

A Study on Tube and Flange Joint of Car Propeller Shaft Made of Carbon Composite Fiber

Jeonghoon Ha¹, Dongchan Shin², Yongtak Lee³ and Kibong Han*

¹Department of Security Service, Jungwon University, 85 Munmu-ro, Goesan-gun, South Korea.

²Convergence Engineering Department, Jungwon University, 85 Munmu-ro, Goesan-gun, South Korea.

³Convergence Engineering Department, Jungwon University, 85 Munmu-ro, Goesan-gun, South Korea.

*Mechatronics Department, Jungwon University, 85 Munmu-ro, Goesan-gun, South Korea.

*(Corresponding Author)

² Orcid : 0000-0002-4777-9571, * Orcid : 0000-0003-3018-0199

Abstract

In this study, a method is proposed which processes the flange and the flange which connects the carbon fiber tube to a concave-convex structure, and carbon composite tube is inserted into the concave-convex portion of the flange to bond it with an adhesive. To test the bonding strength of the safety of the proposed propeller shaft, a carbon fiber propeller shaft that is attached with the existing two types of flange was manufactured. The stress analysis was executed using finite element method and the result shows the carbon fiber propeller shaft that uses proposed flanges had the minimum stress value to the adhesive part. Also by comparing the torsion strength test results, the proposed carbon fiber propeller shaft shows superior value to the value of the existing types of carbon fiber propeller shaft. Plus, the maximum transmission torque of the proposed carbon fiber propeller shaft is 88 greater than the maximum power transmission torque design value of 350 for steel propeller shafts applied to automobiles. In conclusion, the method proposed in this study will contribute to the manufacture and junction of carbon fiber propeller shaft flange and tube by meeting the standard values of the conventional steel propeller shaft's maximum power transmission torque

Keywords: carbon fiber propeller shaft; tube and flange joint of propeller shaft; adhesive strength analysis; propeller shaft structure analysis;

INTRODUCTION

Recently, research on the light weight of automobiles by the regulation of carbon dioxide emission due to environmental problems has been activated, and therefore, they are interested in automobile polymer composites mainly in automobile advanced countries. Composite materials for automobiles are made by mixing glass fiber or carbon fiber with polymer fiber base. Composite materials are not only superior in weight, specific modulus, stiffness, corrosion resistance, impact resistance, but also the components can easily be unified.

These advantages led to the use of composite materials in mechanical parts such as shell plates, leaf springs, and engine parts etc. But the main use of composite materials is propeller shaft. Currently, many researches are being undergone to produce propeller shaft using polymer composite materials [1]. Propeller shaft for automobiles is an important component because of its role in delivering the torque generated by the engine directly to the wheels while steering at the same time. The existing steel propeller shaft is difficult to lighten the weight and unify because of its Two-stage separation type form [2]. To solve this issue, an integral type carbon fiber composite propeller shaft is being manufactured, by taking the advantage of polymer composite material's unifiable character. Carbon fiber composite propeller shaft has the advantage of making the propeller shaft in unified state, and make the parts lighter. However, in making the carbon fiber composite propeller shaft, a metal flange is attached to both ends of a carbon tube, so carbon composite tubes on the joint often break, requiring a high level of skill in joining carbon tubes and metal flanges. Therefore, to solve this problem in carbon fiber composite propeller shaft, the flange, which is the joint between the flange and the carbon composite tube, is machined into a concave-convex structure, and then a carbon composite tube is inserted into the concavo-convex portion of the flange to bond the tube with the adhesive.

To test the safety of the adhesive strength in carbon fiber composite propeller shaft, a carbon fiber composite propeller shaft using two kinds of existing flange is made, and from the result of the stress analysis using the finite element method, it was found that the stress of the adhesive part of the proposed carbon fiber propeller shaft with the flange was minimum. Also, as a result of the torsional strength test, it was found that the maximum torque that the proposed carbon fiber composite propeller shaft and the other two conventional carbon fiber propeller shafts can withstand were $438kg_f \cdot m$, $153kg_f \cdot m$, and $60kg_f \cdot m$, respectively. This test shows that the maximum torque of the proposed carbon fiber propeller shaft is $88kg_f \cdot m$ bigger than that of the steel propeller shaft which is designed to withstand $350kg_f \cdot m$.

