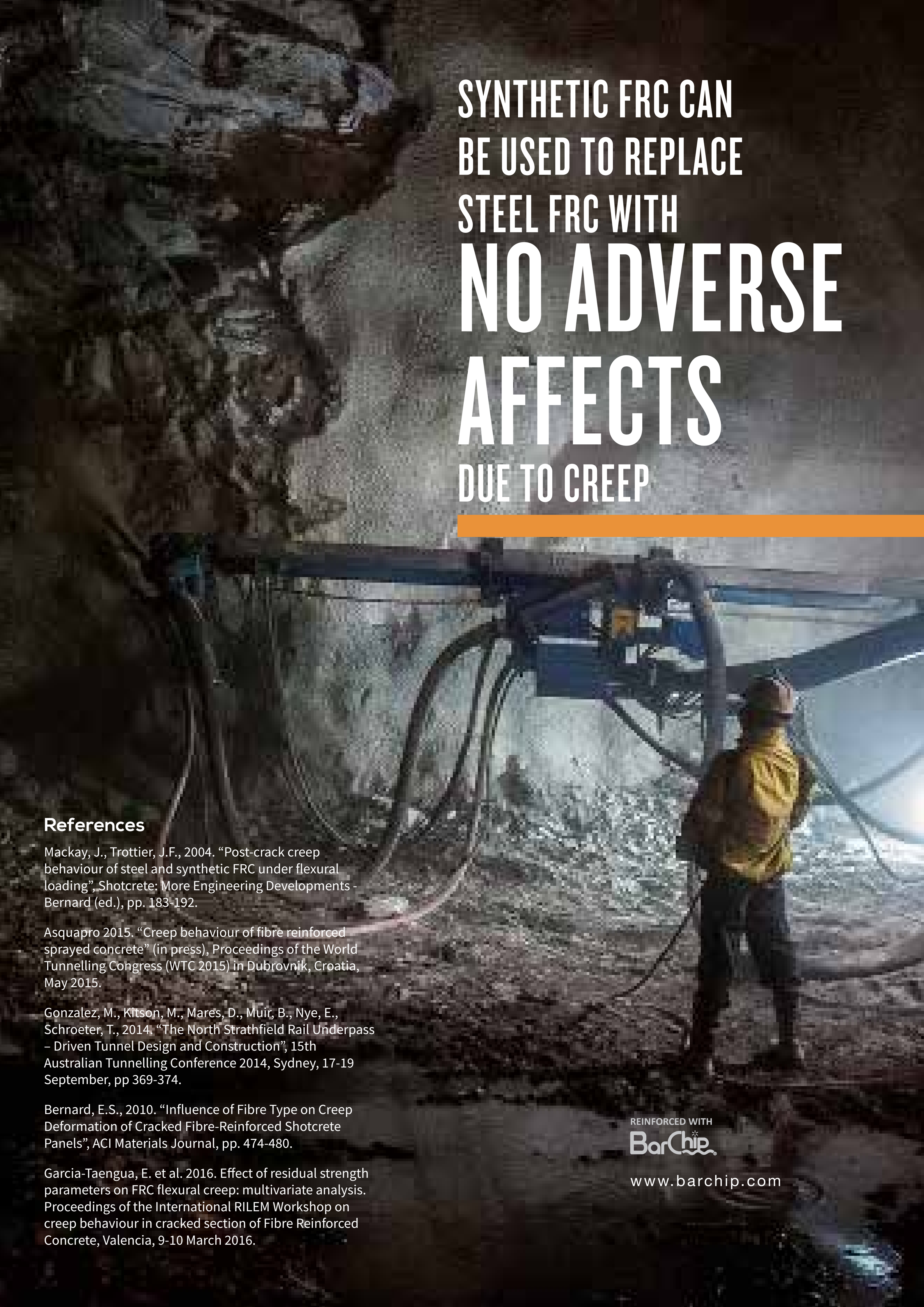
While the isolated magnitude of creep is greater for macro synthetic fibre than for steel fibre, the creep coefficient of the composite is still well within acceptable limits and just as importantly MSFRC does not suffer creep rupture but stabilises in the long term like steel fibre so that isolated fibre creep becomes insignificant *(Asquapro 2015)*.

Once stabilised, the dominant mode of FRC creep is then due to fibre pull-out, which is the same characteristic that occurs in steel FRC sections. At this stage the creep deformations of both macro synthetic and steel FRC are the same (*Bernard 2010, Mackay & Trottier 2004)*.

