

Development of CFRP Propeller Shaft

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ABSTRACT

A propeller shaft made of carbon fiber reinforced plastic (hereafter referred to as “CFRP”), a lightweight material, was developed and used on the 2005 model year LEGEND.

To utilize the characteristics of carbon fiber (CF) which is an anisotropic material, the CFRP tube was produced using filament winding molding method. The winding angle of CF was set at 30 degrees to help ensure tube torsional strength. The press-fitting allowance of the metallic stub shaft in the CFRP tube at the joint was optimized, and adequate margin in strength and durability was assigned with respect to other metallic members to help ensure reliability.

The press-fitted portion of the stub shaft was designed such that the tube broke when subjected to the specific axial load, and the ability of the vehicle to absorb shocks during a collision was ensured.

A 30% savings in weight was achieved in the developed CFRP propeller shaft compared to the conventional steel tube propeller shaft.

1. Introduction

The customers' demand for safe and lightweight automobiles has been growing steadily in recent years. The appearance in the automotive field of lightweight materials that were very expensive in the past is noticeable. The application of carbon fiber reinforced plastics (CFRP) mainly in the aerospace industry is now pervading the automotive industry. The strength and stiffness of this material are being utilized effectively for parts development⁽¹⁾.

Conventionally, CFRP was mainly used in the development of the external parts for the hood, fender, and spoiler in racing cars and prototype vehicles, but it is now also being used in the propeller shaft, which is one of the mainstays of the drive system of the vehicle⁽²⁾.

The 2005 model year LEGEND is a 4WD vehicle fitted with the newly developed Super Handling-All Wheel Drive (SH-AWD) system. This paper describes the technical overview of the CFRP

propeller shaft fitted on the 2005 model year LEGEND. The shaft is shown in Fig. 1.

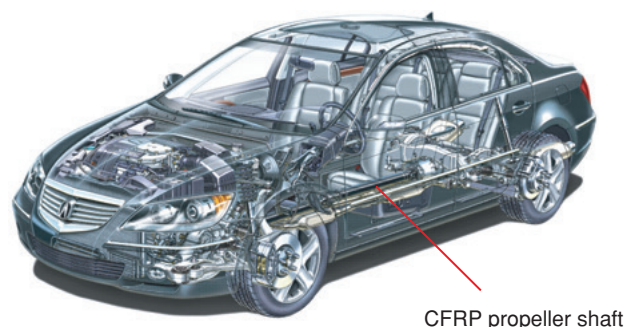


Fig. 1 Perspective drawing of new LEGEND

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2. Materials and Method of Manufacture

2.1. Characteristics of CFRP

Because the reinforcing material carbon fiber (CF) has a low specific gravity, CFRP possesses high specific strength and stiffness, enabling the weight of parts to be reduced. However, the material also displays strength anisotropy dependent on the reinforcing fibers. Figure 2 shows the relationship between the direction of the fibers and the tensile strength of the material. Tensile strength is high in the fiber direction (0°), but drops to approximately one-tenth the original figure when the fibers are aligned at right angles (90°).

This characteristic can be exploited to achieve further weight reduction by aligning the fibers in the direction of the stress on the part.

2.2. Filament Winding Molding Method

Figure 3 shows the manufacturing process for the propeller shaft. CFRP tubes molded by filament winding (FW) method are cut to predetermined dimensions and metal stub shafts are press-fitted into the ends to complete the shaft. The remainder of this section will discuss FW molding, which is employed to exploit the characteristics of the CF.

24K PAN-based CF is applied, and a bisphenol A-based epoxy resin is applied as hardening resin. The CF is served from a creel stand. It is passed through a resin bath to impregnate it with epoxy resin, after which it is wound around a mandrel. The carbon fiber winding is produced from a hoop layer wound at an approximate right angle to the direction of the tube diameter and a helical layer wound at an angle. The helical layer is essential to ensuring the

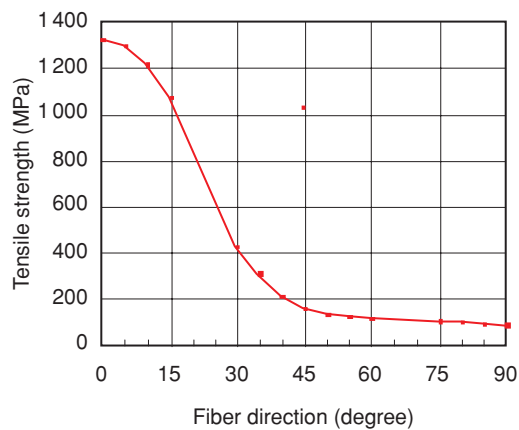


Fig. 2 Effect of fiber angle on tensile strength

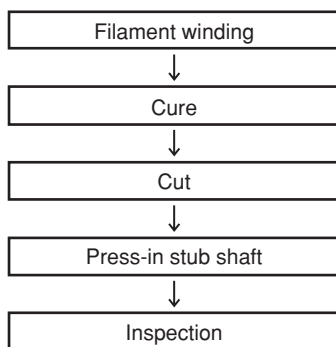


Fig. 3 Manufacturing flow for shaft

torsional strength of the propeller shaft. In the new shaft the helical layer is wound at an angle of 30° . When a preset amount of CF has been wound around the mandrel, it is placed in a heating oven and cured at 130°C for 120 minutes. The heating oven is equipped with a rotating mechanism to help prevent deformation of the tube during curing. The FW molding process is completed when the CFRP tube is removed from the mandrel after curing. The tube then proceeds to the next process, in which it is cut into lengths. Figure 4 shows a schematic of the FW molding process.