Therefore, the carbon fiber propeller shaft proposed in this study not only has superior bonding strength than the two existing carbon fiber propeller shafts but also passes the reference design value of the maximum power transmission torque of the propeller shaft of the car. In conclusion, it is believed that it will contribute greatly to the fabrication by bonding between the fiber tubes in the future.

DESIGN AND ADHESION STRENGTH ANALYSIS OF TUBE AND FLANGE JOINT OF PROPELLER SHAFT MADE OF CARBON COMPOSITE FIBER

Ordinarily, the propeller shaft for automobile has a static maximum torque of $350 \text{ kg}_f \cdot \text{m}$ or more, and the diameter of carbon fiber propeller shaft tube is less than 100 mm due to space constraints of the automobile. This study proposes a jointing method between the tube and flange of an integral carbon fiber propeller shaft for a rear-wheel drive vehicle. Figure 1 shows the joint structure between the tube and flange of an integral carbon fiber propeller shaft. Figure 1(a) shows the method this study proposes.

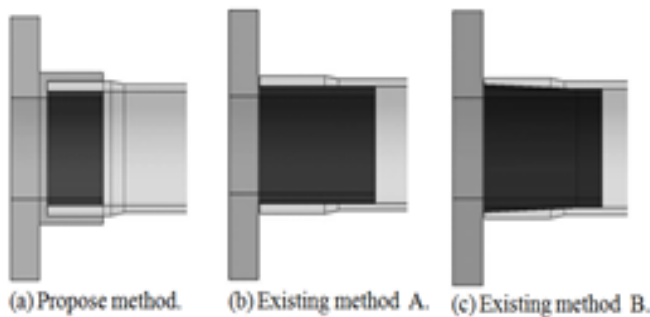


Figure 1: joint structure between the tube and flange

First, a stress analysis was performed to investigate the joint validity of the proposed method and two existing joining methods.

Figure 2 shows the boundary conditions for the stress analysis of carbon composite fiber propeller shaft. In this test, one end of the carbon fiber propeller shaft is fixed, while the other end has the torsional load of $350 \text{ kg}_f \cdot \text{m}$.

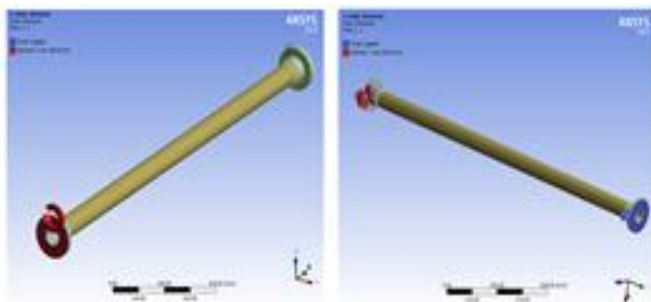


Figure 2: the boundary conditions for the stress analysis of the propeller shaft made of carbon composite fiber

Figure 3 shows the structure analysis of the carbon fiber propeller shaft proposed in this study.

Figure 3(a) shows the stress distribution of the carbon fiber propeller shaft tube. Here, the maximum stress value applied to the shaft tube is 361.0 MPa . Figure 3(b) shows the stress distribution of the carbon fiber propeller shaft flange. In this case, the maximum stress value applied to the shaft flange is 350.5 MPa . Figure 3(c) shows the stress distribution of the carbon fiber propeller shaft tube contact surface. Here the maximum stress value applied to the shaft tube contact surface is 85.5 MPa . Figure 3(d) shows the pressure distribution of the carbon fiber propeller shaft tube contact surface.

