Performance Comparison Steel Rebar vs GFRP in Reinforced Concrete Structures

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ABSTRACT: The paper outlines the history of innovative ASTM specification for corrosion resistant steel and GFRP bars for concrete reinforcement. A review of the mechanical properties of steel vs GFRP rebars will be presented along with the design codes and tools that are available for engineers. Extensive design examples utilizing the ACI and AASHTO codes will be presented along with a thorough evaluation of the carbon footprint (EPDs) for all the reinforcing products.

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1 INTRODUCTION

1.1 *History of ASTM Specification for Steel*

Reinforcing steel, commonly known as rebar, plays a crucial role in reinforced concrete structures. Builders began experimenting with embedding iron in concrete due to lack of concrete tensile strength. The first ASTM specification for deformed reinforcing bars was introduced in 1910. Over the past 50 years, advancements in corrosion resistant rebars were essential for extending the service life of concrete structures, especially in marine environments, bridges and areas exposed to de-icing salts. The need for corrosion resistant steels lead to the development of ASTM A767[1] (Galvanized bars, 1979), ASTM A755[2] (epoxy coated bars, 1981), ASTM A955[3] (stainless steel, 1993, ASTM A1035[4] (Low-Carbon Chromium, 2004) and ASTM A1094[5] (Continuous Hot Dipped Galvanized, 2015).

1.2 *History of the ASTM Specification for GFRP*

GFRP rebar is an alternative to traditional steel reinforcement. GFRP is made from high-strength glass fibers embedded in a polymer resin matrix. The fibers provide the tensile strength while the resin matrix protects against environmental damage. GFRP rebars claim to be non-corrosive due to the fact that it does not contain any steel products. The GFRP rebars are produced in accordance to ASTM D7957[6] (Modulus of Elasticity 40 GPa, 2017) and ASTM D8505[7] (Modulus of Elasticity 60 GPa, 2023)

2 MECHANICAL PROPERTIES

2.1 *Steel Properties:*

Steel reinforcing bars are defined by their yield strength (60, 80 and 100 ksi), high tensile strength up to 150 ksi, ductility of minimum of 7 % and modulus of elasticity of 29,000 ksi. All ASTM Steel Specifications exhibit a yield point which is which is defined as the point that differentiate the elastic and plastic deformation. Typical designs of reinforced concrete structures take into consideration the yielding of the steel before the crushing of concrete, which is considered as a ductile failure.

2.1 *GFRP Properties:*

GFRP bars tensile strength vary depending on bar size and is reduced as diameter increases. The guaranteed tensile strength vary between 124 ksi (#2) and 77 ksi (#10) with a modulus of elasticity of 6,500 ksi conforming to ASTM D7958. However, a newer version of an ASTM D8505, the guaranteed tensile strength ranges from 150 ksi (#2) and 110 ksi (#10) with a modulus of elasticity of 8,700 ksi. GFRP tensile strength at bends is reduced by 40%. Designers need to be aware that GFRP rebars can undergo creep-rupture under sustained loading and fatigue rupture under cyclic loading. GFRP reinforcement shall be proportioned such that sustained designed stress does not exceed 0.30 of the design tensile strength.

2.2 *GFRP vs Steel Properties:*

Table 1 illustrate the differences between the mechanical properties of GFRP rebars and corrosion resistant steel rebars. Additionally, the stress vs strain characteristics of GFRP vs Steel bars are illustrated in Figure 1.

Table 1 Typical Mechanical Properties for #8 rebar

	ASTM D7958	ASTM D8505	ASTM A615 Grade 60 / 413MPa	ASTM A615 Grade 80 / 550MPa	ASTM A615 Grade 100 / 690MPa	ASTM A1035 Grade 100 / 690MPa
Min. Yield Strength, Ksi	NA	**NA**	**60**	**80**	**100**	**100**
Min. Tensile Strength, Ksi	87	120	**90**	**100**	**115**	**150**

Min. Elongation, %	1.1	1.1	9	7	7	7
Min. Actual Tensile/Yield (T/Y Ratio)	-	-	1.10	1.10	1.10	1.25
Modulus of Elasticity, Ksi (Mpa)	6,500 (44,816)	8,700 (59,984)	29,000 (199,948)	29,000 (199,948)	29,000 (199,948)	29,000 (199,948)

