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Study on Bending and Torsional Behaviour of AI Composite Drive Shaft

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Abstract*: One of the biggest questions the automotive industry faces today is that what materials are to be used to reduce drastically the weight of the engine to save fuel. In world over 70% of rear-wheel-drive or four-wheel-drive passenger cars are built with multi-section propeller shafts which require one or more support bearings under the floor of the passenger compartment There are a variety of alternatives being explored by the automobile companies, there is more than one possible answer. At this point the only certainty is that no single material or type of material will dominate. The basic attraction of composite materials for propeller shaft applications is that they make it possible to increase the shaft length, which is otherwise constrained by bending resonance. For many vehicles, a one-piece composite shaft may replace a two-piece steel shaft, which simplifies both the shaft and installation in the vehicle. The potential for carbon fibre composites in automotive propeller shafts as a means of achieving substantial weight reduction has long been recognized, and has been demonstrated in small volume applications. The main barrier to large scale penetration of the market has been product cost, but industrial developments in recent years offer the prospect of substantial reductions hence the automobiles of the future will continue to be a mix of materials. The study shows that Hybrid Aluminum Composite drive shafts have proven that they can solve many automotive and industrial problems that accompany the usage of the conventional metal ones.*

Keywords: AI Composite, Drive Shaft, Bending & Torsional Fatigue

I. INTRODUCTION

Early automobiles often used chain drive or belt drive mechanisms rather than a drive shaft. Some used electrical generators and motors to transmit power to the wheels. Several different types of drive shaft are used in the automotive industry 1-piece drive shaft, 2-piece drive shaft, Slip-in-tube drive shaft .A drive shaft, driving shaft, propeller shaft, or Cardanshaft is a mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them. Drive shafts are carriers of torque they are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, whilst avoiding too much additional weight as that would in turn increase their inertia. An automobilemay use a longitudinal shaft to deliver power from an engine/transmission to the other end of the vehicle before it goes to the wheels.

One of the biggest questions the automotive industry faces today is what materials are to be used to reduce drastically the weight of the engine to save fuel. There are a variety of alternatives being explored by the automobile companies, there is more than one possible answer. At this point the only certainty is that no single material or type of material will dominate. Hence the automobiles of the future will continue to be a mix of materials of which the candidate material will be Hybrid composite/ Aluminium. Composite drive shafts have proven that they can solve many automotive and industrial problems that accompany the usage of the conventional metal ones.

A composite drive shaft offers excellent vibration damping, cabin comfort, reduction of wear on drive train components and increased tire traction. In addition, the use of single torque tubes reduces assembly time, inventory cost, maintenance, and part complexity. An automotive drive shaft transmits power from the engine to the differential gear of a rear wheel drive vehicle as shown in Fig. 1. The material which is being used today is high strength steel. Metallic

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drive shafts have limitations of weight, low critical speed and vibration characteristics. Polymer matrix composites are the most common composite material being used in drive shaft today, the most common are carbon epoxy, glass epoxy and carbon/glass/epoxy hybrids. Graphite has also been used in some cases. When the length of a steel drive shaft is beyond 1500 mm, it is manufactured in two pieces to increase the fundamental natural frequency, which is inversely proportional to the square of the length and proportional to the square root of the specific modulus. The nature of composites, with their higher specific elastic modulus (modulus to density ratio), which in carbon/epoxy exceeds four times that of aluminium, enables the replacement of the two-piece metal shaft with a single component composite shaft which resonates at a higher rotational speed, and ultimately maintains a higher margin of safety. A composite drive shaft offers excellent vibration damping, cabin comfort, reduction of wear on drive train components and increased tire traction. In addition, the use of single torque tubes reduces assembly time, inventory cost, maintenance, and part complexity.

II. LITERATURE SURVEY

For our project we are surveying some reports and references which are helping us to make it easy and simplest and they are as follows

Yang Tan [1] Durk Hyun Cho, Dai Gil Lee [1] has designed and manufactured the one-piece hybrid drive shaft composed of carbon fiber-epoxy composite and an aluminum tube to reduce weight and vibration. The hybrid shaft was manufactured by co-curing the composite to the aluminum shaft with an applied preload to the aluminum before co-curing to reduce thermal residual stresses. The vibration characteristics of the hybrid drive shaft were measured by impulse-frequency responses and whirling tests. The static and dynamic torque tests of the hybrid drive shaft were also performed.