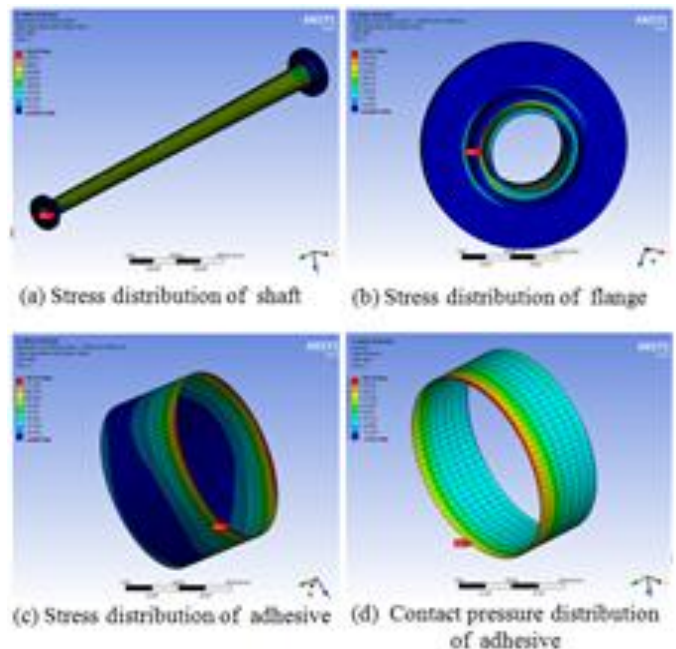


Figure 3: Structure analysis of the proposed propeller shaft

Figure 4 shows the Structure analysis of the existing A type carbon fiber propeller shaft. Figure 4(a) shows the stress distribution of the carbon fiber propeller shaft tube. Here the maximum stress value of the shaft tube is 287 MPa . Figure 4(b) shows the stress distribution of the carbon fiber propeller shaft flange. Here the maximum stress value of the shaft tube is 307 MPa . Figure 4(c) shows the stress distribution of the carbon fiber propeller shaft tube contact surface. Here the maximum stress value of the shaft tube is 126.2 MPa . Figure 4(d) shows the pressure distribution of the carbon fiber propeller shaft tube contact surface.

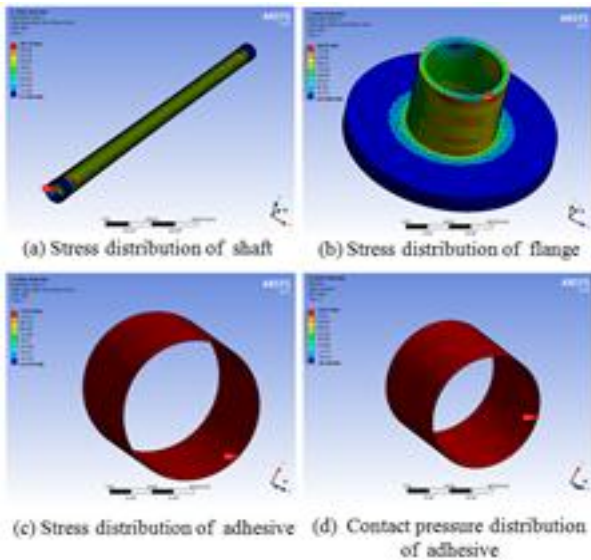


Figure 4: Structure analysis of the existing A type propeller shaft

Figure 5 shows the Structure analysis of the existing B type carbon fiber propeller shaft. Figure 5(a) shows the stress distribution of the carbon fiber propeller shaft tube. Here the maximum stress value of the shaft tube is 864.9 MPa . Figure 5(b) shows the stress distribution of the carbon fiber propeller shaft flange. Here the maximum stress value of the shaft tube is 595.3 MPa . Figure 5(c) shows the stress distribution of the carbon fiber propeller shaft tube contact surface. Here the maximum stress value of the shaft tube is 129.7 MPa . Figure 5(d) shows the pressure distribution of the carbon fiber propeller shaft tube contact surface.

