MuscleReBar®

Technical Information

2. GLASS FIBER REINFORCEMENT

MuscleReBar® (composite rebar) belongs to the family of glass fiber composite materials, glass fiber reinforced polymer (GFRP) to be exact. GFRP consist of fibers of glass set in a resin matrix to form a rebar rod or grid or fibers.

These reinforcement bars are installed in much the same manner as steel. The first known use of GFRPs as reinforcement occurred in 1975 in the former Soviet Union.

Significant studies of using GFRP as reinforcement began in Europe in the 1980s. GFRP reinforcements gained significant support during the 1990s from research of magnetically levitated (maglev) train support structures in Japan. The Japanese in 1996 were the first to introduce design guidelines for GFRP reinforced concrete.

Since then, the use of GFRP as structural reinforcement has increased exponentially and design guidance has been authored by organizations from around the world. Crucially till now, the high initial purchase cost has restricted its application. However, with *MuscleReBar*® this is no longer the case as *MuscleReBar*® is being offered at prices below steel reinforcement market price.

When correctly applied, GFRP reinforced concrete structures have a great deal of advantages, in particular a dramatic reduction in problems related to corrosion, either by intrinsic concrete alkalinity or by external corrosive fluids that might penetrate the concrete. These structures can be significantly lighter and have a much longer service life of up to 100 years.

In particular GFRP rebars are useful for structures where the presence of steel would not be acceptable. For example, magnetic resonance imaging (MRI) machines have large magnets, and accordingly require non-magnetic buildings.

Also, where the design life of the concrete structure is important, GFRP reinforcing has its advantages where corrosion of reinforcing steel is a major cause of failure. In such situations corrosion-proof GFRP reinforcing will extend a structure's life substantially, for example in the marine structures.

GFRP rebars will also be useful in situations where it is likely that the concrete structure may be compromised in future years, for example the edges of balconies when balustrades are replaced and bathroom floors in multi-story construction where the service life of the floor structure is likely to be many times the service life of the waterproofing building membrane.

GFRP reinforcement is stronger, and has a much better strength to weight ratio than reinforcing steel. Also, because it resists corrosion, it does not need a protective concrete cover as thick as steel reinforcement does (typically 30 to 50 mm or more). GFRP reinforced structures therefore can be lighter and last longer.

The material properties of GFRP bars differ markedly from steel, so there are differences in the design considerations. GFRP bars have relatively higher tensile strength but lower stiffness, so that deflections are likely to be higher than for equivalent steel reinforced units.

Structures with internal GFRP reinforcement typically have an elastic deformability comparable to the plastic deformability (ductility) of steel reinforced structures. Failure in either case will occur by compression of the concrete rather than by rupture of the reinforcement. Deflection is always a major design consideration for reinforced concrete. Therefore, deflection limits are set to ensure that crack widths in steel-reinforced concrete are controlled to prevent water, air or other aggressive substances reaching the steel and causing corrosion.

As there is no danger of corrosion, for GFRP reinforced concrete, aesthetics and possibly water-tightness will be the limiting criteria for crack width control. GFRP rods also have relatively lower compressive strengths than steel rebar, and accordingly require different design approaches for reinforced concrete columns.

A potential limit to the use of GFRP reinforcement is the limited fire resistance. Where fire safety is a consideration, structures employing GFRP have to maintain their strength and the anchoring of the forces at temperatures to be expected in the event of fire. For purposes of fireproofing an adequate thickness of cement concrete cover or protective cladding is necessary.

Therefore, it is not always possible to replace the reinforcing steel by MuscleReBar®, because of the above said limitations and the fact that mechanical properties of the two materials differ. For example, E-modulus and shear strength of GFRP bars are lower, but the tensile strength is significantly higher than that of steel. Nevertheless, the applicabilities of the *MuscleReBar®* reinforced elements are greater than their planning restrictions compared to steel reinforced elements.

As such there is growing interest in application of GFRP composite rebar recognized by different countries and number of projects using composite rebar increases day by day around the world, ranging from USA, Russia, Japan, South Korea and Germany.

3 .PRODUCTS AT A GLANCE

Reinforcement bars available as coils

4 mm	
6 mm	Available as 50 m coils
7 mm	(other sizes on request)
8 mm	
10 mm	

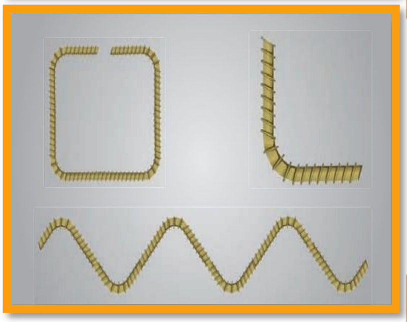
Reinforcement bars available as straight bars

12 mm	
14 mm	Available in standard lengths of
16 mm	10 & 12 m (other sizes on request)

Reinforcement bars available by special order

18 mm	30 mm	
20 mm	32 mm	
22 mm	34 mm	Available in standard
24 mm	36 mm	lengths of 10 & 12 m
26 mm	38 mm	(other sizes on request)
28 mm	40 mm	