Current research and experience shows that macro synthetic fibres can be used as the sole reinforcement of temporary and permanent linings when they are subject to moderate bending moments in combination with sustained axial loading, such as that which occurs in an arch shotcrete lining *(Gonzalez et al. 2014)*.

A multivariate analysis of experimental results from more than one hundred FRC prismatic specimens tested under sustained flexural loads for at least 90 days has been carried out within the frame of RILEM TC 261-CCF: Creep behavior in Cracked Sections of Fiber Reinforced Concrete. The results reveal that differences in fibre material do not play a direct determining role on the response of cracked FRC sections under sustained flexural loads. Rather, their influence is on the flexural toughness of the material, which in turn affects the creep response *(Garcia-Taengua, E. et al. 2016).*

Providing an enormous energy absorption capacity or flexural toughness, macro synthetic fibres are a more cost effective and durable alternative to conventional steel and steel fibre reinforcement.



SYNTHETIC FRC CAN BE USED TO REPLACE STEEL FRC WITH NO ADVERSE AFFECTS DUE TO CREEP

References

Mackay, J., Trottier, J.F., 2004. “Post-crack creep behaviour of steel and synthetic FRC under flexural loading”, Shotcrete: More Engineering Developments - Bernard (ed.), pp. 183-192.

Asquapro 2015. “Creep behaviour of fibre reinforced sprayed concrete” (in press), Proceedings of the World Tunnelling Congress (WTC 2015) in Dubrovnik, Croatia, May 2015.

Gonzalez, M., Kitson, M., Mares, D., Muir, B., Nye, E., Schroeter, T., 2014. “The North Strathfield Rail Underpass – Driven Tunnel Design and Construction”, 15th Australian Tunnelling Conference 2014, Sydney, 17-19 September, pp 369-374.

Bernard, E.S., 2010. “Influence of Fibre Type on Creep Deformation of Cracked Fibre-Reinforced Shotcrete Panels”, ACI Materials Journal, pp. 474-480.

Garcia-Taengua, E. et al. 2016. Effect of residual strength parameters on FRC flexural creep: multivariate analysis. Proceedings of the International RILEM Workshop on creep behaviour in cracked section of Fibre Reinforced Concrete, Valencia, 9-10 March 2016.

BarChip Inc.
The Synthetic Fibre Experts

Precast Segments

Santoña - Laredo Subfluvial Water Tunnel, Spain

Project Details

In order to protect significant ecological marshlands from urban sprawl a new wastewater pipeline is being constructed in northern Spain. The objective of the project is to collect and transport wastewater from multiple municipalities to existing treatment facilities for environmentally friendly processing and disposal. Incorporated in the infrastructure project is a 1.5 km, 4.3 m diameter TBM driven tunnel.

Design Details

The 1.5 km long segmentally lined tunnel is driven by a 4.3 m diameter TBM. The EPB machine used for construction has a maximum thrust of 16,725 kN. The universal rings have a 5 + 1 segmentation and a length of 1.2 m Internal diameter of the lining is 3.5 m with a thickness of 250 mm.

The segment reinforcement consists of 5 kg/m^3 of BarChip48 structural synthetic fibre. 16 kg/m^3 of steel bar, as additional bursting reinforcement, is placed at the jacking face and the radial joints of the segments. The steam cured segments have a characteristic compressive strength of 45 MPa.

Project Benefits

Originally the segments were reinforced with 95 kg/m^3 of rebar cages. Switching to BarChip fibre reinforcement eliminated more than 80% of the steel reinforcement. Aside from the direct cost advantages, the switch to barChip fibre eliminated the rebar cage and its inherent labour and reduced production cycle times by nearly 50%.

Contact your nearest BarChip representative for more information about this project or the cost savings achieved by using BarChip synthetic fibre (see table opposite).

Original Reinforcement Design

BarChip Synthetic Fibre Reinforcement Design

Easily Demoulded and Transported

Stacking and Storage

Precast Segment Cost Comparison

Macro Synthetic Fibre vs. Steel Fibre Reinforcement

BarChip
Synthetic Reinforcing Fibre

40% Cost Reduction With BarChip Synthetic Fibre

The below table supplied by the contractor of the Santoña Laredo Water Tunnel shows that a saving of 40% was achieved on the segmental lining cost with BarChip synthetic fibre reinforcement system.

