

rebar

VOC-free epoxy system for sustainable FRP rebar



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Fibre reinforced polymer (FRP) rebar has emerged as a sustainable, lightweight, corrosion resistant alternative to conventional steel rebar. Minimising the presence of volatile organic compounds (VOCs) during pultrusion of FRP rebar is key, not only for process and operator safety, but also for realising the full potential of sustainable, large scale FRP rebar manufacturing. Olin's novel epoxy system is able to meet and exceed the requirements and specifications of reinforced concrete (RC) applications, as presented below.

Olin's LITESTONE® 3200E/2131H system has been specifically developed and commercialised for FRP rebar manufacturing to deliver VOC-free processability, fibre compatibility and outstanding durability (Figure 1).

FRP composite rebar has been accepted as a non-metallic concrete reinforcement alternative for over three decades due to its unique value proposition including high strength, magnetic transparency, low density, and most significantly, corrosion resistance. FRP rebar is a material of choice for architects and engineers for applications such as water treatment plants, marine structures, toll booths, high voltage substations, bridges and tunnels. In addition to the previously mentioned advantages, builders and project owners can also achieve economic benefits from deployment of FRP rebar through both an increase of construction productivity and a reduction of labor, lifting machine time, and rehabilitation costs.

The 21.3 km Jizan economic city flood mitigation channel in Saudi Arabia is currently the world's largest concrete structure

for which FRP rebar was successfully deployed. The harsh environmental conditions in Jizan such as salt-containment flood water, high subsoil chlorides and sulfates and widespread sand precluded the use of conventional steel rebar. On the other hand, concrete structures reinforced with glass fibre reinforced polymer (GFRP) are expected to provide maintenance-free, service life exceeding 100 years. Studies have shown that the use of GFRP for this project resulted in direct cost savings of 21% and a reduction in CO₂ emission of 33%, when compared to the potential use of epoxy coated steel rebar [1].

VOC-free thermosetting resin for FRP rebar

FRP rebar is typically produced by pultrusion, a continuous manufacturing process, to consolidate fibre and thermoset resins into a highly reinforced structural material. Considering the open nature of the pultrusion process, management of VOCs emissions represents a significant challenge. For example, traditional FRP rebar manufacturing has involved the use of vinyl ester resins, which require styrene as a diluent for viscosity management. Effective mitigation and remediation of the VOCs and emission resulting from the use of styrene



Fig. 1: Examples of GFRP rebar made by LITESTONE® 3200E/2131H system

Tab. 1: Basic properties of epoxy system for FRP rebar

Property	LITESTONE® 3200E/2131H
Mixing viscosity @ 25 °C [MPa·s]	500
Gel time @ 23 °C [hrs] gardner standard model gel timer	>24
Geltime @ 140 °C [secs] Gelnorm gel timer	210
Tg [°C] DSC, midpoint, 10 °C/min	125
Tensile strength [MPa] ASTM D638	90
Tensile modulus [GPa] ASTM D638	3.2

for the safe, large-scale manufacturing of FRP rebar is not a trivial exercise. Epoxy resins can be formulated to achieve VOC-free processing for pultrusion, and also offer the most attractive balance of processing ease, corrosion resistance and mechanical performance, among various thermoset matrices. Furthermore, the excellent adhesion and compatibility of epoxy resins with various types of fibres (glass, carbon or basalt) enables excellent fatigue and mechanical performance for FRP composites. However, the penetration of epoxy chemistry in FRP rebar has not achieved its full potential due to limited industry awareness around performance and durability, linked to the lack of published data on epoxy based FRP rebar.

The limited penetration is reflected by the fact that epoxy was not listed as an eligible matrix for FRP rebar manufacturing until the new ASTM 8505 standard for FRP rebar was published in 2023. In order to create awareness of the outstanding potential of epoxy resins as a VOC-free chemistry for more sustainable manufacturing of FRP rebar, Olin has partnered with FRP rebar manufacturers and certificated testing facilities (Dept. of Civil & Arch. Engineering, University of Miami, and CMTE, Inc.) to demonstrate the ability of epoxy based FRP rebar to meet and exceed the requirements for reinforced concrete (RC) applications. The data and results from these efforts will be discussed in the ensuing sections.

Epoxy based GFRP rebar

The mix viscosity of Olin's LITESTONE® 3200E/2131H system is about 500 MPa, which represents an ideal range for ease of wet-out and fibre impregnation from a resin bath. The gel time at 23°C is more than 24 hours. Gel time at 140°C is about 210 seconds, thereby offering a combination of long potlife in the open bath and fast reactivity when pulled through the furnace, which is well suited for the requirements of the FRP rebar manufacturing process. The thermal and mechanical properties of the cured epoxy system (clear casting) are also listed in Table 1.

The excellent surface appearance and homogeneous cross-section of the rebar indicate uniform wet-out and good fibre impregnation during the process.

