Focus on Design

Formula 1 racer gears up with carbon fiber

Toughened prepreg design provides structural durability for highly loaded Honda gearbox.

Design Results:

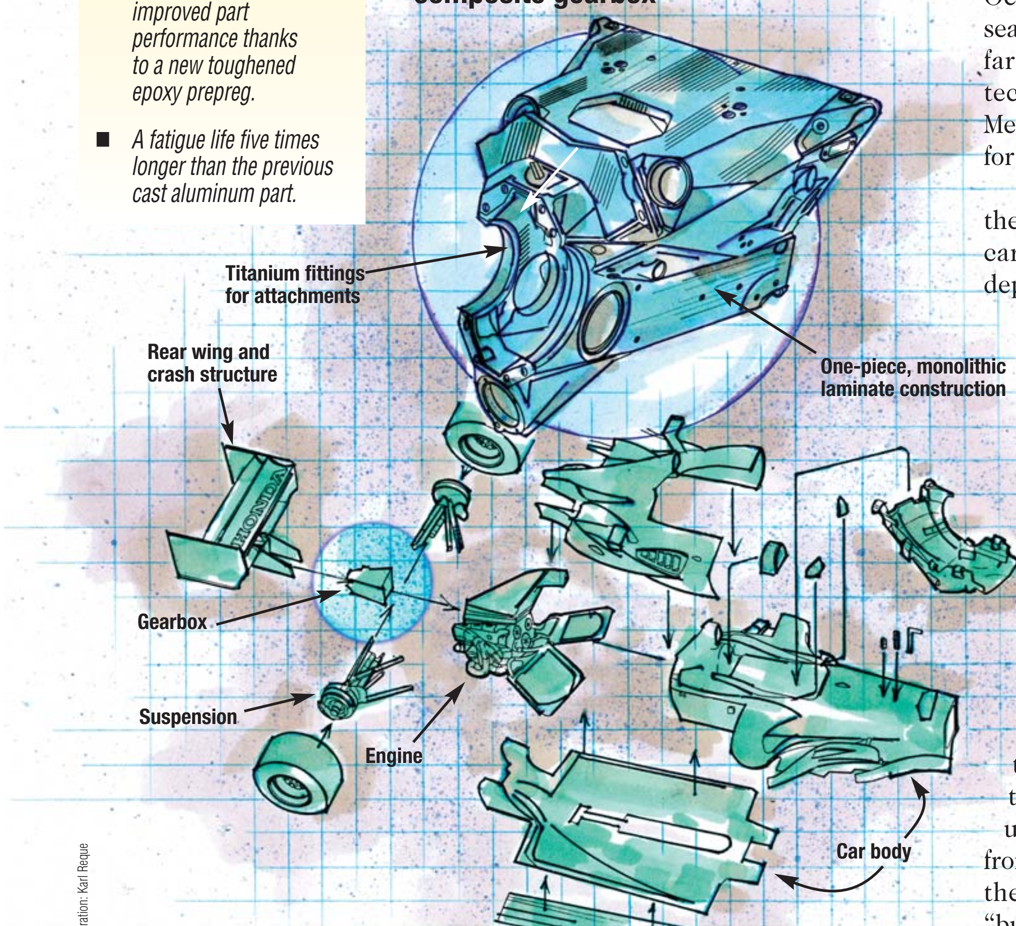
- *A structural chassis element that is 30 percent lighter and has 14 percent more torsional rigidity than an aluminum alternative.*
- *A dramatic increase in interlaminar fracture toughness and greatly improved part performance thanks to a new toughened epoxy prepreg.*
- *A fatigue life five times longer than the previous cast aluminum part.*

Of the myriad forms of motorsports, Formula 1 auto racing is the most advanced in terms of both technology and money. Budgets consume on the order of $300 million to $400 million (USD) per year, and teams numbering in the hundreds labor to build, maintain, test and race the complex machines. Although the FIA (Federation Internationale de l'Automobile) issues specific rules each year that govern the "formula" for these sleek, extremely high-powered cars, a team's success depends on making room within those rules for ingenuity and innovation.

One recent innovation is a composite gearbox developed by the B.A.R. Honda Formula 1 design team, now the Honda Racing F1 Team (Honda Motor Co. purchased British American Tobacco's share of the team in October 2005). Introduced during the 2004 season, the gearbox — not a first for F1 but by far the most successful example of the technology — won the prestigious Simms Medal, presented by the U.K.'s Royal Auto Club for the best innovation in motorsports.

"We consider the composite gearbox to be the 'jewel in the crown' in terms of our race car design," says Honda Racing F1 Team's deputy technical director Gary Savage, who holds a Ph.D in mechanical engineering and is a 16-year veteran of Formula 1 car design. The gearbox's design has continued to evolve from the first 2004 version and is now even lighter and easier to manufacture, he asserts.