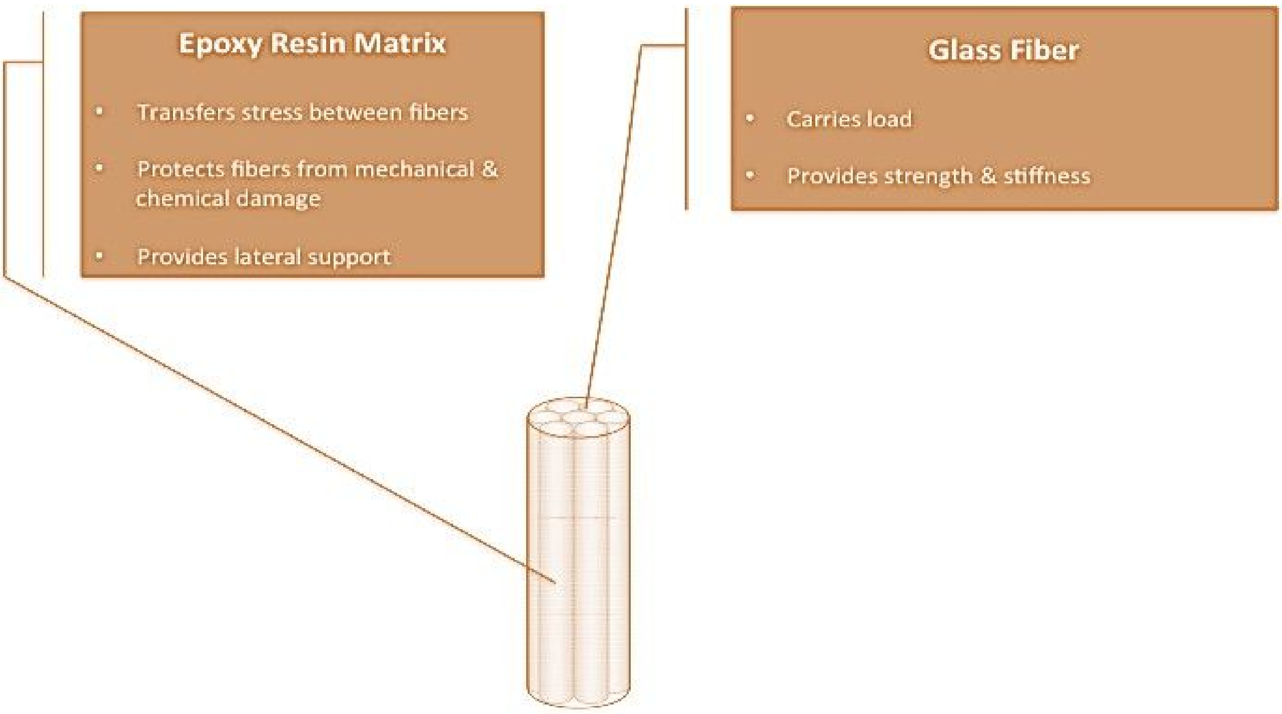
Bent bars & shapes



Straight bars with shear anchorage

4. The MuscleReBar®

The composite *MuscleReBar®* now offers an entirely new range of applications in civil engineering. The reinforcing bar consists of a multitude of continuous fibers, oriented in the direction of the load, each with a diameter of approx. 20 µm. They are bonded in an epoxy resin matrix



The fibers provide the longitudinal strength and stiffness of the material. The resin matrix holds the fibers in place, distributes the load and protects the fibers against physical & chemical damage.

The standard *MuscleReBar®* is a glass fiber reinforced round bar with surface ribbing. The product was conceptualized as plain reinforcement for concrete components. Its physical as well as its bond properties is comparable to those of reinforcing steel. This is achieved with the use of high quality components, the specialized production process and the unique, patented geometry of the ribs. They are certified for a design service life of 100 years.

MuscleReBar® is linearly elastic up to failure. For all bar diameters it occurs at stresses well above 1,000 MPa. As a result of the comparatively low modulus of elasticity *of* MuscleReBar® (≥ 55 GPa), the failure of *MuscleReBar®* reinforced concrete members is preceded by large deflections. When the load is removed the deflection returns to near zero.

MuscleReBar® cannot be permanently deformed or bent. If a straight bar is bent it returns to its original shape as soon as the applied force is removed. Bars with small diameters can be bent elastically (circular tunnel cross-sections). Customized bent bars and stirrups may be prefabricated at the shop.

5. MuscleReBar® the Company

The Indian company MuscleReBar®, established more than 2 years ago, takes a leading position in the production of GFRP composite materials.

The company is characterized by its dynamism, the high quality of its products and its continuous research of improved materials and production methods.

The Company's strong scientific base and patented manufacturing process enables it to be the only producer of GFRP able to manufacture high quality GFRP bars which are economically competitive with steel reinforcement prices globally.

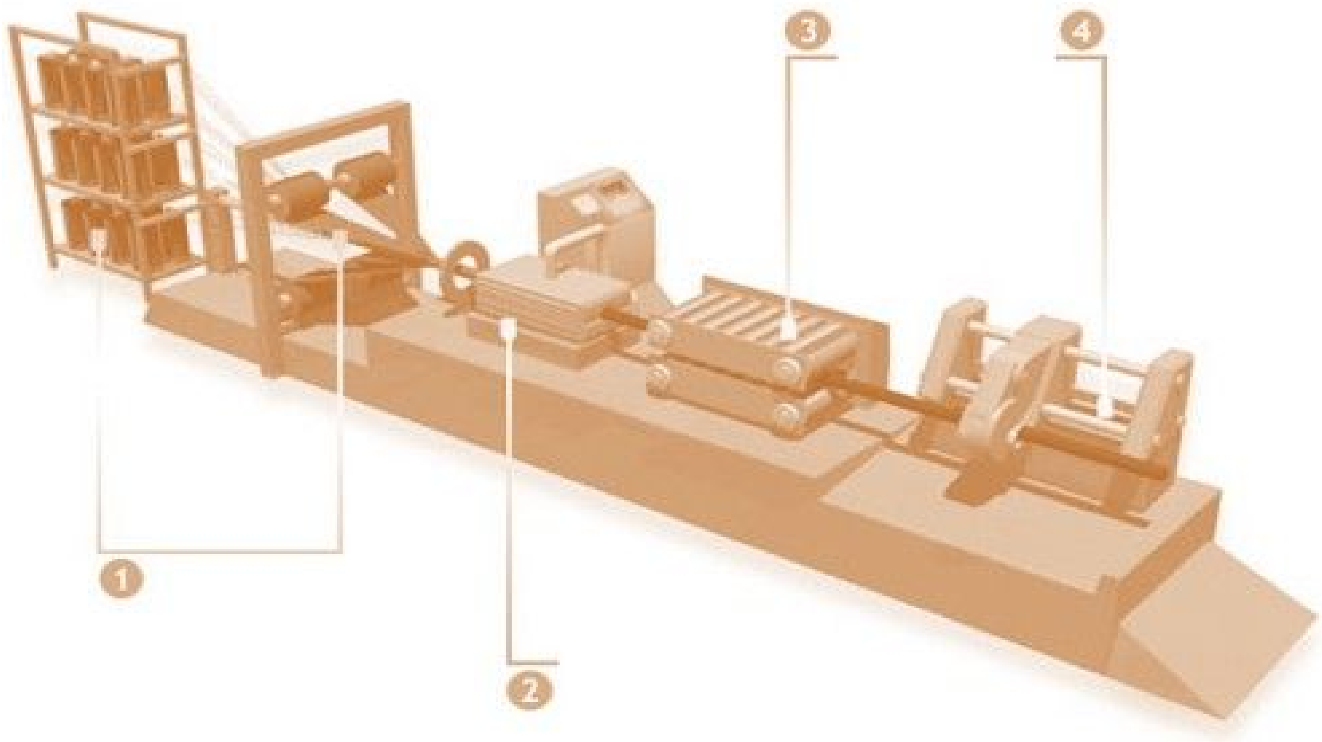
MuscleReBar® has recently ventured into the African and Bangladesh market establishing MuscleReBar® as a manufacturing brand.