Tensile strength and tensile modulus of elasticity are the key characteristics for FRP rebar from a design standpoint due to the loadbearing requirements involved in RC applications (Table 2). The mean tensile modulus of the rebar was found to be 71.1 GPa, which is 59% higher than specification in ASTM D7957 (i.e. ≥44.8 GPa). Guar. transverse shear strength and Guar. bond strength to concrete are also well above the specifications provided in ASTM D7957, demonstrating the superior durability and performance of GFRP rebar

Tab. 2: Key mechanical and alkaline resistance testing data of #5 epoxy based GFRP

Standard test method	Test description	Spec. ASTM D7957	Test value (3 lot, 24 bars)	Unit
ASTM D7205 Tensile behavior 	Guar. tensile force	≥ 130	177	kN
	Mean tensile strength	n/a	1,172	MPa
	Mean tensile modulus of elasticity	≥ 44,8	71.1	GPa
	Mean tensile strain	≥ 1.1	1.7	%
ASTM D7617 Shear behavior 	Mean transverse shear strength	n/a	222	MPa
	Guar. transverse shear strength	≥ 131	182	MPa
ASTM D7913 Concrete bond strength 	Mean bond strength	n/a	17.9	MPa
	Guar. bond strength	≥ 7.6	12.9	MPa
ASTM D7705 Alkali resistance test 	Tensile strength retention without load	≥ 80	93.2	%

Tab. 3: Durability performance post alkaline solution treatment

Test method	Test description	Spec, FDOT 932	Values	Result
#3 BFRP rebar				
ASTM D7705	Tensile load retention (with load)	>70%	78.3%	Pass
ASTM D7617	Trans. shear strength retention	n/a	84.2%	n/a
ASTM E2160	Degree of cure	>95%	99.1%	Pass
	Glass transition temperature (DSC)	>100°C	139°C	Pass
#4 BFRP rebar				
ASTM D7705	Tensile load retention (with load)	>70%	92.3%	Pass
ASTM D7617	Trans. shear strength retention	n/a	107.6%	n/a
ASTM E2160	Degree of cure	>95%	99.4%	Pass
	Glass transition temperature (DSC)	>100°C	128°C	Pass
#5 BFRP rebar				
ASTM D7705	Tensile load retention (with load)	>70%	89.8%	Pass
ASTM D7617	Trans. shear strength retention	n/a	106.2%	n/a
ASTM E2160	Degree of cure	>95%	99.1%	Pass
	Glass transition temperature (DSC)	>100°C	139°C	Pass

produced with the LITESTONE® epoxy system. As per ASTM D7957, the alkali resistance for the GFRP bar was tested using ASTM D7705-12 (2019) Procedure A, which requires an accelerated environmental treatment involving a 90-day immersion in alkali condition at 60°C.

The tensile strength retention without load of tested #5 GFRP rebar is just above 93%, which satisfies the requirement of higher than 80% tensile strength retention provided in the standard. The excellent durability of GFRP rebar post immersion in alkali conditions reflects the outstanding corrosion resistance of this new epoxy system.

Epoxy based basalt fibre reinforced polymer (BFRP) rebar

While glass fibre remains the most commonly used reinforcement for FRP rebar, there has been an increasing interest in the use of basalt fibres as a reinforcement. That is driven in particular by the sustainability aspects inherent to the production of basalt fibres. The durability of BFRP bars used in RC applications remains largely unvalidated, in part due to the

lack of published data. LITESTONE® 3200E/2131H system was used to pultrude #3, #4, #5 size BFRP rebars. It is noted that the previous ASTM D7957 standard did not include specifications for BFRP rebar. The specifications proposed by the Florida Department of Transportation (FDOT) for BFRP, as part of FDOT 932 specs, were used as a reference. The results confirm that the tested epoxy based BFRP bars meets and exceeds durability requirements of the FDOT 932 specs when used for RC applications (Table 3). The detailed testing data can be found in our previous publication [2].

New standard for FRP rebar, now including epoxy

In 2023, ASTM International's composite materials committee (D30) published a new standard specification (ASTM D8505) for the latest generation of FRP rebar, which now includes both GFRP and BFRP with enhanced durability and performance requirements. As mentioned earlier, due to limited awareness, epoxy was not previously listed as an eligible

matrix in the ASTM D7957 standard for GFRP rebar. However, the new standard ASTM D8505 includes epoxy as an eligible matrix and the use of Olin's LITESTONE® epoxy system would offer a significant opportunity to upgrade and enhance the design and construction of durable concrete structures reinforced with FRP rebar.

Performance at scale

LITESTONE® 3200E/2131H is part of the Olin Epoxy LITESTONE® systems portfolio for composites. The LITESTONE® portfolio provide solutions for most epoxy composites applications (including rebar pultrusion) at the scale and supply security needed to support the long-term growth of the industry. □

More information:
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References

- [1] J. Constr. Eng. Manage., 2022, 148(9): 05022007
- [2] CAMX 2020, TP20-000000123