A.R. Abu Talib a, Aidy Ali b, Mohamed A. Badie a, NurAzidaChe Lah b, A.F. Golestaneh b[2] has studied and done a finite element analysis of composite drive shafts incorporating carbon and glass fibers within an epoxy matrix. A configuration of one layer of carbon–epoxy and three layers of glass–epoxy with 0, 45and 90 was used. The developed layers of structure consists of four layers .The results show that, in changing carbon fibers winding angle from 0 to 90, the loss in the natural frequency of the shaft is 44.5%, while, shifting from the best to the worst stacking sequence, the drive shaft causes a loss of 46.07% in its buckling strength, which represents the major concern over shear strength in drive shaft design.

Hak Sung Kim, ByungChul Kim, Tae Seong Lim, Dai Gil Lee[3] has investigated the low velocity impact damage characteristics of aluminum/composite hybrid drive shaft .The hybrid drive shaft was manufactured by stacking carbon epoxy composite prepregs and insulating layer for galvanic corrosion on the inner surface of an aluminum tube, and co-curing them in an autoclave under recommended cure cycle. After impacting the co-cured hybrid drive shafts using a drop-weight impact tester, the damage and delamination of the composite layers were observed with an ultrasonic C-scan, from which the damage modes of aluminum/composite hybrid shaft were found with respect to the stacking sequence of composite materials, the thickness of the aluminum tube and the impact energy. Finally, optimal stacking sequence of the composite material and optimal thickness of the aluminum tube for the drive shaft for low velocity impact were suggested. Finite element analysis was carried out for a hybrid aluminum/ composite drive shaft to predict the torsional strength. Five cases with different composite materials, stacking sequences and numbers of layers were studied.

S.A. Mutasher [4] has done A hybrid aluminum/composite is an advanced composite material that consists of aluminum tube wound onto outside by layers of composite material. The result from this combination is a hybrid shaft that has a higher torque transmission capability, a higher fundamental natural bending frequency and less noise and vibration. This paper investigates the maximum torsion capacity of the hybrid aluminum/composite shaft for different winding angle, number of layers and stacking sequences. The hybrid shaft consists of aluminum tube wound outside by E-glass and carbon fibers/epoxy composite. The finite element method has been used to analyze the hybrid shaft under static torsion. ANSYS finite element software was used to perform the numerical analysis for the hybrid shaft. Full scale hybrid specimen was analyzed. Elasto-plastic properties were used for aluminum tube and linear elastic for composite materials. The results show that the static torque capacity is significantly affected by changing the winding angle, stacking sequences and number of layers. The maximum static torsion capacity of aluminum tube wound outside by six

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layers of carbon fiber/epoxy composite at winding angle of 45_ was 295 N m. Good agreements was obtained between the finite element predictions and experimental results.

Y.A. Khalid, S.A. Mutasher, B.B. Sahari, A.M.S. Hamouda[5] Throughout this experimental study, a bending fatigue analysis was carried out for hybrid aluminum/composite drive shafts. The hybrid shafts used were fabricated using filament winding technique. Glass fiber with a matrix of epoxy resin and hardener were used to construct the external composite layers needed. Four cases were studied using aluminum tube wounded by different layers of composite materials and different stacking sequence or fiber orientation angles. The failure mode for all the hybrid shafts was identified. The macroscopic level tests indicate that the cracks initiating in the zones free of fibers or in the outer skin of resin and increase with increasing number of cycles until the failure of specimen. It has also been noticed that there is no fiber breakage from the rotating bending fatigue test. Results obtained from this study show that increasing the number of layers would enhance the fatigue strength of aluminum tube up to 40%, for [±45]

III. PRIDICTION OF TORSIONAL STRENGTH AND BENDING FATIGUE BEHAVIOR OF COMPOSITE DRIVE SHAFT

The torsional stability of a composite drive shaft under torsion was studied under different fiber orientations and the stacking sequences. thefiber orientation and the stacking sequence of the layers of a composite shaft strongly affect the buckling torque and increasing the applied torque decreases the natural torsional frequencies. The static and dynamic torsional characteristics of a hybrid shaft composed of an aluminum tube and a thin carbon fiber composite layer. the torque capacity was increased about 12-fold for the aluminum tube wound with six layers of carbon fiber and a winding angle of 45 degree compared with an ordinary aluminum tube. A finite element method was used to investigate maximum torsion capacity of a hybrid aluminum/composite drive shaft. The hybrid shaft is consisting from aluminum tube wounded outside by E-glass and carbon fibers/epoxy composite and their hybrids at different winding angle, number of layers and stacking sequences.