The company holds two manufacturing plants one at Aurangabad, Maharastra and other at Khalapur in Raigad district.

Company's research center is located at Aurangabad.

6. THE PULTRUSION PROCESS

The *MuscleReBar*® manufacturing process, known as the Pultrusion or extrusion process, is shown schematically below



1. First, the glass fibers are pulled through a reel stand into a synthetic resin bath;
2. They are then formed into the required diameter with the and the surface of the glass fiber bar is then ribbed with additional binding roving;
3. After which the bar is immediately transferred to the curing furnace;
4. The cutting machine immediately follows the pulling unit.

The *MuscleReBar*® glass fiber bars are continuously produced.

7. Characteristics and applications

Based on the described properties and advantages, *MuscleReBar®* is suitable for the following reinforced concrete applications, for example.

- Economically competitive & stable price

Due to competitive initial purchase price (up to 20% lower than steel purchase price on large orders) and stability in comparison to the volatile nature of steel prices in India, it is a suitable replacement for applications such as dry shrinkage mesh or contained building foundations.

- High corrosion resistance

MuscleReBar® can be used in structural elements exposed to a higher corrosion hazard as a result of carbonation or chlorides – i.e. wherever steel or galvanized steel is used, for example in structural elements which are exposed to deicing or sea salt in marine structures or bridge decks

- High resistance to chemicals

In structural elements, which are exposed to chemical and biological attack, such as in refinery cooling tower foundations, industrial flooring or water treatment plants.

- Requirement for minimal concrete cover

In concrete elements with small cross-sections, where a sufficient concrete cover cannot be achieved for steel, for example in thin curtain panels.

- Electrically non-conductive

In concrete elements, which have to contain non-conducting, reinforcing materials due to electromagnetic impacts. For example rail way switch boards

- Non-magnetic & radio wave transparency

For use as reinforcement in structural elements requiring minimal interference to magnetic fields or radio waves. For example in Hospital MRI rooms & radar stations

- Ease of machining

In tunnel engineering, where it is necessary to cut the concrete and where a steel reinforcement damages the cutting tools .

<u>MuscleReBar®</u> – non-metallic composite reinforcement intended for reinforcing concrete structures both independently and in combination with metal reinforcement. The rebar is supplied ready-made and does not require additional processing.

Material properties

High corrosion resistance
not subject to corrosion, allowing to reduce the protective layer of concrete

High tensile strength
MuscleReBar® composite reinforcement is 2.5 times stronger in tensile than steel reinforcement of class AIII

High chemical resistance
MuscleReBar® composite reinforcement is resistant to chlorides, acids and chemicals, it can be used in acid and alkaline environments

Dielectric
a non-conductive electrical insulator

Non-magnetic
not an obstacle to the penetration of electromagnetic waves

Product lightness
with equal strength replacement, it is 9 times lighter, what let saving on logistics, handling operations

No thermal conductivity
composite reinforcement does not conduct heat and, in comparison with steel, it does not lose its Properties at very low temperatures. The coefficient of thermal expansion is similar to the coefficient of concrete, and this prevents damage caused by changes in temperature. MuscleReBar®composite reinforcement has more than a hundred times lower thermal conductivity than steel rods

8. Material properties of straight bars

1.

Material properties of straight bars	A-III Reinforcing steel	Stainless steel (EN 10088)	MuscleReBar
Characteristic yield strength fyk (N/mm^2)	500	500	1200
Design value of yield strength fyd (N/mm^2)	435	435	435*
Tension modulus of elasticity (N/mm^2)	2,00,000	1,60,000	55,000
Concrete cover	As per local standards	ds+10 mm	ds+10 mm
Bond strength(Mpa)	13	13	11
Thermal conductivity I (W/mK)	60	15	0.35
Coefficient of thermal expansion α (1/K)	$0.8\text{-}1.2 \times 10^{-5}$	$1.2\text{-}1.6 \times 10^{-5}$	$9\text{-}12 \times 10^{-5}$
Magnetism	Yes	Low	No
Density γ (g/cm^3)	7.85	7.85	1.9