3. Basic Construction and Target Performance

In vehicles that use a propeller shaft such as four-wheel drive vehicles, the propeller shaft may obstruct the backward movement of the engine when the vehicle is involved in a collision.

To help prevent this, the structure of the propeller shaft must be designed to break stably in the axial direction when subjected to a specific load.

The basic construction of the CFRP propeller shaft is shown in Fig. 5. The CFRP propeller shaft is made of the No. 1 shaft, No. 2 shaft, three isokinetic joints, and the center bearing support.

A CFRP tube molded by FW molding was used, and the serrated portion of the metallic stub shafts was press-fitted at the two ends of the tube to complete the shaft.

In a conventional propeller shaft, the steel tube and stub shaft are joined by welding so an extremely high strength is retained to transfer the driving torque.

In the CFRP propeller shaft, the CFRP tube and stub shaft are joined by press-fitting the serrated portion. By adjusting the form of the serrated teeth, the number of teeth, the press-fitting length, and the press-fitting compaction allowance, the original function namely the transmission of the driving torque has been balanced to

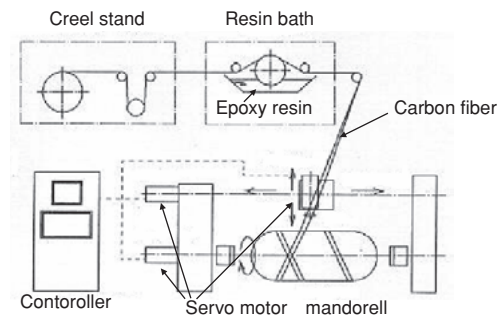


Fig. 4 Filament winding molding

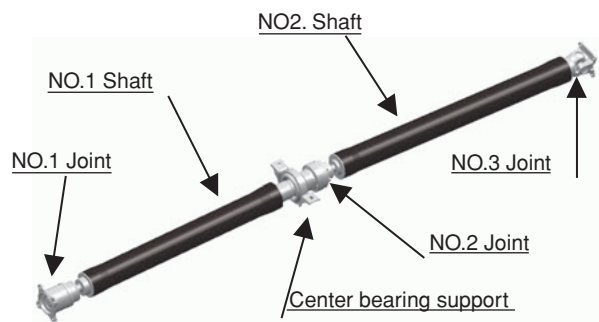


Fig. 5 Construction of CFRP propeller shaft

a higher level with the breakage in the axial direction at low load during a collision⁽³⁾. A diagram of the serrated portion is shown as Section AA in Fig. 6. The diagram demonstrates how press-fitting causes the stub shaft to bite into the inner walls of the CFRP tube.

The torsional strength of the metal stub shaft was established with reference to torque demands in an actual vehicle. The torsional strength of the press-fit portion of the stub shaft and the CFRP tube are designed to be higher than that of the stub shaft, to help ensure that it is the stub shaft that will break if the allowable torque is exceeded.

From considerations of the practicality of the vehicle, a sliding arrangement was used in the No. 1 joint so that the CFRP propeller shaft is protected from damage when engine displacement occurs during normal running or a light collision. The construction for absorbing the displacement is shown in Fig. 6.

When a larger load than that produced in a minor collision is imparted to the vehicle chassis, the load generated by rearward motion of the engine causes the stub shaft, the serrated portions of which were press-fitted into the ends of the tube, to slide inside the tube and break it from within.

It is essential that the breakage from within the tube occur at an appropriate load to help ensure that the shaft does not obstruct the rearward motion of the engine.