Number of Rings in Project	Segment / Ring	m^3 of Concrete / Ring	Segmentation
1,218	6	3.534	5 + 1
1) BarChip Fibre Reinforced Segments			
	Unit Cost / m^3	m^3 / Ring	Cost / Ring
C45/55 with BarChip Synthetic Fibre Reinforcement System	€ 115	3.534	€ 406.41
Rebar: Bursting ladders	€ 1.1 / kg	16 kg /m^3	€ 62.20
	Man-hours / Ring	Cost / Hour	
Labour to place bursting ladders	0.25	€ 25	€ 6.25
	Percentage	Segments for Repair	
% of segments requiring major repairs	0.5%	36.54	
	Man-Hours / Segment	Cost / Hour	
Labour for repair	3	€ 25	€ 13.5
Cost of craneage in/out repair areas	1	€ 25	€ 4.5
Administration/QC costs	1	€ 50	€ 9
	Cost / Segment	Total Cost	
Cost of repair materials	€ 4.17	€ 152.25	€ 0.75
Total Cost/Ring			**€ 502.61**
2) Rebar Cage Reinforced Segments			
	Unit Cost / m^3	m^3 / Ring	Cost / Ring
C45/55 Concrete with 95 kg/m^3 Steel Bar Reinforcement	€ 156	3.534	€ 551.3
Cage Fabrication	Man-Hours / Ring	Cost / Hour	
Labour for fabrication	3	€ 25	€ 75
Administration/QC Costs	0.5	€ 50	€ 25
Jigs / Spacers	0.5	€ 25	€ 12.5
Welding / tie wire	0.25	€ 25	€ 6.25
Placing of Cages Into Moulds	Man-hours / Ring	Cost / Hour	
Labour to place cages	0.5	€ 25	€ 12.5
Cost of craneage	0.5	€ 25	€ 12.5
QC costs (checking cover)	0.5	€ 50	€ 25
Repair of Damaged Segments	Percentage	Segments For Repair	
% of segments requiring major repairs	2 %	146.16	
	Man-hours / Segment	Cost / Hour	
Labour for repair	3	€ 25	€ 54
Cost of craneage in/out repair areas	1	€ 25	€ 18
Administration / QC Costs	1	€ 50	€ 36
	Cost / Segment	Total Cost	
Cost of repair materials	€ 4.17	€ 609	€ 3
Total Cost / Ring			**€ 831.05**

Cost comparison data supplied by Santoña Laredo construction contractor. Cost of labour and installation of the rebar cage are based on time estimations.

North Strathfield Rail Underpass

Permanent Sprayed Concrete Lining

The North Strathfield Rail Underpass tunnel in Sydney, Australia, is a 148 m long rail tunnel designed for freight trains up to 1.5 km in length. While short, the tunnel required and includes numerous technical innovations and takes full advantage of the benefits offered from BarChip fibre reinforced shotcrete. The 9 m wide, arched roof single tunnel was excavated by a road header underneath operational passenger and freight railway lines with a maximum cover of 3 m.

The project has been being delivered by the NSRU Alliance (TfNSW, John Holland and Bouygues). The lead designers are the DJV of SKM and PB with Mott MacDonald the designer of the driven tunnel discussed here.

The tunnel has a maximum ground cover of 3 m and the ground consists of track ballast overlying fill and shale rock which is weathered near the surface. The permanent ground support in the tunnel consists of a 250 mm thick BarChip macro synthetic fibre reinforced single pass (wet mix) sprayed concrete lining. Steel canopy tubes drilled ahead of the tunnel face provide the initial ground support ahead following shotcrete lining. No steel sets or lattice girders were used on this project. The design is based on an arched profile ensuring that the shotcrete itself is always in compression under both dead and live loading. The macro synthetic fibres in the initial structural shotcrete lining have four functions;

1. To reduce shrinkage crack widths in the shotcrete if they occur.
2. To provide residual strength and distribute load within the lining should the shotcrete crack due to some unknown flexural force or ground movement.
3. Are environmentally friendly and will not deteriorate over the 100 year life of the tunnel.
4. The final shotcrete layer is 100 mm in thickness using micro synthetic fibres to reduce spalling in the event of a fire. Although macro fibres were not specifically used for fire and are not as effective as micro fibres for this purpose, the underlying macro synthetic fibres in the structural shotcrete layer will also help to reduce spalling in the event of a fire.