2. Comparison:

		Bar Diameter						
	bar size dia in mm	6	7	8	10	12	14	16
GFRP	effective cross section mm^2	23.76	29.23	39.6	78.5	86.6	134	
	Peak Tensile strength kN	29	35.1	51	71	97	107	
	Tensile Strength Mpa	1200	1200	1200	1200	1200	1200	
	Weight gm/mtr	55		100	160	230	300	
	Effective cross section mm^2	28.3	38.5	50.3	78.5	113	154	201
TMT bar	Peak Tensile Strength in kN	12.7	17.3	22.6	35.3	50.9	69.3	90.5
	Tensile Strength Mpa	450	450	450	450	450	450	450
	Weight gm/mtr	220	non std	395	617	889	non std	1580
Maximum tensile Strength MPa= Peak tensile force (N)/ Area mm^2								

Properties	Terms	Values
Characteristic tensil strength	ftk	1200 N/mm^2
Design tensile strength	fGFKd	435 N/mm^2 or according to CSA S806 & CSA S6-06
Modulus of elasticity	EGFK	55,000 N/mm^2
Compressive strength	σGFK2	400 N/mm^2
Shear strength (characteristic)	–	200 N/mm^2
Concrete cover	cv	ds + 10 mm or according to local standard requirements
Bond Strength	τ_f	11 Mpa
Density	γ	1.9 g/cm^3
Thermal conductivity	λ	0.35 W/mK
Elongation at fracture, %	–	2.2
Coefficient of thermal expansion	α	9-12 x 10^{-5} 1/K
Critical core temperature	–	350° C
Chemical resistance	–	Excellent
Electro-magnetic conductivity	–	None
Life expectancy	–	100 years

The values listed in this table are determined at room temperature.

7. STANDARDS & DESIGN GUIDES

USA

- ACI 440.1R-06 (2006) “Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars”, American Concrete Institute

- ACI 440.3R-04 (2004) “Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures”

- AASHTO GFRP-1 (2009) “AASHTO LFRD Bridge Design Guide Specifications for GFRP- Reinforced Concrete Bridge Decks and Traffic Railings”, American Association of State Highway and Transportation Officials.

Canada

- CAN/CSA-S807-10 “Specifications for Fiber-Reinforced Polymers.”

- CAN/CSA-S806-12 “Design and Construction of Building Components with Fiber- Reinforced Polymers.”

- CAN/CSA-S6-06 (2006) Fiber-Reinforced Structures, “Canadian Highway Bridge Design Code”, pp.693-728.

Switzerland

- Fib Bulletin No.40 (2007) “FRP Reinforcement in RC Structures.”

Japan

- JSCE Series 23 "Recommendation for Design and Construction of Concrete. Structures Using Continuous Fiber Reinforcing Materials."

- JBDPA Design Manual (2009) “Japanese Design and Construction Guidelines for Seismic Retrofit of Building Structures with FRP Composites.”

Germany

- DIN1045-1 “EN-Concrete Reinforced and Pre-stressed Concrete Structures - Part 1: Design and Construction.”

AND…

- EN-13706 (Europe)
- CNR-DT 203 & CNR-DT 205 (Italy)
- GOST 9.071-76 (Russia)

8. STORAGE, TRANSPORT & MACHINING

STORAGE & TRANSPORT

In general, high intensity long-term exposure to UV-rays can lead to the discoloration of polymers. After a prolonged (more than 6 months) exposure the surface of the material becomes brittle. Unless special protective measures are undertaken, this results in the lasting deterioration of the polymers. As a result, *MuscleReBar*® should be covered and stored in a dry environment, especially when stored for longer time periods. Tests on bars that were stored outdoors for up to eight weeks without being protected showed that climatic exposure in Russia lead to a discoloration without causing a reduction of the bond or the tensile strength.

To avoid damage to the ribs, the material should not be dragged on the ground. It should not be subjected to strong abrasive forces.

When hoisted by crane, the deflection of *MuscleReBar*® bars is similar to that of steel bars of equal diameter. It is important that the appropriate cross beam/lifting equipment is used at all times.

CUTTING

Cutting *MuscleReBar*® is significantly easier than cutting steel rebar. Either a hacksaw, band saw, or a grinder, using a diamond or a tough metal disc, is recommended. Both are fine enough to achieve a clean cut. *MuscleReBar*® should not be trimmed with bolt cutters or shears, as the glass fibers fray when the material is sheared off.

If desired, grates at the bar ends can be removed with a file or a rasp. Because of the relatively low strength perpendicular to the glass fibers, *MuscleReBar*® bars should not be subjected to impact forces.

BENDING

MuscleReBar® bars are linearly elastic up to failure. They cannot be bent permanently (plastically). A bent bar returns to its original shape once the bending force is removed.

Small diameter *MuscleReBar*® bars can be bent into a radius as long as they are fixed in position while the concrete hardens. The stress induced in the

bar by the bending process is to be added to the stress induced by the subsequently applied load. The total stress must not exceed the permissible value.

MuscleReBar® customized stirrups and bent bars may be pre-fabricated at the factory for larger orders

CONNECTION

Reinforcement cages made of *MuscleReBar*® bars are best assembled with ordinary tying or coated wire. Damage to the bars caused by properly installed tying wire is insignificant

In cases where reinforcement cages are to be entirely free of steel, plastic wire ties, such as those used by electricians, can be used. A tightening wrench facilitates pulling and trimming of the ties.

Plastic clips are under development and shall be available soon to connect *MuscleReBar*® at ninety degree angles to form meshes. The clips may be affixed to the bars using a rubber hammer or a similar tool. On a solid surface the clips may even be affixed by stepping on them with shoes.

Bar couplers, that are glued onto the *MuscleReBar*® in the factory, are under development and shall soon be available. They are an alternative means of connecting *MuscleReBar*® and steel bars. When the *MuscleReBar*® bars are screwed onto the steel bars, it is important that they are handled and turned at the connector, not at the bar. The glued couplers should not be exposed to temperatures above 100° C. Special care needs to be taken when welding in the vicinity of the couplers.

