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Thermoplastic Composites for the Hot Jobs

New test data characterize the high-temperature performance of TP composites.

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Applications for the high-performance thermoplastic composites are boundless. But, as with all new materials, development of design data lags behind, making relatively cautious design approaches necessary. The result is that all of the true value and efficiency of the materials may not be fully used.

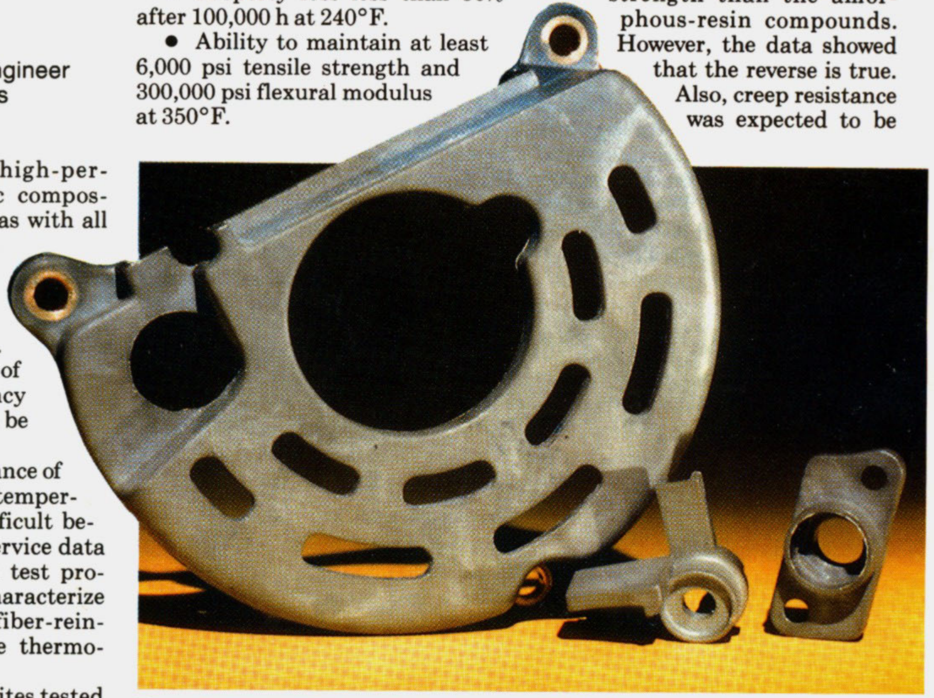
Assessing the performance of the materials at elevated temperatures is particularly difficult because almost no test or service data exist. For this reason, a test program was initiated to characterize glass-fiber and carbon-fiber-reinforced, high-temperature thermoplastic composites.

Thermoplastic composites tested are based on polyethersulfone (PES), polyetherimide (PEI), HTA (a new ICI high-temperature amorphous resin similar to PES), polyphenylene sulfide (PPS), polyetheretherketone (PEEK), and polyetherketone (PEK). A melt-processable fluoropolymer, polyfluoroalkoxy (PFA), is also included in the study.

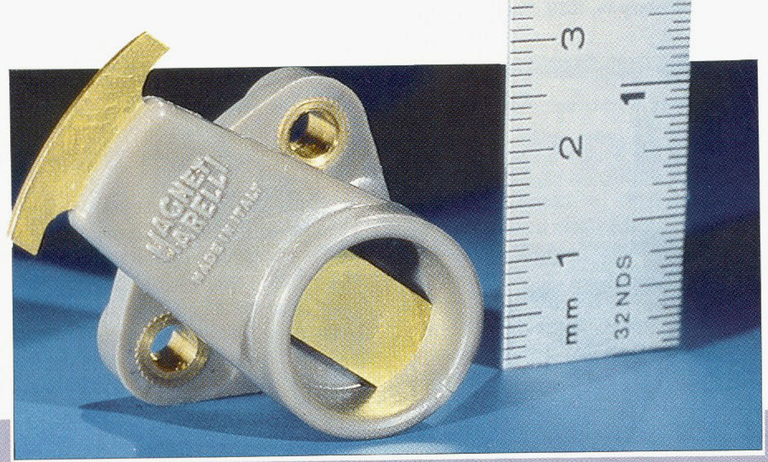
In establishing ground rules for the test program, a high-temperature thermoplastic material was considered to be one that met one or more of these criteria:

- Ability to withstand short-term, no-load exposure to a temperature of 400°F.
- Property loss less than 50% after 100,000 h at 240°F.
- Ability to maintain at least 6,000 psi tensile strength and 300,000 psi flexural modulus at 350°F.
- Appreciable chemical resistance at elevated temperature.
- Heat-deflection temperature at 264 psi exceeding 400°F.