The tunnel excavation is now completed with low surface settlement and no disruption to the railway operations above.

BarChip Inc.
The Synthetic Fibre Experts

BarChip synthetic fibre eliminates the need to place steel mesh, significantly decreasing cycle times of shotcrete works.

Helsinki Metro West Extension

Permanent Sprayed Concrete Lining

The Helsinki Metro System is undergoing a major expansion from Ruoholahti to Matinkylä in Espoo via Lauttasaari and is Finland's largest infrastructure project.

The metro expansion consists of 13.9 km twin tube tunnels, 6 m diameter with connection tunnels every 150 to 170 m. Seven new stations will be built along the line with a further station planned for Niittykumpu. Upon completion the west metro will transport over 100,000 passengers every day. The entire metro system will be a fully automated, driverless system.

The Helsinki West Metro extension has a number of subsea sections which raised serious concerns over the corrosion and durability of steel fibre reinforcement. As a result, the original specification of 40 kg/m^3 of steel fibre was changed to 7 kg/m^3 of BarChip54 synthetic fibre.

The change to BarChip structural synthetic fibre also delivered owner Lansimetro a number of benefits;

- An 82.5% reduction in handling, storage and transport of fibre materials
- A 66% reduction in wear, tear and maintenance of shotcrete equipment
- Eliminated any risk of corrosion

BarChip structural synthetic fibre reinforcement was specified for the shotcrete support lining after achieving the specified 1000J (EFNARC) at the lowest cost per Joule.

Mt Ovit Road Tunnel

Sprayed Concrete Lining

The twin tube **Mt Ovit Tunnel** is one of Turkeys most significant pieces of civil infrastructure. The tunnel measures 14.7 km and upon completion will be the worlds 6th longest road tunnel and Turkeys longest.

Initially, this project faced major safety concerns and time delays caused by the installation of steel mesh. Given the potential delays caused by the extremities of winter conditions on Mt Ovit, it was crucial to the project owners that there be minimal to no delays in excavation speeds. "The use of steel mesh reinforcement in the shotcrete lining (of the Mt Ovit Tunnel)…presented safety issues and relatively slowed application." (P. Guner, 2014).

To solve these problems designers looked to Macro Synthetic Fibres as a possible alternative which could eliminate the need to fix reinforcement to the tunnel wall.

Once the Mt Ovit Tunnels designers decided to make the switch to BarChip Macro Synthetic Fibres excavation speeds increased from 7.10 m/day to 9 m/day and overall production speeds increased 25%. This speed increase led to the project being completed an estimated 106 days earlier than expected which represents a huge saving in costs for the project owner and minimised the impact of a harsh Mt Ovit winter.

Furthermore, the shift to BarChip fibres led to a far safer work environment for the tunnels work crew as it removed the need for workers to operate under dangerous, unreinforced ground.

Euclid Creek Storage Tunnel

Cast In-Situ Final Lining

Owner: NEORSD

General Contractor: McNally-Kiewit ECT

Joint Venture Contractor & Owner Engineer: Hatch Mott MacDonald (HMM)

The Euclid Creek Storage Tunnel (ECT) Project forms a major component of the Northeast Ohio Regional Sewer District's (NEORSD) Project Clean Lake Program and is the first of seven storage and conveyance tunnels in the program. The 3.4 mile, 24 foot diameter ECT is largely a precast concrete, segmentally lined, single shield driven CSO tunnel.

A 300 foot long tail tunnel running in the opposite direction to ECT was required to provide a future connection to the 2nd phase Dugway Storage Tunnel. A 125 foot long, 30 foot diameter starter tunnel was constructed as the TBM launching chamber. At completion of the TBM drive these tunnels required a cast in place final liner originally designed with a single layer of steel bar, which was later changed to BarChip synthetic fibre reinforcement.

Design Change

The design comprised a rock load of 2,240 psf and external hydrostatic water pressure equivalent at ground surface, or 12,600 psf. The final design of the cast in place lining was determined to be a minimum 16 in. thick 6,000 psi compressive strength concrete lining reinforced with an inner mat of steel bars. The reinforcement selected was no. 8 bars on 12 in. centre to centre spacing each way. To reduce costs and shorten the schedule the contractor requested a change order be considered to replace the single layer of reinforcing steel with synthetic fibre reinforcement.