Wire rope grips can be used to connect *MuscleReBar*® to steel reinforcing bars. The *MuscleReBar*® should be placed in the curved form piece of the grip. Two short pieces of smaller diameter steel rebar should be placed in the grip, between the *MuscleReBar*® and the steel bar, to minimize the damage to the *MuscleReBar*® caused by the clamping force.

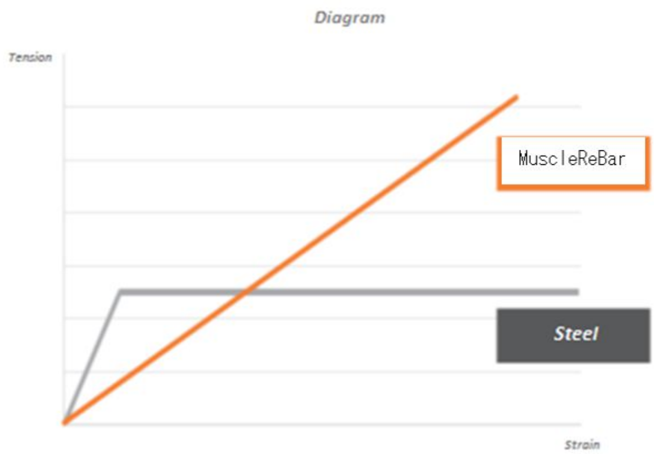
9. TENSILE STRENGTH & E-MODULUS

In contrast to steel, *MuscleReBar®* behaves in a linear elastic manner up to failure. Yielding is not observed. The modulus of elasticity of straight bars is well above 55 GPA (60 GPA for ø 14 mm bars).

The mean value of the short-term tensile strength measured in tensile tests on bare *MuscleReBar®* lies between 1,000 MPa (large diameter bars) and well above 1,500 MPa (8 mm).

The true value is much higher, as the fibers themselves have a tensile strength of more than 3,000 MPa. With the volumetric fiber content of approximately 80% *MuscleReBar®* must have a short-term tensile strength of approx. 2,200 MPa. The measured values are much lower, as the bars fail prematurely at the clamped ends and due to internal stresses being induced in the bars during the tests (eccentricity, application of force along the bar circumference only, etc.). As the long-term strength of FRPs cannot be derived from their short-term strength, the meaning of the short-term values for structural designs is a best a nominal figure.

To determine the tensile strength and the stress-strain relationship both ends of *MuscleReBar®* bars are glued into shafts. The load is applied at approximately 1 kN/sec. in a hydraulic press. Up to a load of sixty percent of the ultimate load, the modulus of elasticity is determined using highly sensitive strain gages. Afterwards the load is increased until failure occurs.



The tests have demonstrated that the measured short-term tensile strength for all bar diameters is greater than 1,200 N/mm^2 and that the modulus of elasticity is 55,000 N/mm^2.

The long-term strength of FRPs depends on both the maximum temperature and on the frequency and amplitude of the temperature changes where the bars are exposed.

Characteristic values (CSA S806) / specified values (CSA S6-06 - CHBDC) of the tensile strength of *MuscleReBar®* for common Canadian environmental conditions and for typical design service live spans are listed in the table below:

application	design serv. life [years]	environment	thickness (h)	effect. temp.	n	η_{env}	$f_{Fk,t}$ [MPa]
diaphragm wall	5	wet	1000 mm	10 °C	2.7	0.64	612
industrial floor slab	100	indoor, const. temp.	150 mm	23 °C	2.65	0.65	617
retaining wall	100	outdoor, direct sun	400 mm	20 °C	3.5	0.57	537
bridge deck	100	outdoor, direct sun	150 mm	25 °C	3.75	0.55	516
façade element	100	outdoor, direct sun	60 mm	30 °C	4.0	0.52	495
underside of bridge	100	outdoor, direct sun	250 mm	20 °C	3.5	0.57	537
sea wall	100	wet	500 mm	20 °C	4.5	0.48	457
impact on barrier wall	0.1	outdoor, direct sun	> 200 mm	20°C	1.0	0.85	807

Mean Annual temperature of 10°C

The values in the above table are characteristic values (as defined in CSA S806). These correspond to the "specified tensile strength" as defined in CSA S6-06 (CHBDC). To determine design values of the tensile strength these values are to be multiplied / divided by the appropriate safety or reduction factors specified in the relevant sections of the codes.

10. TRANSVERSE SHEAR STRENGTH

The transverse shear strength of the *MuscleReBar®* bars are frequently measured from random production runs in Russia. The testing is performed per ACI 440.3R test method B.4 and ASTM D7617. The property is consistent across bar diameters. The transverse Shear Strength is 200MPa

11. CREEP RUPTURE (SUSTAINED LOADS)

GFRP bars subjected to a constant load over time can suddenly fail after a time period called the endurance time. The endurance time is greatly affected by the environmental conditions such as high temperature, alkalinity, wet and dry cycles, freezing and thawing cycles. As the percentage of sustained tensile stress to short-term strength of the bar increases, the endurance time decreases

For this reason, the design limits on GFRP bars in consensus standards limit sustained loads on GFRP bars to very low levels of utilization. We recommend designers use the appropriate consensus guideline for creep rupture stress limits of *MuscleReBar®*.

12. DURABILITY & ALKALI RESISTANCE

One of the main concerns about the use of GFRP is its potential to be degraded in the long term by the high pH environment of the concrete itself. This phenomenon is analogous to an alkali silica reaction with certain types of aggregate. A great deal of research has been performed on this subject with the conclusion being that a properly designed and manufactured composite system of resin and glass can adequately protect the glass fibers from degradation.

MuscleReBar® is made from epoxy resin matrix and Alkali resistant *Advantix®* glass fibers. Selection of high caliber raw materials, results in a good bond between the *Advantix®* glass fiber itself and the protective resin and is key to successful long-term performance of the *MuscleReBar®*.