Most test results were in the ranges and general material sequences anticipated. But some data reversed expected directions. For example, over a temperature range of 300 to 450°F, the crystalline-resin-based composites were thought to offer higher ultimate strength than the amorphous-resin compounds. However, the data showed that the reverse is true. Also, creep resistance was expected to be better in the amorphous materials. Yet, stress-relaxation characteristics of the crystalline-based composites proved to be superior.

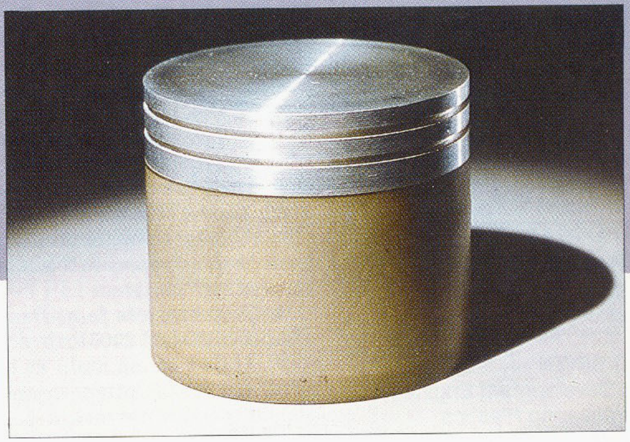


For the alternator end cap in its Formula One racecar engine, Ferrari Motor Corp. needed a material that could maintain its strength, integrity, and electrical resistance in continuous service at temperatures as high as 300°F. The nod went to a 30% glass-fiber-reinforced PEEK molding, which also provides excellent resistance to oils and greases and to the vibration in the service environment. The two small pieces, also molded from 30% glass/PEEK, are connector supports.



Light weight, ease of assembly, and resistance to transmission oil up to 356°F are among the reason why INA Corp. chose a 30% glass-fiber-reinforced PES composite for roller-bearing cages used in automotive transmissions. The components are molded to extremely close tolerances, eliminating many machining operations needed by the metal cages formerly used.

Polyetheretherketone, in both reinforced and unreinforced grades, serves in many high-temperature applications. The rotor arm for the Ferrari Testarosa rotates at rates to 3,500 rpm at operating temperatures to 248°F The neat PEEK resin meets all requirements for strength, dimensional stability, and electrical properties. The lightweight piston skirt, molded from a 30% carbon-fiber reinforced PEEK, is used in diesel engines, where dimensional stability is required at temperatures as high as 375°F.



Thermal properties

The composites in the study involve both crystalline and amorphous base resins. The crystalline resins are PEEK, PEK, PPS, and PFA; PES, PEI, and HTA are classified as amorphous.

Amorphous resins undergo a glass-transition temperature, (T_g), above which, mechanical properties are low. The resins soften over a broad temperature range and have no specific melting point (T_m). In contrast, crystalline resins have a distinct T_m, and they may also have a minor T_g or other thermal transitions.

In fiber-reinforced composites, the matrix transfers stress to the reinforcement, vastly increasing load-bearing capability. For short-term, high-heat applications, the value of heat-deflection temperature (HDT) under load can be used to predict performance. Composite integrity should be maintained up to T_m or T_g.

Composites having chemically coupled fibers can bear short-term loads up to the T_g. HDTs of those not chemically coupled, such as PFA, are well below their T_g.

Thermal properties of glass-fiber and carbon-fiber-reinforced resin systems are nearly the same. The HDTs of several carbon-fiber-reinforced composites are slightly above those of their glass-fiber-reinforced counterparts, but long and short-term load-bearing capabilities are nearly identical. Flammability ratings of all composites tested are V-0 (UL Subject 94) without flame-retarding additives.

Mechanical, physical properties

Composites have higher specific gravities than do the base resins. Those containing carbon are lighter than those containing the same level of glass, however, because of the lower specific gravity of carbon compared to that of glass (1.80 vs 2.54).

In all cases, carbon fibers provide higher strength and stiffness properties than does glass reinforcement. For example, in the same base resin, carbon reinforcement increases tensile strength by 20% and flexural modulus by 50% over those properties in a glass-reinforced analog.

In addition, long carbon-fiber re-

PHYSICAL, MECHANICAL
Reinforcement (wt %)
Glass
Carbon
Specific gravity
Water absorption, 24 h (%)
Mold shrinkage (in./in.)
Tensile yield str (10^3 psi)
Flexural strength (10^3 psi)
Flexural modulus (10^6 psi)
Impact strength, Izod
Notched/unnotched (ft-lb/in.)
THERMAL
Melting point (°F)
Glass-transition temp (°F)
Heat-deflection temp, 264 psi (°F)
Continuous-use temp, UL 746 (°F)

[a] Long-fiber (Verton) composite.