Hybrid Aluminium/ Composite Specimen Modelling

A full length FE model was constructed for the 175 mm long hybrid shaft under static torsion load. Fig. 4.1 shows the configuration and dimensions of the hybrid specimen. Each layer on the hybrid shaft was modeled as a separate volume and meshed using solid46 element. The layered element solid46 allows for up to 100 different material layers with different orientations and orthotropic material properties in each layer. The element has three degrees of freedom at each node and translations in the nodal x, y, and z directions. The layers were assumed perfectly bonded with the surface of aluminum tube. An eight-node solid element, solid45, was used for the aluminum tube. The element is defined with eight nodes having three degrees of freedom at each node translations in the nodal x, y, and z directions.

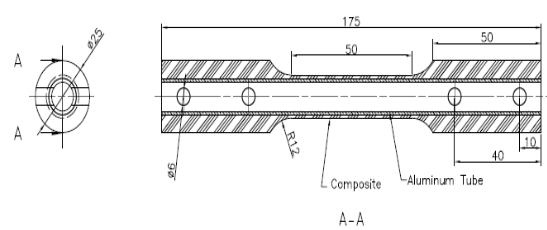

Fig.1. Configuration and dimensions of torsion test specimen

Fig.2 shows the fill scale finite element mesh for the hybrid aluminum/composite drive shaft. The mapping mesh technique was used for the entire domain. Due to the complexity of failure mechanisms in the hybrid aluminum/composite drive shaft, it is difficult to define an applicable failure criterion however, it is expected that the shear failure of the hybrid aluminum/composite drive shaft is dominated by properties of carbon and glass fiber/ epoxy composite layers, and the laminate fails just after the shear strain reached maximum failure strain from experimental results in any direction. So, the maximum strain failure criterion was used to predict the failure load in this study and the failure index determined. The failure index is calculated as follows:

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$$I = \frac{\phi}{\phi_f}$$

Where I is the failure index, ϕ is the allowable angle of twist and ϕ_f is the failure angle of twist obtained experimentally. The fracture is expected to occur when the ϕ reached the ultimate failure angle of twist, which means that the failure index equal one at the failure torque. Torque failure indexes relations were found and comparisons with experimental results are presented. Five cases were studied as shown in Table 1.

TABLE 1 LAMINATES AND THEIR STACKING

	Glass fibers	Carbon fibers
Case 1	$[\pm 45]_n$	$[\pm 45]_n$
Case 2	$[90]_m$	$[90]_m$
Case 3	[+45/-45/90/90]	[+45/-45/90/90]
Case 4	[90+45/-45/90]	[90/+45/-45/90]
	Glass + Carbon fibers	
Case 5	$[(\pm 45)_{carbon}/(\pm 45)_{glass}]$	$[(\pm 45)_{carbon}/(\pm 45)_{2,glass}]$

n = 1,2 and 3; m = 2,4 and 6.

TABLE 2. MECHANICAL PROPERTIES OF COMPOSITE MATERIAL

Properties			Glass fiber/epoxy composite	Carbon fiber/epoxy composite
Longitudinal modulus	E_{11}	(GPa)	36.6	101.2
Transverse modulus	E_{22}	(GPa)	5.4	5.718
Shear modulus	G_{12}	(GPa)	4.085	4.346
Poisson's ratio	ν_{12}		0.3	0.31
Volume fraction	v_f		0.476	0.545
Longitudinal strength	X^L	(MPa)	618.9	1475.4
Transverse strength	X^T	(MPa)	14	20
Shear strength	τ_0	(MPa)	28	36

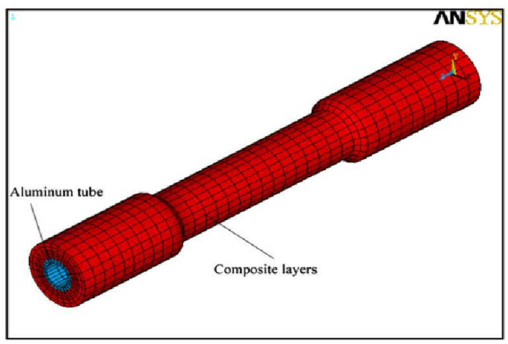

Fig. 2. Finite element meshes

Material Properties

The elastic constants were found experimentally for composite materials as shown in Table 2. These properties were used with conventional laminate theory to calculate the theoretical effective properties of the orthotropic monolithic model as shown in Table 3. Table 4 shows the mechanical properties of aluminum tube (AA6063-T4). The glass and carbon fiber/epoxy layers were modeled with homogenized linear elastic orthotropic materials, and the elasto-plastic characteristic of aluminum tube was modeled by input the stress–strain relationship to ANSYS program .