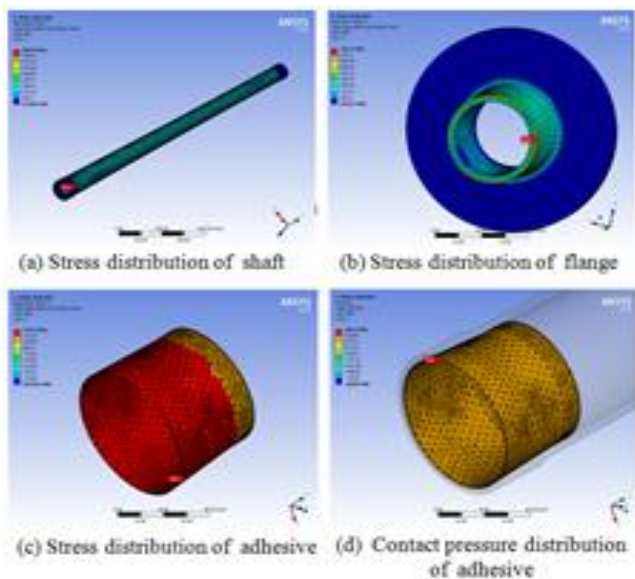


Figure 5: Structure analysis of the existing B type propeller shaft

From these result of the structure analysis, it was found that the carbon fiber propeller shaft proposed in this study had the minimum stress on the joints compared to the carbon fiber propeller shafts in the conventional two types. Therefore, producing propeller shafts using the proposed method is the solution to minimize the damage in carbon fiber propeller shaft joint.

TUBE AND FLANGE FABRICATION OF THE CARBON FIBER PROPELLER SHAFT

Figure 6 shows the manufacturing process of the carbon fiber propeller shafts proposed in this study [3][4]. Here, the manufacturing process of the carbon fiber propeller shaft includes a winding process, a curling process, a bonding process, and a surface dipping process. Figure 6(a) shows the winding process. To make the inner and outer carbon fiber tube, a helical winding method, and a hoop winding method was used in each process. Also the material used in this process is carbon fiber (T700) and Epoxy resin. Figure 6(b) shows the curling process. This is the process of uniformly processing the surface of the tube after the winding work is finished. Figure 6(c) shows the process of bonding the carbon fiber composite tube to the flange using an adhesive. Figure 6(d) shows the dipping process as the last step of the carbon fiber propeller shaft.

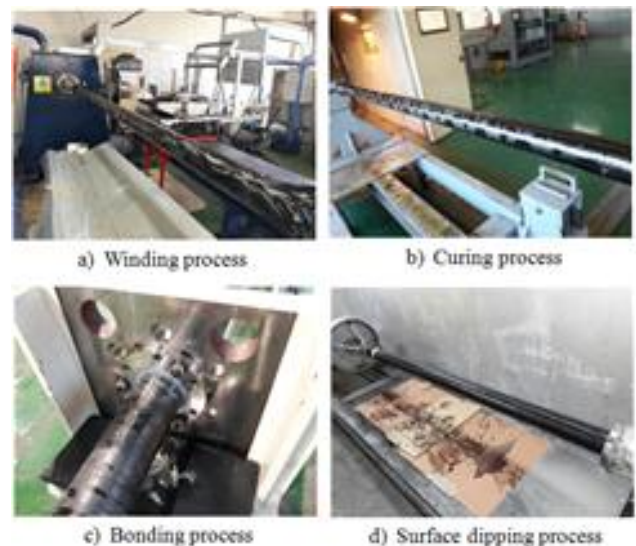


Figure 6: Manufacturing process of the carbon fiber propeller shaft

Figure 7 shows the processed flange used to produce carbon fiber propeller shaft. Here, figure 7(a) shows the method proposed in this study. It consists of a flange and a tube, and the flange part that comes into contact with the tube is made into a concave-convex shape, and then a tube is fitted to the concave-convex part and joined with an adhesive. Figure 7(b)

shows the existing shape which is produced by the outer diameter of the cylinder of the flange and the inner diameter of the tube put into contact with each other and connected by an adhesive after. In Figure 7(c), after the outer diameter of the cylinder and the inner diameter of the tube are tapered, the flange cylinder is inserted into the inside of the tube.