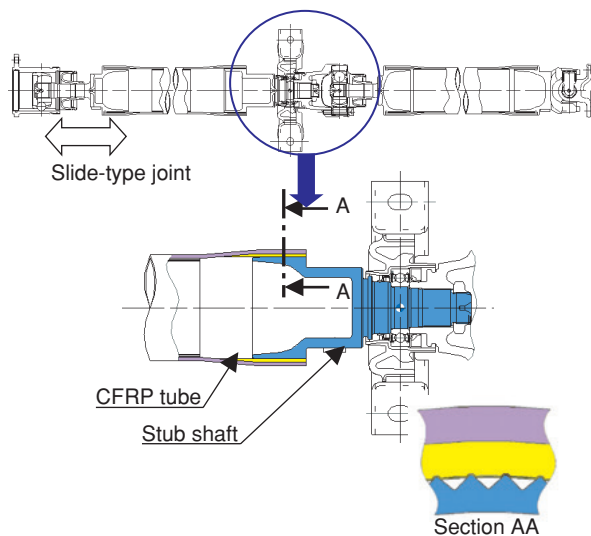


Fig. 6 Structure prior to breaking

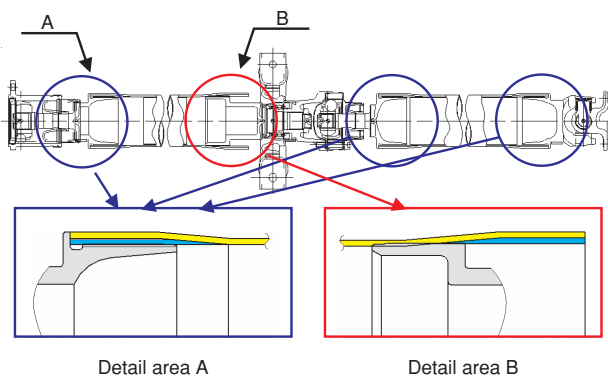


Fig. 7 Detail of press-in structure and shaft break mechanism

The construction before the breakage is shown in Fig. 6, while the construction after the breakage is shown in Detail B in Fig. 7.

To help ensure that the tube would only break at loads above a specific level, it was essential to control which press-fitted stub shaft section would slide inside it and cause the breakage. As shown in Fig. 7, the stub shaft is pressed into the propeller shaft at four locations. A structure was therefore devised to enable the press-fitted section which would break the tube when a load was applied in the axial direction to be specified, thereby ensuring predictable breakage of the tube.

A flange was fitted at the location (Detail A) in the stub shaft and touching the end face of the CFRP tube such that it does not cause breakage of the CFRP tube as shown in Fig. 7. Even if a load were applied, the stub shaft would not be pushed into the CFRP tube.

This arrangement enabled the position of breakage of the CFRP tube to be controlled.

4. Characteristics of Individual Parts

4.1. Load Performance

Figure 8 shows the target load and the relationship between load and stroke with the CFRP propeller shaft of the 2005 model year LEGEND.

Testing confirmed that the tube broke when the press-fit section of the stub shaft was pressed inside it, and that this breakage occurred predictably at a low load.

4.2. Torsional Strength

The propeller shaft was subjected to torsion tests under the type of conditions found in an actual vehicle. No cracks occurred in the joint sections under normal torque conditions. When excess torque was applied, a torsion breakage occurred at the press-fit section of the stub shaft, as predicted by the initial design specifications.

Fatigue tests were also conducted, and no cracks or other defects which would affect performance occurred at the joint sections of the shaft, confirming the achievement of an equivalent level of performance to that of a steel propeller shaft.

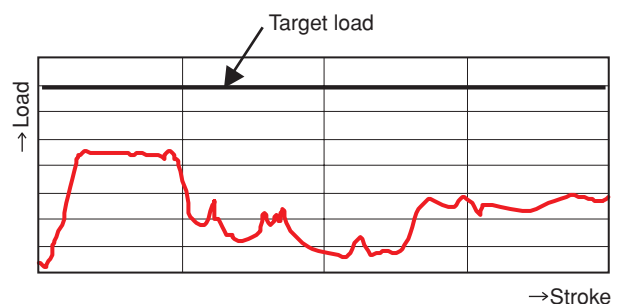


Fig. 8 Load characteristic

4.3. Environmental Resistance

The environmental resistance of the CFRP tube was confirmed.

To confirm resistance to engine oil, AT fluid, acid, alkali, and grease, the CFRP tube was subjected to immersion treatment, then subjected to a compression test with a load applied on the circumference of the tube to measure the strength retained by the tube as shown in Fig. 9. No difference in strength was observed before and after the treatment, thus confirming that no material deterioration occurred with respect to the items mentioned above.

In addition, no decline in performance was observed in durability tests conducted under actual use conditions, designed to test factors such as heat resistance and water resistance.

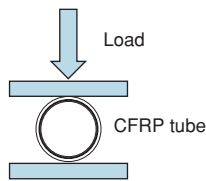


Fig. 9 CFRP compression test

5. Conclusion

A propeller shaft made of CFRP was developed and applied on the 2005 model year LEGEND.

1. The shaft was broken at the desired crushing load considering the construction of the press-fitted part of the stub shaft, and the performance of the actual vehicle in absorbing the load during collision was confirmed.
2. The stub shaft press-fitting compaction allowance was optimized to help ensure the strength of the joint sections.
3. Evaluation of the CFRP tube during FW molding confirmed that the material would possess adequate durability in actual use.
4. By using a two-part CFRP propeller shaft system instead of a steel three-part propeller shaft system approximately 30% of weight savings and approximately 25% of reduction in the number of parts were realized in the 2005 model year LEGEND.

References

- (1) Yamane, Y., et al.: Development of a Lightweight CFRP Hood and Rear Spoiler, Honda R&D Technical Review, Vol. 15, No. 1, p. 209-214
- (2) Kawarada, K., et al.: Development of New Composite Propeller shaft, TOYOTA Technical Review, Vol. 43, No. 2
- (3) JP, 09-175202, A (1997)

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