HONDA RACING F1 Team's composite gearbox



Performance required

The gearbox is a roughly pyramidal enclosure, approximately 46 cm long by 22 cm high by 30 cm at its widest point (18 inches by 9 inches by 12 inches), which encases the car's high-grade steel gears that are responsible for transmitting the engine's rotational power to the rear wheels. Made from a monolithic, uncored laminate that varies in thickness from 2 mm to 4 mm (0.08 inch to 0.16 inch), the gearbox case includes two interior "bulkheads" that support the gears and half-

Source: Honda Racing

The 2006 version of Honda's F1 car incorporates an all-composite gearbox made with a toughened, high-temperature prepreg from Cytec Engineered Materials.

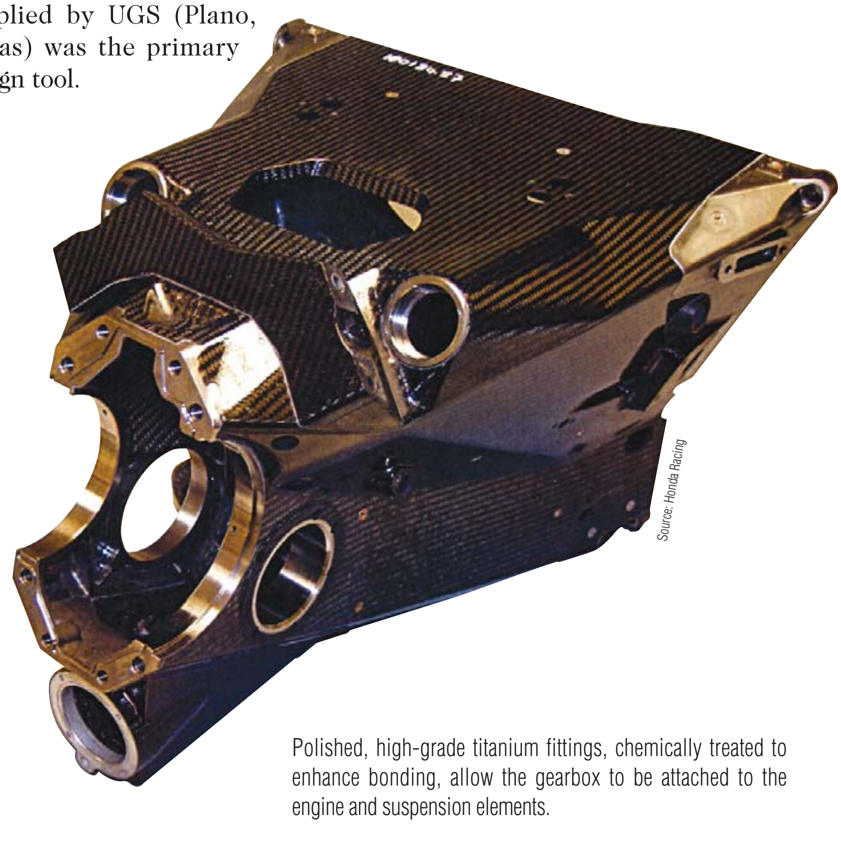
shafts. A number of high-grade titanium exterior fittings and attachment points (chemically treated to enhance bonding) allow the gearbox to be mounted to the engine and rear axle/suspension elements. Because of the high loads it has to endure and the various car parts that connect to it, the gearbox is considered a primary structural element of the car's overall chassis design.

Savage says the composite solution came about because of the lackluster performance of previous aluminum versions (some teams also use titanium or magnesium). Because weight and low inertia are so critical at this level of racing, aluminum castings for the gearbox had to be extremely thin and, as a result, rapidly developed fatigue cracks due to imposed vibrational and torsional stresses. "The original metal box didn't have sufficient fracture toughness and fatigued too easily — it would last anywhere from 1,200 km to maybe 8,000 km before needing repair or replacement," says Savage. "We would go through 30 or 35 gearboxes each season."

A replacement composite gearbox, however, would have to withstand extreme loads. It would need not only to hold up under the stress of transmitting 900 hp from the engine to the rear wheels, but also have sufficient stiffness to resist huge cornering, acceleration and braking loads imposed by the wheels, axles and suspension — loads up to 5G are commonplace. In addition to the operational stresses, the gearbox also would have to survive the peak loads imposed by the FIA-required rear crash test — a 14 m/sec impact with a 780 kg/1,700 lb weight, equivalent to being hit from behind by a fully loaded car. Operating temperatures in excess of 150°C/302°F would be likely because of gearbox proximity to the engine exhaust and the frictional heat generated by the gears. Designing the part for such daunting performance requirements required a combination of sophisticated modeling capabilities and a good measure of composites savvy, says Savage.