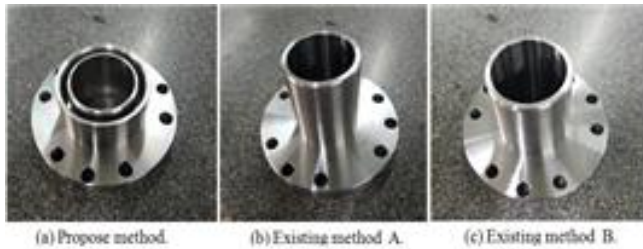


Figure 7: Types of processed flange

EXPERIMENT RESULTS AND ANALYSES

In this study, to evaluate the torsional strength of the proposed carbon fiber propeller shafts, the bond strength between steel flanged and carbon fiber composite tubes was measured. Figure 8 shows test specimens for measuring the adhesive strength of the adhesive used in this study. In order to ensure the reliability of the bonding strength, eight specimens were fabricated in accordance with the specifications and tensile tests were carried out. The bonding strength was evaluated by averaging these values.

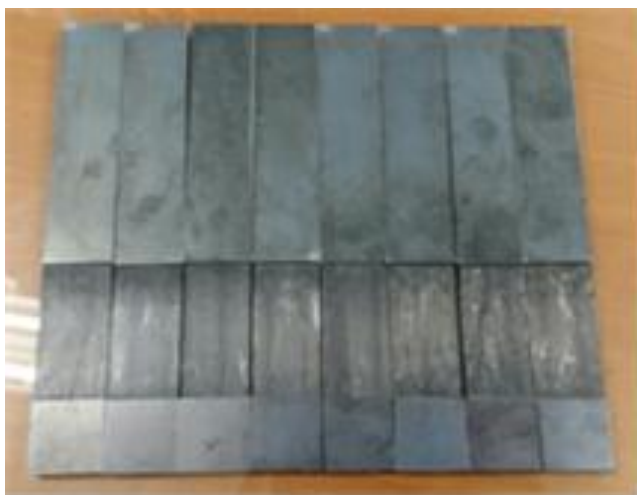


Figure 8: Specimens for bonding strength test

Table 1 shows the tensile strength for each of the eight specimens. As a result of the bond strength test, it is shown that the average is 10.5 MPa. This is generally greater than 7 MPa in adhesive strength, which suggests that this study can be used to fabricate carbon fiber propeller shafts.

Table 1: Adhesive strength results by tensile test

| Specimen | Bonding Strength (MPa) | Specimen | Bonding Strength (MPa) |
|----------------|------------------------|----------|------------------------|
| 1 | 9.10 | 5 | 13.24 |
| 2 | 11.49 | 6 | 9.74 |
| 3 | 8.76 | 7 | 9.76 |
| 4 | 11.42 | 8 | 11.15 |
| Average | 10.58MPa | | |

Figure 9 shows the testing device to test the torsional strength of the carbon composite fiber propeller shaft's structural safety evaluation. Here, one end is fixed, and the other is applied with a torque at a speed of 0.1 deg/sec until the carbon fiber propeller shaft is broken.



Figure 9: Torsional strength testing device

Figure 10 shows the torsional strength test results of the carbon fiber propeller shaft proposed in this study. Here, the maximum torque value before the breakage is 438.9 kgf · m.

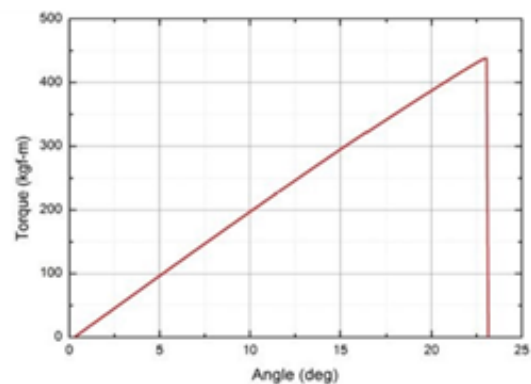


Figure 10: Torsional strength test results of the proposed propeller shaft

Figure 11 shows the torsional strength test results of the existing A type carbon fiber propeller shaft. Here, the maximum torque value before the breakage is 125 kgf · m.