Boundary Condition

The shaft in FEA subjected to pure torsion, for this, one end was fixed with all the DOF arrested. On the other end the torque was applied as distributed forces in tangential direction to the outside of the fixture of the hybrid shaft. The distributed forces were calculated by converting the applied torque to tangential force by multiplying with outside diameter and dividing the same by number of nodes on the side of the fixture of the shaft model. To restrict the movement of the nodes in the radial direction at the end at which the force is applied, the DOF in r-direction was arrested. The nodes are to be rotated along cylindrical coordinate system so that the applied forces in nodal h-direction are tangential to the perimeter of the shaft. No cantilever effect will be formed since the forces will deform the shaft about its axis by pure twisting. Fig. 4.3 shows the deform shapeof the hybrid shaft under static torsion load.

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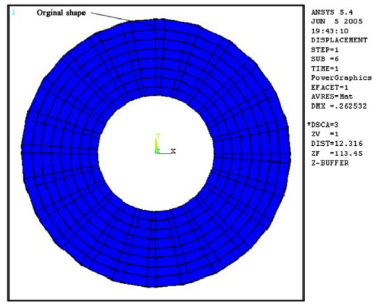

Fig.3 deform shapeof the hybrid shaft

Bending Fatigue Behaviour of Composite Drive Shaft

It is well known that fatigue strength is smaller than static strength due to the degradation of structure during fatigue cycle. However, fatigue behaviors of composite materials are quit different from isotropic materials, such as metals and polymers. In composite materials, the micro cracks are initiated at the early stage of loading but composite still withstand the load until the final failure.

Geometry & Material

The aluminum tube (AA6063) used for this investigation was of outer diameter and the thickness (1/2 x 1/16) in (12.7 x 1.5) mm, respectively fiber used for the filament-wound laminated hybrid aluminum/ composite tube is of glass fiber type. The epoxy resin and hardener types used for this project were of MW 215 TA and MW 215 TB, respectively

Fig.4. Sample of hybrid aluminum/composite fatigue specimens used.

Fabrication of Hybrid Aluminium / Composite drive Shaft

The wet-winding method of filament winding was used to manufacture the hybrid aluminum/composite drive shaft. The fiber was wound over an aluminum tube mandrel of 1/200(12.67 mm) outer diameter, following wet impregnation through a resin bath. Resin system was prepared by mixing epoxy, and hardener with the volume fraction ratio of 4:1. During the whole filament winding process, the fiber tension was kept constant and the revolution speed of the mandrel as 13.6 rpm. The nose which fed the fibers was axially traveled at the speed regulated to generate the desired winding angles. The specimens will be fabricated in such a way that the stress level in central gauge section must greater that in all other structure points. This will be done by paying a particular.attention to end effect problem which is a point of concentration stresses at the aluminum/composite drive shaft, as shown in Fig. 4.11 for fatigue test specimen. After filament winding let the rotational speed of mandrel as slow as possible so that the glass fiber was just impregnated to each other and continue until the matrix totally solidified. After the solidification, the reinforcement of aluminum/composite shaft will be machined to fit with fixtures.

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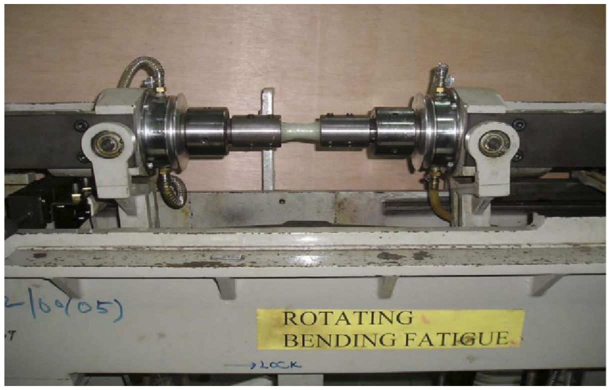

Fig.5 Fatigue specimen installed in the rotating bending fatigue machine.