Pushing materials to the limits

"The design procedure used in Formula 1 is 'semi-quantitative' — a combination of finite element stress analysis and prior knowledge and experience, coupled with laboratory testing," says Savage. Purely theoretical numerical analysis isn't practical, he explains, because of limited materials and structural data and the severe time pressures of the sport. Team engineers, therefore, came up with a best estimate for the gearbox's configuration, given the shape and volume of the internal gears, the required attachment points, the need to transition from the three-dimensional shape at the rear crash structure down to a simplified engine mount area and, very importantly, concern for part manufacturability. Unigraphics NX CAD design software supplied by UGS (Plano, Texas) was the primary design tool.



Source: Honda Racing

Polished, high-grade titanium fittings, chemically treated to enhance bonding, allow the gearbox to be attached to the engine and suspension elements.

Source: Honda Racing

The composite gearbox is much more fatigue-resistant than previous aluminum versions, and has exceeded design life expectations.

MSC.Software Corp. (Santa Ana, Calif.) supplied the NASTRAN and PATRAN finite element modeling programs used to refine the design. Engineers subjected the resulting computer model to a wide range of load cases to determine the margin of safety (MoS) to first ply failure. "Any MoS value greater than zero was good," notes Savage.

While certainly a devotee of composites, Savage points out that despite many advantages, composites are limited by relatively poor interlaminar properties. "The energy-absorbing capability of composites is a consequence of the 'work of fracture,'" he explains. "The increased work of fracture obtained from higher-strength fibers increases energy absorption, but this can only be achieved if you can reduce the tendency to delaminate under load — the resin's toughness plays a significant role in optimizing the part's ability to absorb energy." Thus, he was very interested when composite supplier Cytec Engineered Materials (Tempe, Ariz.) introduced its 2035 super-toughened epoxy, specifically targeted to motorsports. The resin is an improved version of Cytec's 2020 epoxy prepreg resin, with higher impact resistance, better damage tolerance and good high-temperature performance, thanks to added thermoplastic toughening agents.

Savage's team developed a testing regime to qualify the new prepreg's performance improvements. Using the short beam shear test on a three-point flexure test fixture (see "Testing Tech," *HPC* September 2005, p. 9), test coupons made with 2035 and 2020 resins were prepared and tested for interlaminar shear strength. Interlaminar fracture toughness was determined with a double cantilever beam test, using coupons that had a "crack initiator" or small piece of aluminum foil, coated with release agent, placed between the central plies; crack length measurement was made with small gauges on one side of the test specimens. Tests were conducted in the Honda team's in-house laboratory, with Instron Corp. (Norwood, Mass.) test machines.

When test results showed improved tensile and interlaminar shear strength and almost double the interlaminar fracture toughness compared to the 2020 specimens made with intermediate-modulus carbon fiber, Savage was sold and proceeded to specify the new resin system for not only the gearbox, but other composite parts on the car as well. In the last year, Cytec has continued to modify the resin and now offers a version with equivalent toughness and even higher temperature performance, known as 2040, which the Honda team is now using to make its 2006 parts.

An evolutionary part

While the gearbox part is produced as a single piece, it requires multipart tooling to enable part removal after cure. Tooling is fabricated with Cytec's carbon/epoxy tooling prepreg. The part material is a 200 g/m^2, 2x2 carbon/epoxy twill prepreg, impregnated with the 2040 resin system. Although a tight fit, technicians are able to place anywhere from 10 to 18 plies into the tool, with a higher number of plies at more highly stressed locations, to form a quasi-isotropic layup. The two bulkheads, combining carbon and titanium, are hand layed up in separate tools. The bulkheads and titanium engine and suspension mounts are bonded into place with a two-part Loctite epoxy paste adhesive from Henkel Corp. (Bay Point, Calif.). Savage says that continual improvements in tool design, like a slightly smaller draft, have resulted in a simpler part shape and correspondingly easier lamination process that can be completed in half the time required for the original 2004 prototype. "Unfortunately we don't produce enough parts to justify a more efficient method like automated resin transfer molding (RTM)," he notes.

When compared to the original aluminum version, the current 2006 composite gearbox is 30 percent lighter, has 14 percent more torsional rigidity and 19 percent greater lateral stiffness. According to Savage, fatigue life has improved by 500 percent, compared to aluminum, and fewer than half the number of gearboxes are needed, despite increased mileage. Individual composite gearboxes, so far, have lasted more than 40,000 km (about 24,850 miles). "They may have an unlimited life compared to the aluminum version," Savage speculates, "although we probably won't know for sure, because the parts are obsolete before they wear out as a consequence of the pace of development within the sport." Such developmental changes will undoubtedly lead to even greater innovations for lower weight and higher performance, in a sport where the cars are already more than 85 percent composite. HPC

— *Sara Black, Technical Editor*

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