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Torsional Fatigue and Static Torsion Strength and Test Validations of Composite Tube Hybrid Drive Shafts

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Abstract: Drive shafts are the transmission components which transfer power from power source to required location. The connection may be between steering wheel and rack & pinion mechanism or gearbox to differential. As in gearbox to differential connection, operational conditions are harsh and high loads are generated, steel materials are mainly preferred to be used. Though steels have such advantages in cost, performance and durability, it is heavier compared to other engineering materials. Since international regulations dictate to decrease the carbon emissions rates due to global concerns, weight decrement of automobile components plays an important role in solving such problem. Considering the operational requirements and boundary conditions, weight reduction in steel parts might be tough. For this reason, alternative materials must be deeply investigated and implemented into the traditional technologies. In the scope of this study, fatigue and torsional strength of propeller shaft with composite tube and aluminum subcomponents were investigated.

Keywords: Composite shaft, Drive shaft, Lightweight applications

Introduction

Steel and steel alloys are predominantly used in today's automotive industry since it provides many advantages in terms of its cost, strength, durability and manufacturability. However, in the recent years, lightweight applications gain popularity due to global concerns and electrification trend in automotive industry. Each reduction in the weight designates the efficiency of the vehicle which play an important role in competitive automotive market. Even 1 kg improvement in vehicle's weight leads to 20 kg less emission during the entire service life of vehicle (Hortooglu et al., 2023) so that common objective of manufacturers is to minimize the weight of each component without sacrificing performance, strength or other essential characteristics.

Ecological concerns have prompted the manufacturers to come up with more advanced design solutions. Aluminum, magnesium, titanium and many other materials present advanced characteristics and lighter weight opportunities compared with steel and steel alloys. However, many of them such as titanium is expensive and shows inefficient manufacturability. Magnesium is mainly utilized in unloaded location and some low loaded housing applications due to its low density. However, casting operation of magnesium housings is a challenging process due to high-flammability characteristics. Therefore, aluminum and composite have been leading the lightweight studies recently.

Literature

Comprehensive studies have been conducted for many years for the sake of lightweight constructions in automobile industry. Ozgen et al. (2019) studied on static torque transmission capability, torsional buckling and natural bending frequency optimization of propeller shafts composed of carbon epoxy and glass epoxy composite tube. Finite element analyses of composite tube were performed and validated by tests. Sun et al. (2019) conducted different analyses for embedded-in-flanges composite and glued tube for different ply angles. They revealed that bonding type does not affect the natural frequency. Ply angle and damper utilization played a neglectable role in natural frequency. Elanchezhian et al. (2018) compared the advantages and disadvantages of composite and steel tubes. Kim et al. (2004) studied the effects of foreign object impacts and damage characteristics of hybrid drive shaft. It was concluded that ±10° stacking angle with glass fabric insulation layer significantly decreased the damage area of the composite shaft. Bert and Kim (1994) investigated the buckling characteristics of hollow laminated composite drive shaft and offered a close form solution for buckling calculations. Qi et al. (2021) researched the effect of reinforced fibers on vibration characteristics of composite tubes. It is unveiled that increasing the elasticity modulus of the fibers enhanced the natural frequency of fiber-reinforced composite shafts.

In the scope of our study, static torsion and fatigue analysis of hybrid drive shafts were performed. Criteria and close form solutions for composite tubes were investigated and results were compared with each other. It is revealed that composite tubes are safe to be used for drive shaft applications.

Drive Shafts

Traditional drive shafts have been used for many years in automotive industry. All components of drive shaft subjected to torque are made of steel materials due to low cost and high-performance characteristic. With a different viewpoint to traditional driveshafts, a hybrid driveshaft which consists of aluminum (Al), steel (St) and composite components were utilized in. The weight of the drive shaft by means of lighter component utilization is achieved as %39 percent. A representative model of hybrid drive shaft is given in **Figure 1**.

