KACE

Technical material comparison

Composites vs. traditional metals in industrial applications

Material overview and properties

The choice of structural materials directly impacts performance, lifecycle, and operational economics. The table below provides a qualitative comparison of structural steel, aluminum, glass fiber reinforced polymer (GFRP), and carbon fiber reinforced polymer (CFRP).

Material	Weight category	Corrosion resistance	Part integration *	Price level (raw material)
Structural steel (S355)	🔴 High	🔴 Poor (corrodes without treatment)	🔴 Low (requires welding/bolting)	🟢 Low
Aluminum (6082-T6)	🟡 Medium	🟡 Moderate (prone to galv. corrosion)	🟡 Medium (machining/ extrusion)	🟡 Medium
Glass fiber composite (GFRP-Uni)	🟢 Low	🟢 Excellent (inherently non-corrosive)	🟢 High (can be molded)	🟡 Medium / high
Carbon fiber composite (CFRP-Uni)	🟢 Very low	🟢 Excellent (inherently non-corrosive)	🟢 Very high	🔴 High

** Part integration means that composite materials allow complex geometries to be molded as a single unified piece, rather than welding or bolting numerous smaller components together as required with metals.*

Technical material data

Material type	Density (ρ, g/cm^3)	E-modulus / stiffness (E, GPa)	Tensile strength (σ, MPa)	Specific stiffness * (GPa/(g/cm^3))	Specific strength * (MPa/(g/cm^3))
Structural steel (S355)	7.85	210	510	26.8	~60-80
Aluminum (6082-T6)	2.70	70	310	25.9	~100-120
Glass fiber composite (GFRP-Uni)	1.8 - 2.1	38 - 45	900	18 - 25	~350 - 550
Carbon fiber composite (CFRP-Uni)	1.6	135 - 175	1500	84 - 109	~800 - 1500

** Specific stiffness and specific strength represent the mechanical properties of the material relative to its weight. A higher value indicates greater performance per kilogram of material.*

What do the technical data mean in practice?

Strength-to-weight ratio: Carbon fiber reinforced polymer (CFRP) delivers nearly 15 times the specific strength of steel and close to 4 times the specific stiffness. This translates to immense weight reductions in structures subjected to tensile loads.

Fatigue failure: Metals like steel and aluminum are prone to developing microscopic cracks over time under cyclic loading. Composites possess a fundamentally different internal structure where fibers arrest crack propagation, providing exceptional fatigue resistance under repetitive stress.

Thermal expansion: Aluminum undergoes significant dimensional changes with temperature fluctuations. Conversely, carbon fiber features a coefficient of thermal expansion near zero along the fiber direction, making it ideal for applications requiring extreme dimensional stability.

Advantages of glass fiber composite (GFRP) vs. steel and aluminum

Glass fiber reinforced polymer (GFRP – Uni) represents a highly attractive alternative to traditional materials such as structural steel (S355) and aluminum (6082-T6), particularly in applications where low weight, corrosion resistance, and high specific performance are paramount.

A primary advantage of GFRP is its low density ($\rho \approx 1.8–2.0$ g/cm^3), compared to both steel (≈ 7.85 g/cm^3) and aluminum (≈ 2.70 g/cm^3). This enables substantial weight savings, which is especially critical in demanding applications where reducing mass lowers energy consumption, increases payload capacity, and simplifies structural foundations or handling.

In terms of **specific strength** (σ/ρ), GFRP offers clear advantages. While its absolute tensile strength ($\sigma \approx$ 700–1000 MPa) is comparable to or slightly below high-strength steel, the low structural weight results in a specific strength multiple times higher than both steel and aluminum. This makes GFRP exceptionally efficient for structures where strength-to-weight efficiency is critical.

Regarding **stiffness characteristics**, the analysis indicates that GFRP has a lower absolute E-modulus ($E \approx$ 38–45 GPa) than steel ($\approx$ 210 GPa) and aluminum ($\approx$ 70 GPa), meaning it is less rigid in an absolute sense. Nonetheless, its specific stiffness ($E/\rho \approx 18–25$ GPa/(g/cm^3)) remains highly competitive, closely approaching that of aluminum. This renders GFRP well-suited for structural configurations where weight reduction takes precedence over absolute rigidity.

Another crucial benefit of GFRP is its **corrosion resistance**. Unlike steel, which requires extensive surface treatments and ongoing maintenance to prevent rust, GFRP is naturally resilient against moisture, chemicals, saltwater, and aggressive atmospheric environments. This significantly lowers lifecycle costs and extends asset longevity across chemical processing, transportation, and marine infrastructure.

Furthermore, GFRP enables advanced **material optimization through directional alignment (unidirectional fibers)**. By orienting the load-bearing fibers precisely along the primary stress paths, engineers can optimize strength and stiffness exactly where required—a tailoring capability unachievable with isotropic metals like steel and aluminum.