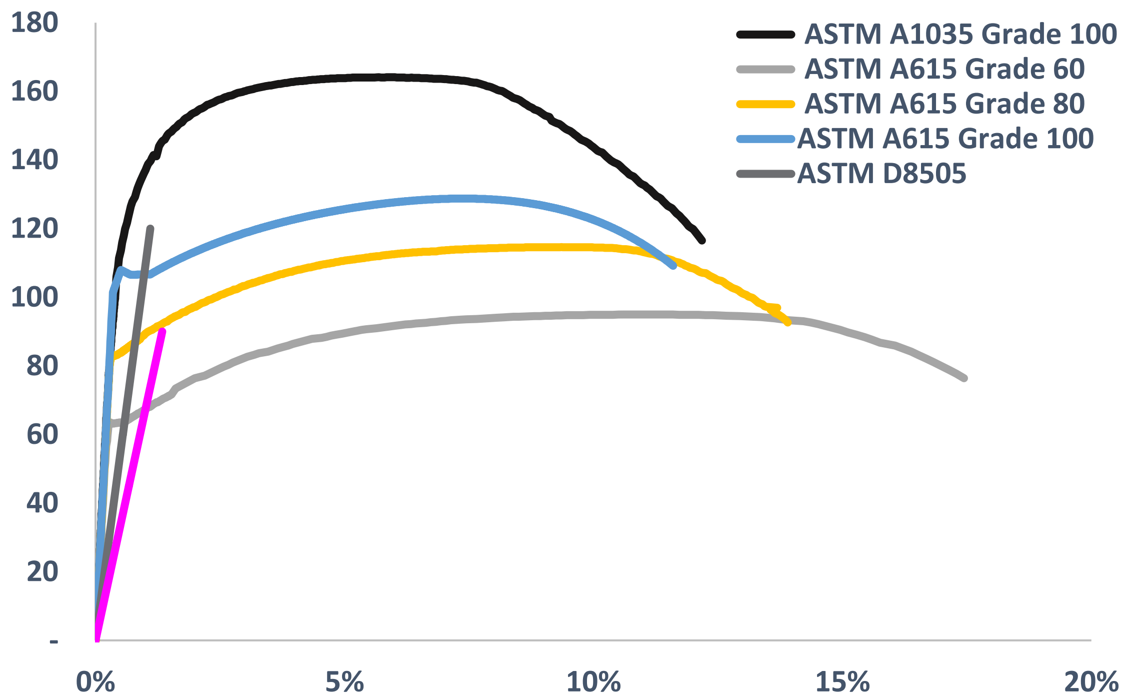


Figure 1 Stress vs Strain of #8 reinforcing bars

3 DESIGN PHILOSOPHY DIFFERENCES

While corrosion resistant steels are designed in accordance with the American Concrete Institute, ACI 318-22 design code and guidelines adhering to the principles of tension controlled failure of the reinforcement. The GFRP design guidelines in accordance to ACI 440-1 design code allows both concrete compression failure or tension controlled failure of GFRP reinforcement as can be seen from Figure 2.

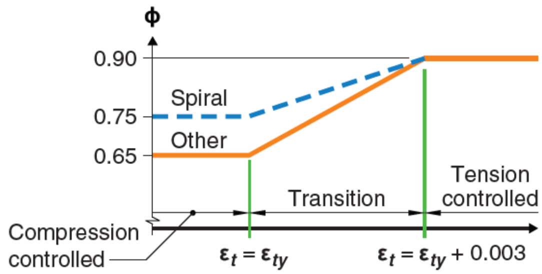


Fig. R21.2.2b—Variation of ϕ with net tensile strain in extreme tension reinforcement, ε_t.

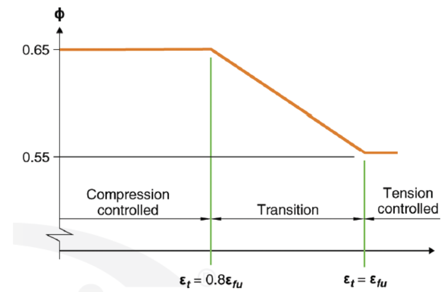


Fig. R21.2.2—Variation of ϕ with net tensile strain in extreme tension reinforcement ε_t.