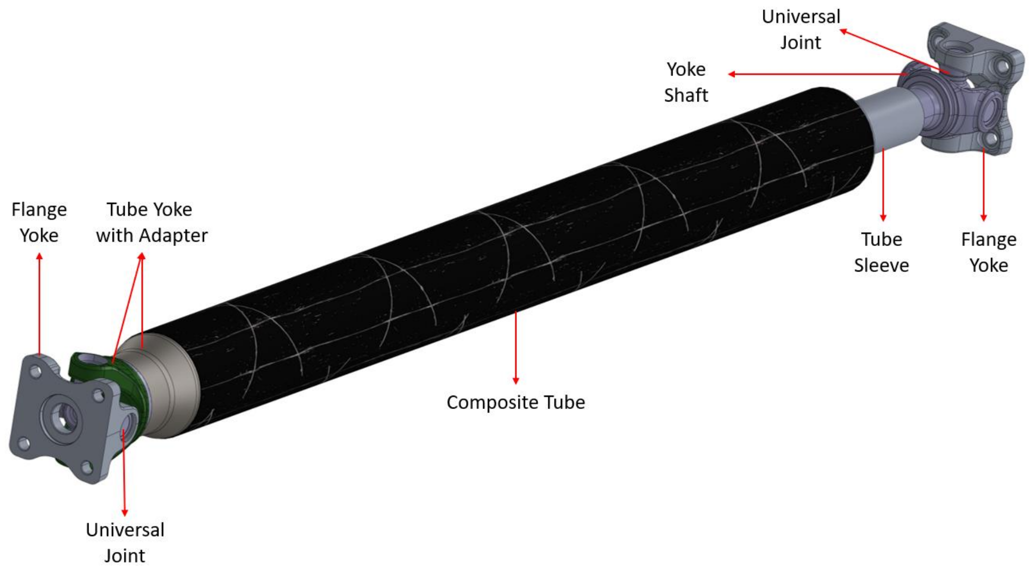

Figure 1. Hybrid drive shaft representative model

Method

Tube yoke-tube and tube sleeve-tube connection is performed by adhesive special to composite bonding application. Adhesive selection criteria, thickness, length, analysis and test result are given by Hortooglu et al.

(2023). Bonded components were designed and manufactured regarding aforementioned selection parameters for the required torque levels. Part designs were validated by FE analysis which can be seen in Figure 2.

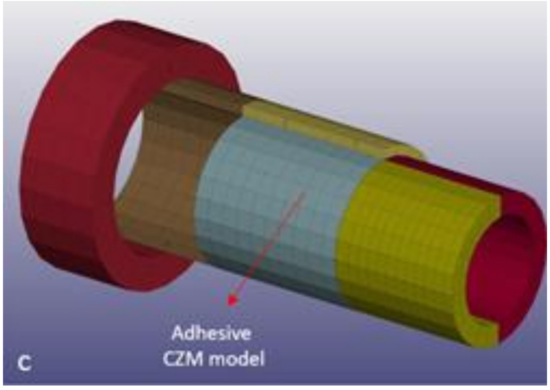

Figure 2. FE analysis of bonded components

Ozbek et al. (2022) develops a FE method in order to find out stress levels of aluminium. flange yoke (Ozbek et al., 2022). Results of the study were validated by static torsional tests. Figure 3 shows the FE analysis of aluminum flange yoke.

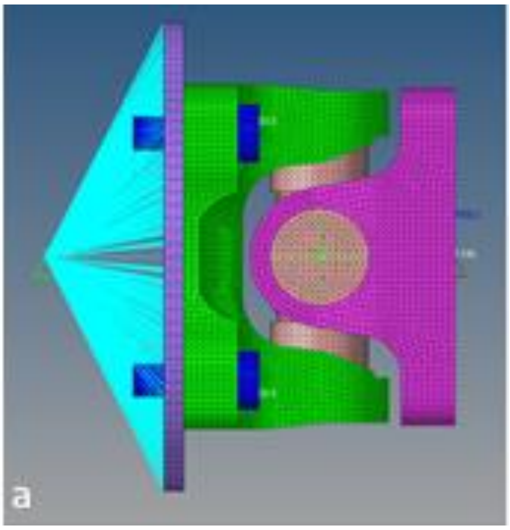

Figure 3. FE analysis of aluminum flange yoke

Composite tube dimensioning, stacking angle and stacking order are essential for the performance of the driveshaft. Parameters, formulas and test results were presented by Tarakcı et al. (2022) Composite tubes were procured and some tests were performed in order to validate composite tube design criterions which can be seen in Figure 4.