Current international codes and guidelines on GFRP reinforcement and the design of GFRP reinforced concrete structures require durability tests on the basis of a residual strength approach (CSA, ACI, GOST etc.). Bars are aged either under load or at relatively small loads (e≤ 0.3 %) in an alkaline solution for specified periods of time. After the aging process the bars are unloaded. Their residual tensile strength is tested in conventional tensile tests.

To characterize the long term properties of the *MuscleReBar®*, rebar samples were subjected to a 0,1n (5%) solutions of potassium and sodium hydroxide per resistance value classification under GOST 9.071-76 standard testing procedures in Russia.

The resistance was evaluated by measuring swelling during exposure of samples in static condition at the ambient temperature (20+/-2)°C for 14 days and at (80+/-5)°C for 75 hrs. *MuscleReBar®* achieved chemical resistance in excess of GOST Group 1 of chemical resistance (alkaline-resistant, no chemical destruction observed) to impacts of 0,1n alkali solutions at ambient and elevated temperatures.

It is important to note that tensile modulus properties are typically not affected by the alkaline bath at elevated temperatures. Subjecting the GFRP bars to an aqueous, high pH solution at elevated temperatures is not intended to be a perfectly accurate measure of the long term residual properties of the GFRP bar, rather its purpose is to differentiate high caliber GFRP bars such as *MuscleReBar®* from lesser quality ones. The unlimited supply of free ions in the purely aqueous elevated pH solution are much more harmful than actual field conditions.

This conclusion is drawn from a series of tests performed on GFRP bars extracted from service in several structures across Canada by the ISIS research network that reveals NO DEGRADATION of GFRP bars after being in service for eight to ten years. At this time, there is no consensus as to what would be an accurate service life prediction model for the use of GFRP bars.

13. BOND BEHAVIOR

To determine the bond behavior of *MuscleReBar®* reinforcement, four eccentric pullout tests was performed on 150 x 200 x 200 mm concrete cubes, using two pairs of 6 & 8 mm bars according to the ACES. The displacement at the unloaded end of the bar was plotted as a function of the load. The compressive strength of the concrete was > 40 N/mm^2




The results of the test series are….

- • the failure mode is, as with steel rebar, extraction of the concrete corbels from the concrete block. The ribs of the rebar were largely undamaged

- • As is the case for reinforcing steel, higher bond stresses are observed in higher grade concrete.

- • No significant differences were observed regarding the slip of the unloaded bar end of *MuscleReBar®* and steel bars. The maximum bond stress was recorded at a slip between 10 mm and 15 mm

- • Even though the bond stress of *MuscleReBar®* is greater at the same amount of slip, the tensile splitting forces are lower than those of steel rebar.

- • Further bond tests have shown that in normal grade concrete the bond behavior of *MuscleReBar®* is controlled by the strength of the concrete corbels, and in high strength concrete (> 60 MPa compressive. strength) by the strength of the *MuscleReBar®* ribs.

14. Crack Width

Following approach can be taken to derive the approximately required cross sectional area of *MuscleReBar®* crack reinforcement from the required amount of steel rebar. The crack width is proportional to the diameter of the rebar, independent of the reinforcing material, which is used. If more bars of a smaller diameter are installed the cracks will be smaller.

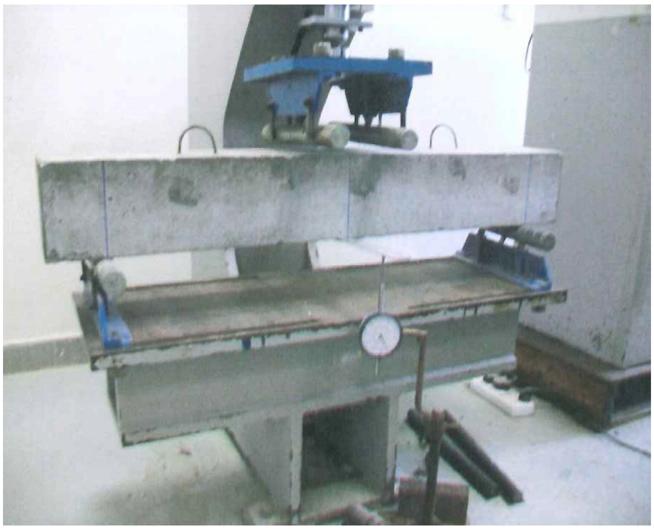
$$\frac{W_{k,\,ComBAR^{®}}}{W_{k,\,steel}} = 1{,}0 = \frac{200.000\ N/mm^2}{60.000\ N/mm^2} \cdot \left[\frac{\varnothing_{ComBAR}}{\varnothing_{steel}}\right] \cdot \left[\frac{f_{ComBAR}}{f_{steel}}\right]$$

For equal bar diameters this implies

$$req.\ A_{ComBAR^{®}} = \sqrt{\frac{200.000}{60.000}}\ A_{steel} = 1{,}83\ A_{steel}$$

15. Deflection

As noted earlier, the modulus of elasticity of *MuscleReBar®* is low compared to steel rebar (EF= 55GPa). Therefore, special attention needs to be devoted to checking the serviceability limit state requirements. In a test at ACES (Arab Center for Engineering Studies) laboratories in UAE test four concrete slabs of identical dimensions (1,100 x 1,50 x 150 mm), were tested in a four point bending test (bending zone without shear: 1,000 mm). Slabs 1 and 2 were reinforced with two numbers of ø 8 & ø 6 mm steel rebars (grade A-III) respectively, while slabs 3 and 4 with two numbers of ø 8 & ø 6 mm *MuscleReBar®* respectively. The position and distribution of the bars were identical.



The maximum load sustained by the MuscleReBar® reinforced slabs was more than twice as high as the load sustained by the steel reinforced slab of equal diameter. The maximum deflection was about three times as high.