Figure 2 Design Philosophy failures between GFRP (right) and Steel designs (left)

4. DESIGN EXAMPLES

GFRP D7957 vs Steel ASTM A615 (ACI 440.11-22 vs ACI 318-22

Design a rectangular beam for service load moments M_{DL} = 109 kip-ft including self-weight

(ω_{DL} = 1.0 kip/ft) and M_{LL} = 239 kip-ft (ω_{LL} = 2.2 kip/ft with 20% sustained). fc' = 5000 psi (344 Bar) and simply-supported span l = 29.5 ft.(8.99 m)

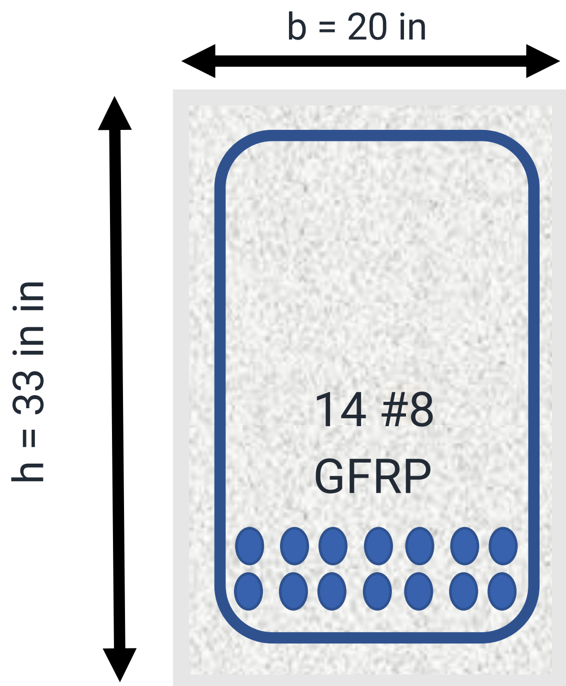
Use #8 GFRP Bars ASTM D7957

GFRP Material Properties:

f_{fu} = 84.5 Ksi (582 MPa)

E_f = 6500 Ksi (44816 MPa)

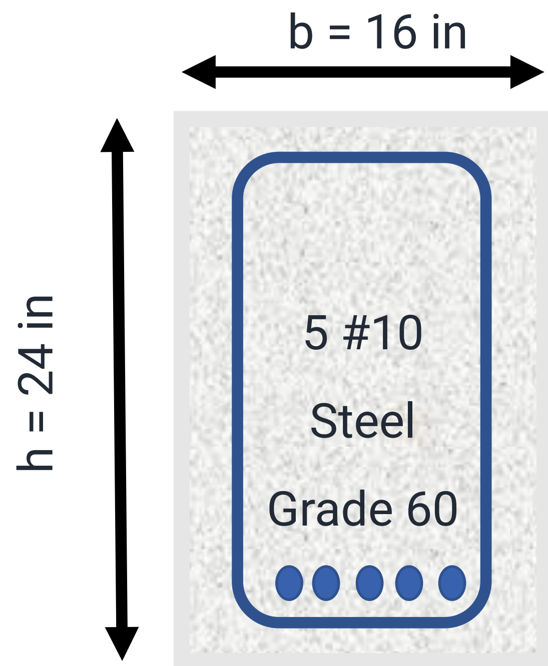
$$\varepsilon_{fu} = \frac{f_{fu}}{E_f} = \frac{71.9\ Ksi}{6500\ Ksi} = 0.011$$



GFRP Reinforced Concrete Beam

A_f = 11.06 in^2

(71.35 cm^2)



Steel Reinforced Concrete Beam

A_s = 6.35 in^2

(40.97 cm^2)

5. CONCLUSIONS

Main factor affecting dimensions of concrete beams reinforced with GFRP rebars and increased reinforcement was deflection Control.

GFRP reinforced concrete beam required 75% more reinforcement than Grade 60 steel reinforced concrete beam.

GFRP reinforced beam required 70% more concrete volume than steel reinforced concrete beam.

6. REFERENCES

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