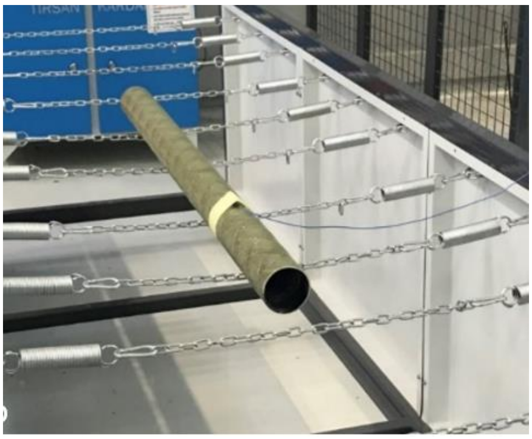

Figure 4. Natural frequency test of composite tube

Universal joint, tube yoke and yoke shaft were chosen steel materials depending on various reasons. Tube yoke is manufactured by forging to increase compressive stresses thus, to increase material strength. However, it is hard to manufacture tube yoke with a long sleeve extension where composite tube and tube yoke are bonded. Therefore, forged tube yoke and a sleeve were welded together. Yoke shaft possesses a small diameter with a relatively sharp transition section by the end of the spline through yoke. To satisfy the high torque requirements, steel material was selected. Universal joint is the lightest component among others and therefore, it is a must to use a strong material. Considering its negligible effect in the total weight of driveshaft, steel material was preferred to be used. Comprehensive studies can be conducted for each component for the sake of decreasing the total weight of driveshaft. Only the composite tube fatigue and torsional strength were focused on that study.

Fatigue and Torsional Tests

Assembly of hybrid drive shafts is given in Figure 2. In order to comprehend the operational behavior of composite tube drive shaft, it must be subjected to various test conditions regarding to requirements of equivalent drive shafts. The requirements of drive shafts are given in Table 1.

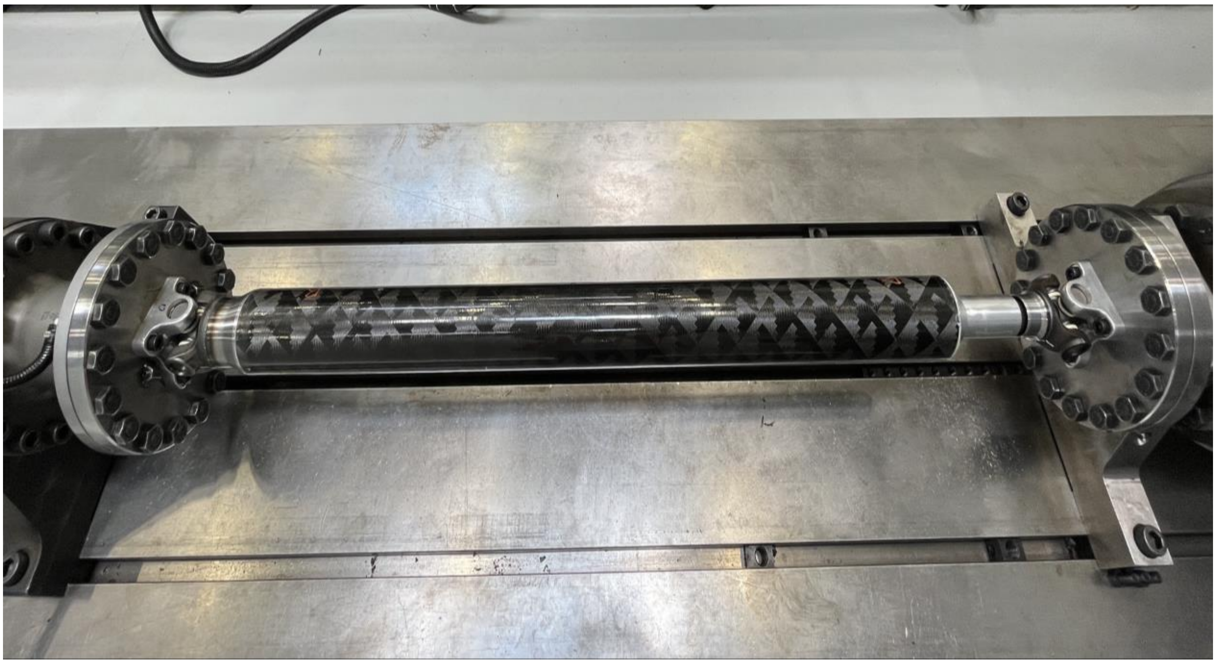

Figure 2. Hybrid drive shaft

Table 1. Drive shaft requirements

Test Condition	Torque Requirement (N.m)	Cycle Requirements
Torsional Fatigue Test	1200	400.000
Static Torsion Test	3500	1