After the first cracks the deflection of all slabs were nearly identical. After the service load was reached the deflection of the *MuscleReBar®* reinforced slabs was about 2.5 times greater. At 90% of this stress the difference of the deflections was 1.5 to 2.0

Conclusion

- • In any design of GFRP reinforced concrete members special attention needs to be paid to checking the deflection requirements.

- • To achieve the same maximum deflection in a *MuscleReBar®* reinforced member as in the geometrically identical steel reinforced members approx. 2.5 times the reinforcement cross-section will be required.

16. Thermal Behavior

The Coefficient of Thermal Expansion of GFRP bars is an inherent characteristic property and if sufficient concrete cover of 2db or 30 mm (whichever is greater) is used, it is not an important design consideration

Coefficient of thermal Expansion

The Coefficient of Thermal Expansion of GFRP bars is an inherent characteristic property and if sufficient concrete cover of 2db or 30 mm (whichever is greater) is used, it is not an important design consideration

This is because there is not enough radial force to cause reflective concrete cracking if adequate concrete confinement is present. These findings are elaborated in the work of Aiello, Focacci & Nanni in ACI Materials Journal, Vol. 98 No. 4, July-Aug 2001, pp. 332-339 “Effects of Thermal Loads on Concrete Cover of FRP Reinforced Elements: Theoretical and Experiential Analysis.” Therefore, structural elements reinforced with *MuscleReBar*® are not affected by temperature changes. Furthermore, expansive cracking did not occur in lab experiments in Russia, even when *MuscleReBar*® reinforcing bars were placed close to the surface of the specimen and the moisture content was varied over time. The radial coefficient of thermal expansion was determined on test specimen at temperatures ranging from 0° ^{C} to 70° ^{C}

Coefficient of thermal Expansion α	MuscleReBar Bar
Radial [1/K]	9-12 x 10^{-5}/°C

For comparison the coefficient of thermal expansion of concrete is between 0.5 and 1.2 x 10^{-5}, that of reinforcing steel is 1.0 x 10^{-5}, that of stainless steel 1.5 x 10^{-5}.

Behavior – Ambient temperature

The ambient temperature of a structural element reinforced with *MuscleReBar*® should not ideally exceed 60°^{C}. Unless noted otherwise, all technical values specified in the product data sheet were determined at room temperature. Please contact the technical services at Megha Engineering in case *MuscleReBar*® is to be installed in structural elements that will be exposed to increased temperatures over longer time spans.

Behavior – Low Temperature

The behavior of *MuscleReBar®* was tested at extremely low temperatures (up to (minus) -40
°C) It was shown that the material properties of *MuscleReBar®* remain nearly unchanged at extremely low temperatures.

17. Fire resistance

The resins used in the production of *MuscleReBar®* withstand temperatures up to about 200°^{C} over short time spans. The glass fibers soften/melt at about 600°C. *MuscleReBar®* can catch on fire when exposed to an open flame. After a few seconds the bars stop burning, when no more flammable material remains on the surface of the bars. *MuscleReBar®* bars do not contain fire-resisting additives.

In case an increased fire resistance of MuscleReBar®-reinforced structural elements is required, non-structural measures, such as an increase of the concrete cover or an encasement with fire-resistant material, are recommended. Most fire protection methods customary to conventionally reinforced concrete construction can be applied.

CONCRETE COVER & 90 MINUTE FIRE RATING

The isothermal lines for concrete also apply to *MuscleReBar®* reinforced elements. The critical temperature of *MuscleReBar®* bars is 350°C. When *MuscleReBar®* are installed in a member with a 30 Minute fire rating the required concrete cover is 30 mm. For a 90 Minute fire rating the required concrete cover for *MuscleReBar®* is 65 mm. Values for other fire ratings can be interpolated or determined using the isothermal lines of the specific concrete used in the member. Wherever possible, *MuscleReBar®* reinforced members should be protected against fire by applying fire coatings or by encasing the concrete member in fire cladding. These measures result in an overall more economical structure.

18. Design Considerations

On the basis of through investigation and the information summarized in the product data sheet, structures can be designed with *MuscleReBar®* reinforcement according to accepted regulations and codes, such as ACI 440.1R-6 (USA), CSA-S806-02 (Canada) or DIN-1045-1 (Germany) if the following issues are taken into consideration.

1. *MuscleReBar®* is conceptualized as plain reinforcement for concrete construction. For material properties concrete please refer to current national codes. Material properties of *MuscleReBar®* are listed on under Section. 6 of this technical information. Loads may be determined in accordance with current national codes.

2. *MuscleReBar®* behave linearly elastic up to failure. Yielding is not observed. **Plastic hinges** do not form. As a result, the loads on GFRP reinforced concrete elements cannot be determined using plastic limit analysis. As cracked sections transfer increasingly larger loads, **moment redistribution** is observed only to a very limited extent in *MuscleReBar®* reinforced concrete members. Moment redistribution should, therefore, not be considered in the design. For safety reasons **non-linear material properties** should not be considered in the design. They may be considered in the analysis of members and in the determination of deflections.

3. We recommend that, for long-term application, the characteristic tensile strength be determined according to the data presented in Section 9 of this technical information sheet. Alternatively a conservative maximum allowable stress at the ultimate limit state (ULS) may be set at 435 N/mm^2.

4. *MuscleReBar®* is not corrosive. As a result a concrete cover of d_s + 10 mm in accordance with DIN 1045-1, is recommended for all exposition classes. The reduced value of d_s + 5 mm can be applied for precast elements. Alternatively per Canadian CSA S 806-12 the minimum clear concrete cover in reinforced concrete members shall be 2db or 30 mm (whichever is greater).