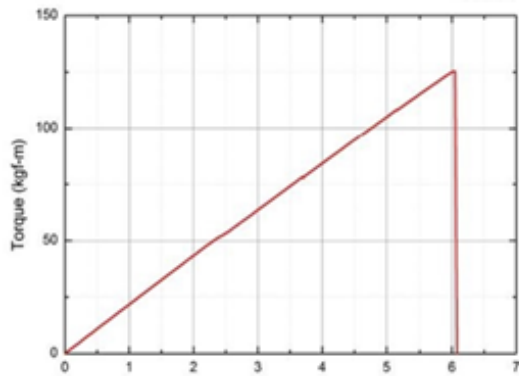


Figure 11: Torsional strength test result of the existing A type propeller shaft

Figure 12 shows the torsional strength test results of the existing B type carbon fiber propeller shaft. Here, the maximum torque value before the breakage is $60.1 kg_f \cdot m$

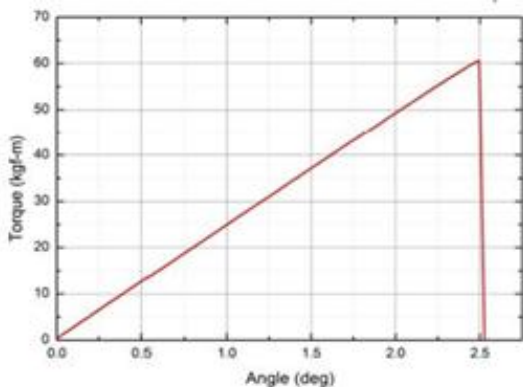


Figure 12: Torsional strength test results of the existing B type propeller shaft

From these results, to verify the safety of the carbon fiber propeller shaft proposed in this study, the joint area was first analyzed by the finite element method, and then the torsional strength was tested on the basis of this analysis. As a result, the proposed propeller shaft meets the designed standard value of the steel propeller shaft.

CONCLUSION

This study proposed a method of connecting the carbon fiber tube and flange of the carbon fiber propeller shaft used in automobiles. In order to do this, a finite element method was used to analyze the stress level to the joint part. From this result, an integral carbon fiber propeller shaft was manufactured. A torsion stress test was undergone to test the safety of the produced an integral carbon fiber propeller shaft, and the result shows the value of $438.9 kg_f \cdot m$. It is confirmed that it satisfies the design standard ($350 kg_f \cdot m$ or more) of the steel propeller shaft used in the existing

automobile. Therefore, the method proposed in this study will contribute to the development of integrated carbon fiber propeller shafts in the future by securing safety in the safe bonding between carbon fiber propeller shaft tube and flange.

ACKNOWLEDGMENT

This research is the result of research carried out in the project of "Technology development project for local specialization industry" supported by "Ministry of Trade, Industry & Energy - Republic of Korea".

REFERENCES

- [1] DK Lee, "Fabrication Methods for Composite Automotive Components", *Advanced Materials and Manufacturing in Automotive Engineering*, vol. 28, no.1, pp. 27~32, 2006.
- [2] KS Kim and KM Bae, "Trend of Carbon Fiber-reinforced Composites for Lightweight Vehicles", *Elastomers and Composites*, vol. 47, no.1, pp. 65~74, 2012.
- [3] JY Han and CH Hong, "Buckling Analysis of Filament-wound Composite Towers for Large Scale Wind-Turbine", *The Korea society of ocean engineers and technology*, vol. 25, Issue 2, pp. 79~84, 2011.
- [4] Robert M. Jones, "Mechanics of composite material", McGraw-Hill Book Company, Chapter 3, 1975.