Dimensions of composite tubes were investigated by considering the requirements as given in Table 1. 100mm inner diameter with 4mm thickness was selected accordingly. After assembly of subcomponents, 3 static and 3 fatigue tests were performed for hybrid drive shafts in Tirsan Kardan R&D center. Static torsion and torsional fatigue tests were conducted by fixing the fixed side of the propeller shafts and applying the torque on the opposite side. Sinusoidal torque in 2 Hz was applied for torsional fatigue tests.

Results and Discussion

Static torsional test results and failure points are presented between Figure 3 and Figure 5.

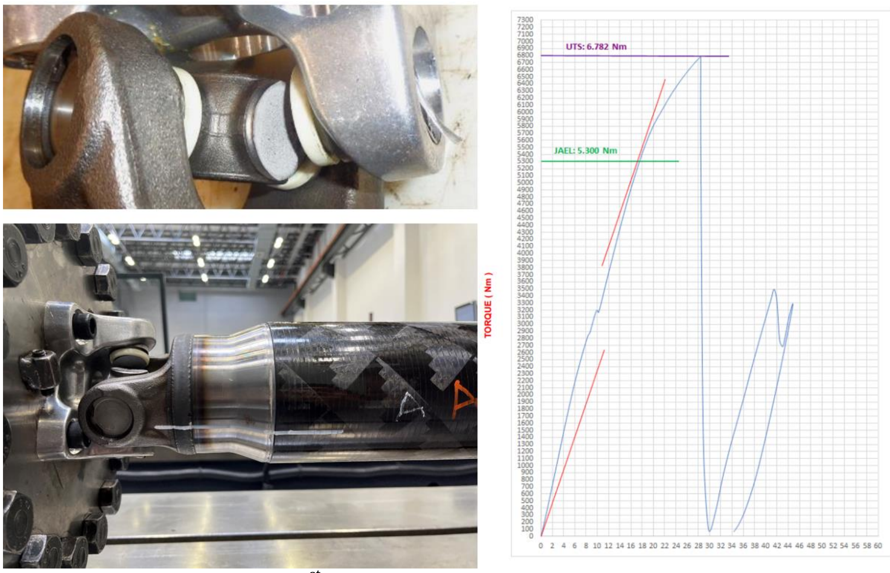

Figure 3. 1st Hybrit drive shaft static torsion test

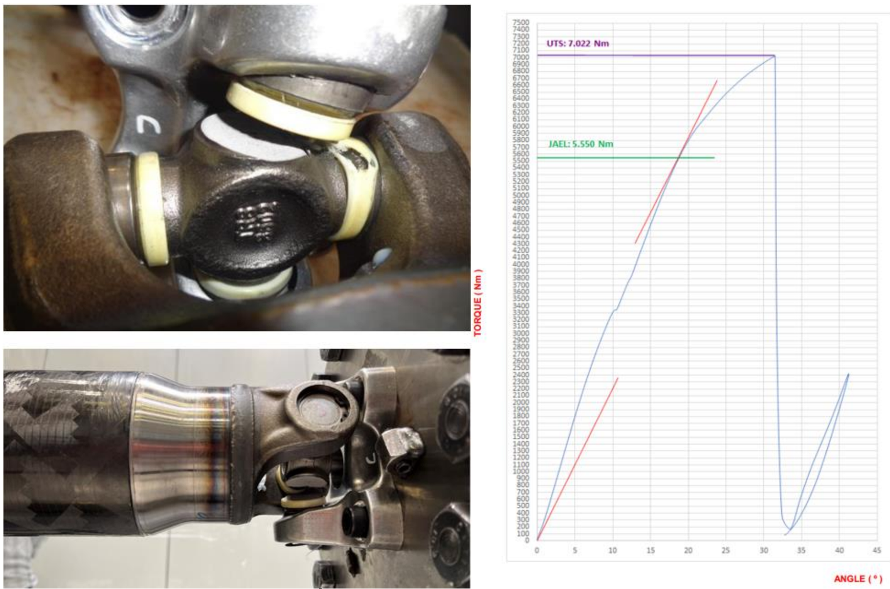