5. The long-term deflection and bond creep of *MuscleReBar®* is comparable to those of steel rebar.

6. The modulus of elasticity of *MuscleReBar®* is substantially less than that of steel rebar. As a result, the behavior in the serviceability limit state is often more critical in the design than it is in steel reinforced concrete members.

7. Development lengths of straight *MuscleReBar®* are to be determined according to the relevant international codes. Ideally the development length of straight bars may be reduced by installing a bar with a headed end. *MuscleReBar®* headed ends are currently under development to be used as shear reinforcement in slabs and beams.
   They will be designed to transfer loads at minimal slip. Stirrups or bent bars are also possible.

8. MuscleReBar® has an estimated compressive stress of 400 N/mm2. However, due to the lack of experimental data ACI and CSA still do not recommend usage of GFRP bars in compressive elements. We therefore, discourage the use of MuscleReBar® bars as compression reinforcement.

9. Structural elements reinforced with MuscleReBar® behave in a ductile fashion. As is the case with steel reinforced elements, failure is indicated well in advance by wide cracks and large deflections.

10. The coefficient of thermal expansion is compatible with that of concrete. Neither cracks nor other signs of damage due to temperature-induced volume changes have been observed in structural elements reinforced with MuscleReBar®.

11. The long-term ambient temperature of elements reinforced with MuscleReBar® should not exceed 60°C. The elevated temperatures during curing of massive concrete elements do not cause any harm to the material. A reduction of the strength of the material was not observed.

12. A fire rating of MuscleReBar® is not yet available. In case fire resistance of MuscleReBar®-reinforced structural elements is an issue, nonstructural fire proofing measures, such as an encasement with fireboard, should be considered. The same methods as those used on conventionally reinforced concrete structures can be considered. For more information refer to Section. 17.

13. Splices of MuscleReBar® are designed and executed in the same manner as splices of conventional steel rebars are.

14. Due to the comparatively low modulus of elasticity of MuscleReBar®, special attention needs to be paid to the control of the deflection and the crack width. Crack widths should be limited to no more than 0.7mm (internal members) and 0.5mm (exterior members).

19. Reference Tables

a. Comparison between steel and GFRP rebar

Steel reinforcement A-III (A400)						GFRP MuscleReBar®				
	Cross section	Weight l.m.	by ultimate limit state				Weight l.m.	Cross section		
ø						ø			by standard value	
mm	mm²	kg	N	kgf		mm	kg	mm²	N	kgf
6	28.3	0.222	9 905	991		4	0.024	8	10 000	1 000
8	50.3	0.395	17 605	1 761		6	0.046	21.2	21 200	2 120
10	78.5	0.617	27 475	2 748		7	0.066	30.2	30 200	3 020
12	113.1	0.888	39 585	3 959		8	0.078	40.7	40 700	4 070
14	154	1.21	53 900	5 390		10	0.115	56.7	56 716	5 672
16	201	1.58	70 350	7 035		12	0.202	86.5	86 546	8 655
18	254	2	88 900	8 890		14	0.256	122.7	122 656	12 266
20	314	2.47	109 900	10 990		16	0.32	165	165 046	16 505
22	38	2.98	133 000	13 300		18	0.544	213.7	213 716	21 372
25	491	3.85	171 850	17 185		20	0.62	268.7	268 666	26 867
28	616	4.83	215 600	21 560		22	0.664	329.9	329 896	32 990

b. Property Comparison

Parameter	Steel	GFRP
Material density, kg/m³	7 850	1 900
Modulus of elasticity under tension, MPa	200 000	50 000
Tensile strength, Mpa	590	1 000
Minimum operating temperature, °C	-40	-70
Maximum operating temperature, °C	+350	+100
Ultimate shear strength, MPa	not rated	150
Ultimate compression strength, MPa	350	300
Strength of adhesion to concrete, MPa	not rated	12
Decrease in tensile strength after aging in alkaline medium,%, not more than	not rated	25
Elongation, %, not more than	14	2,3
Yield strength, N/mm²	390	not rated
Fire-resistance	Calculated parameter (depends on the thickness of concrete, support, protection)	Calculated parameter (depends on the thickness of concrete, support, protection)
Corrosion resistance to aggressive media	no	yes
Health hazard	no	no
Longevity	According to working conditions and regulatory documents	Higher than durability of concrete
Seismic resistance	Depends on the correct selection of reinforcement	Depends on the correct selection of reinforcement

a. GFRP Packing / weight data

Diameter GFRP	Release form	Meters per ton
4	coil / rod	41666
6	coil / rod	20833
7	coil / rod	15151
8	coil / rod	12195
10	coil / rod	7812
12	coil / rod	4950
14	rod	3906
16	rod	3125
18	rod	2061
20	rod	1915
22	rod	1506
24	rod	1394
26	rod	1123
28	rod	909
30	rod	833
32	rod	633

d. GFRP Packing data

Diameters of MuscleReBrebr	Kind of packaging	Length of bar	Quantity of bars in a packaging	Meters in a coil*
Ø 4 mm	bars / coils	up to 12 meters	50	up to 100 meters
Ø 6 mm	bars / coils		50	
Ø 8 mm	bars / coils		50	
Ø 10 mm	bars / coils		25	
Ø 12 mm	bars / coils		15	up to 50 meters
Ø 14 mm	bars		10	-//-
Ø 16 mm	bars		5	-//-
Ø 18 mm	bars		5	-//-
Ø 20 mm	bars		5	-//-
Ø 22 mm	bars		5	-//-
Ø 24 mm	bars		5	-//-
Ø 26 mm	bars		5	-//-
Ø 28 mm	bars		5	-//-
Ø 30 mm	bars		5	-//-

20. Contact Us

K-255, Waluj MIDC, Aurangabad. – 431116.

https://goo.gl/maps/Ui9kcTZ6xA6J2JfU7

+91 9860200594 | +91 6361072916

WWW.MUSCLEREBAR.COM

muscleRebar@gmail.com

9860200594