The benefits of using synthetic fibres as perceived by the project team included the following:

- Eliminate the need to detail, fabricate, deliver, handle, place and tie reinforcing steel
- Separate operation of moving gantry to place and tie rebar not needed
- Simplify the wood bulkheads at end of forms - no penetrations
- Reduce the labour hours thereby reducing risk of injury due to exposure
- Reduce risk of injury by eliminating the need for labourers to be placed in awkward positions to place and tie reinforcing steel from a gantry
- Reduce pumping issues with synthetic fibres over steel fibres
- Improve long term durability and quality as there are no deteriorating effects from the oxidation of reinforcing steel

BarChip Inc.

The Synthetic Fibre Experts

Oliola Water Tunnel

Cast In-situ Final Lining

The Oliola Water Tunnel is part of the Segarra – Garrigues canal in North East Spain. This project was awarded to a Joint Venture of Acciona Infrastructures and M. y J. Gruas. The Euro 30.1 million contract comprises of a 4.8 diameter water tunnel approximately 7,000 metres in length.

Both the primary and the secondary linings and the precast segments use BarChip Shogun synthetic fibre in place of steel fibre and / or welded wire fabric. Approximately 30 tonnes of BarChip Shogun reinforcement was used over the entire project, dosed at 5 kg/m^3.

Ground support consists of 5 x 2.0 metre rock bolts at 1 metre centres installed behind the cutting head and 50 mm of BarChip fibre reinforced shotcrete. A specially designed precast invert segment which forms part of the final lining is placed behind the TBM for the travelling backup and grouted into place.

The secondary lining is 300 mm in thickness and the form work consists of two 6 metre lengths capable of being moved and positioned individually. BarChip Shogun fibre was used to replace two layers of wire welded fabric. Replacing the steel reinforcement with BarChip Shogun reduced installation and cycle times and eliminated the high risk of corrosion.

Legacy Way Road Tunnel

Cast In-Situ Final Lining

Brisbane's **Legacy Way Tunnel** is a 4.6 km long twin tube TBM driven road tunnel. Transcity, a joint venture between Brisbane-based BMD Constructions, Italian tunnelling company Ghella and Spanish tunnelling and civil infrastructure company, Acciona Infrastructures won the design and construct contract. The Transcity JV won the 2013 ITA tunnelling award category Major Tunnelling Project of the Year (Over $500M) for the Legacy Way tunnel, which is due for completion in 2015.

The two tunnels are connected by 37 underground cross passages, spaced every 120 metres along the length of Legacy Way. Each passage is 4 metres wide, 3.5 metres high and 10 metres long. Excavation consisted of rock hammer, road header and where necessary drill and blast. Ground support comprised a temporary steel or synthetic fibre reinforced shotcrete lining, followed by a cast in situ synthetic fibre reinforced permanent arch lining.

The permanent arch lining was poured in one 8 to 12 hour shift. The arch lining was up to 1 m thick in places and solely reinforced with 4 kg/m^3 of BarChip synthetic fibre reinforcement. Design specification called for a maximum crack width of 0.2 mm. FEA Analysis undertaken by BarChip and on-site in-situ trials undertaken by Transcity, combined with 12 hour and 3 day beam testing showed that BarChip concrete fibre reinforcement was able to meet the design specification.

BarChip Inc.

OUR VISION

BarChip has a simple vision - revolutionise the world of concrete reinforcement. For over 100 years the technology of concrete reinforcement has barely changed. We set out to create a new reinforcement for the 21st century. We created BarChip synthetic fibre reinforcement.

OUR PROCESS

We believe that long term business relationships can only be sustained by a commitment to provide the highest quality products and services. We make sure to understand your concrete, know the performance requirements and work with you to get the right design and the right performance outcomes.

YOUR PRODUCT

When you work with BarChip you know that your concrete asset has been reinforced to the latest engineering standards. It will never suffer from corrosion. It will be cheaper and quicker to build. It will be safer and it will keep performing throughout its entire design life.

BarChip Inc.
info@barchip.com
Australia: +61 1300 131 158
N. America: +1 704 843 8401
EMEA: +353 (0) 1 469 3197
Asia: +65 6835 7716
S. America: +56 2 2703 1563
Brazil: +55 19 3722 2199

The Synthetic Fibre Experts

Distributors are located in other regions. For contact details visit www.barchip.com.

www.barchip.com