Figure 4. 2nd Hybrit drive shaft static torsion test

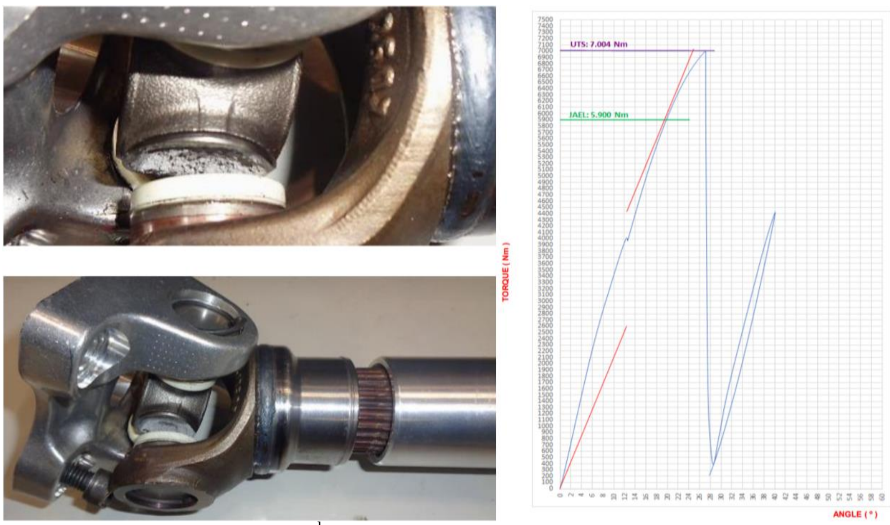

Figure 5. 3rd Hybrit drive shaft static torsion test

Johnson apparent elastic limit (JAEL) and ultimate tensile strength (UTS) for each hybrid drive shaft with respect to test results are given in Table 2.

Table 2. JAEL and UTS values

Drive Shaft	JAEL	UTS
1st Drive Shaft	5300	6782
2nd Drive Shaft	5550	7022
3rd Drive Shaft	5900	7004

All the failures were occurred on universal joints as expected. Composite tubes were cut and any fiber rapture was not observed in the internal media. Static torsional tests fulfilled the requirements. 3 torsional fatigue tests were performed after satisfactory results in static torsion tests. Test results are shown between Figure 6 and Figure 8.

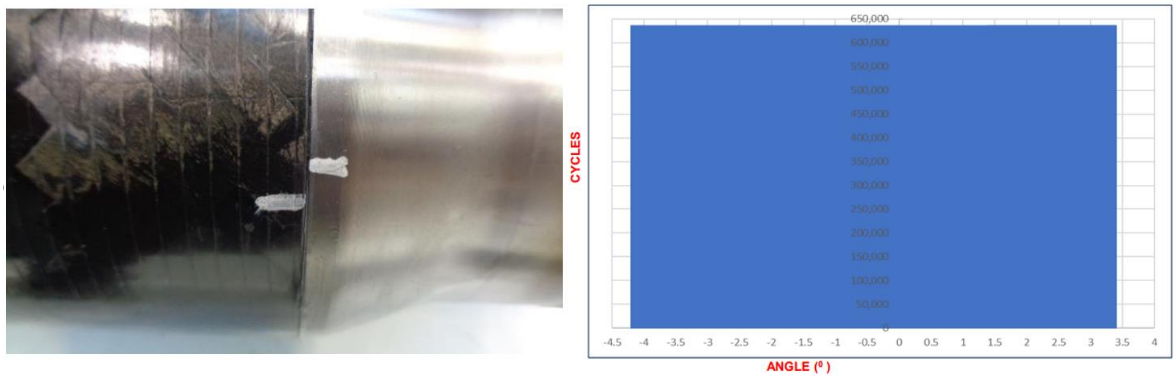

Figure 6 1st Torsional fatigue test

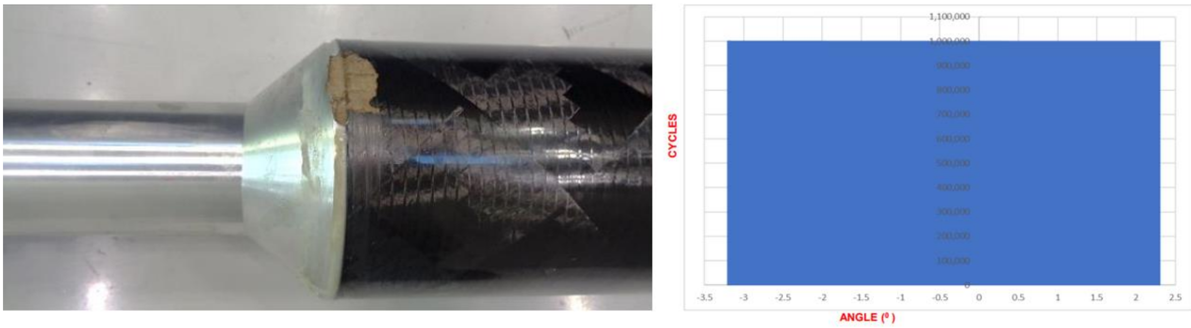

Figure 7 2nd Torsional fatigue test

Figure 8 3rd Torsional fatigue test

Table 3 Torsional fatigue test results

Drive Shaft	Cycle	Failure Location
1st Drive Shaft	635.441	Adhesive
2nd Drive Shaft	1.000.000	Not failed
3rd Drive Shaft	1.036.237	Aluminum TS

Hybrid drive shafts were not failed in composite tube, however shown different failure characteristics in various locations. The adhesive failure of drive shaft was observed in the first test. The test of second drive shaft was stopped after 1.000.000 cycle. Third drive shaft failed in the neck of aluminum tube sleeve. Both composite tubes and the entire drive shafts satisfied the criteria given in Table 1.

Conclusion

Hybrid drive shafts were subjected to torsional fatigue tests and static tests. All the driveshafts shown reliable results and satisfied the requirements of their equivalents. It is revealed that composite tubes can safely be utilized in transmission applications.

Recommendations

Although it is not presented in the scope of this study, the selection of composite tube must be carried out carefully. The stacking angle, natural frequency, number of carbon and fiber glass layers and order of carbon and fiber glass layers should be conducted with with regard to intended application and requirements of the operation. All parameters mentioned play essential role in the characteristics and properties of composite tube.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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References

Bert, C. W., & Kim, C. (1994). Analysis of buckling of hollow laminated composite drive shaft, composite science and technology. *Composite Science and Technology*, *53*, 343-351.

Elanchezhian, C., Ramnath, V. B., Raghavendra, K.N., Muralidharan, M., & Rekha, G. (2018). Design and comparison of the strength and efficiency of drive shaft made of steel and composite materials. *Materials Today, 5*(1), 1000-1007.

Hortooglu, S. K., Ozbek, O., Tarakcı, S., & Isık, E. (2023). Verification of adhesive application in composite driveshafts by using finite element method. *CMES-2023.*

Isık, E., Ozbek, O., & Tarakcı, S. (2022). A new aluminum design solution for traditionally forged steel flange yoke Used in drive shafts. *DEU International Symposium Series on Graduate Researches*.

Kim, H. S., Kim, B. C., Lim, T. S., & Lee, D. G. (2004). Foreign objects impact damage characteristics of aluminum/composite hybrid drive shaft. *Composite Structures, 66*(1-4), 377-389.

Ozgen, G. A., Yuceturk, K., Tanoglu, M., & Aktas, E. (2019). An investigation on hybrid composite drive shaft for automotive industry. *International Journal of Mechanical and Materials Engineering*, *13*(4), 258-263.

Qi, L., Li, C., Yu, X., Min, W., Shi, H., Tao, L., Wang, H., Yu, M., & Ni, Lei., & Sun, Z. (2021). Effect of reinforced fibers on the vibration characteristics of fibers reinforced composite shaft tubes with metal flanges. *Composite Structures, 275*(1).

Sun, Z., Xiao, J., Yu, X., Tusiime, R., Gao, H., Min, W., Tao, L., Qi, L., & Zhang, H., Yu, M. (2019). Vibration characteristics of carbon-fiber reinforced composite drive shafts fabricated using filament winding technology. *Composite Structures*, *241*, 111725.

Tarakcı, S., Hortooglu, S. K., & Isık. E. (2022), Kompozit Kardan mili borusu tasarım kriterlerinin belirlenmesi uzerine bir calısma. *International Mediterranean Science and Engineering Congress.*

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