Result of Torsional Strength of Composite Shaft

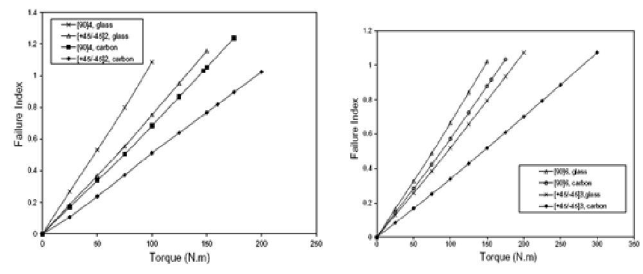

Fig 6. Failure of aluminium Glass Epoxy of six Layers

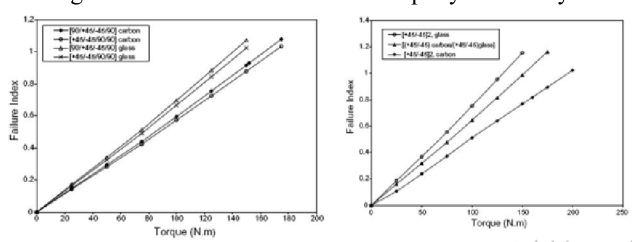

Fig.7 Failure of aluminium Glass Epoxy of four Layer

The failure indices of the aluminum tube wound externally by four layers of carbon and glass fiber/epoxy composite at different winding angles are shown in Fig. 4.13. It can be seen that 450 angle can withstand more torque than that for 900 in all cases. Moreover, at a lower torsion load, the failure indices are close to each other this is because the aluminum tube is still within the elastic limit. When the failure index is one, the failure torque is 131 N m and 195 N m for aluminum tube wound externally by four layers of glass & carbon fibers at winding angle of 450 respectively. Similar results to those four layers were drawn for six layers of glass and carbon fibers as shown in Fig. 4.14. A hybrid shaft wound externally by carbon fiber/epoxy is stronger than the hybrid shaft wound externally by glass fiber/epoxy and supports high torque capacity.

Result of bending fatigue behavior of composite drive shaft

The S–N relationship for the applied stress and fatigue life of aluminum tube in compare with aluminum tube wounded on the outside by two layers of [±45] and [90]2 is shown in Fig. 4.19& 4.20 The lines being linearly fitted to the data were obtained and the fatigue data also exhibited scatter. From this figure one can see that the composite layers are enhancing the fatigue life by 25% and 17% for [±45] and [90]2, respectively.

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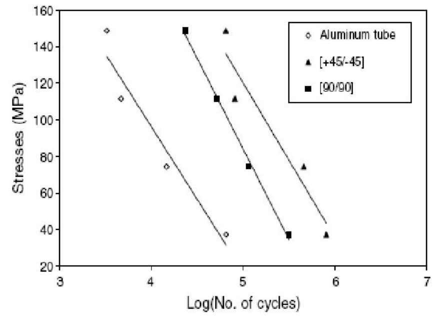

Fig.9. Relationship between applied stress and fatigue life

Rotating bending fatigue was carried out for a hybrid aluminum/composite drive shaft from this we can conclude that by increasing the number of composite layers would increase the fatigue strength for a hybrid aluminum/ composite drive shaft & there is no fiber breakage observed from the rotating fatigue tests, sometime, even when the delamination take place and the aluminum tube completely crack the specimen still can with stand the loading but becomes unstable. Changing the stacking sequence of composite laminate may enhance the fatigue strength e.g. aluminum shafts with laminates of a stacking sequence [+45/-45] has the highest fatigue strength, up to 40% when compared to others.

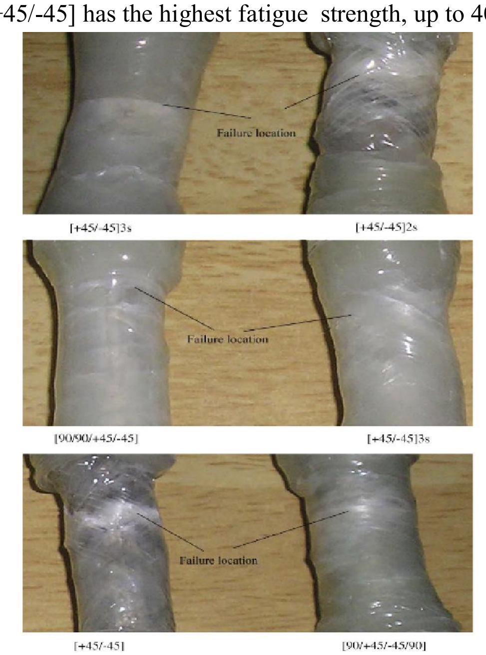

Fig 10. Different locations and style of failure for different laminates

IV. CONCLUSION

Following are the conclusion from the study.

1. The hybrid drive shaft was 50% lighter than the existing steel drive shafts. The fundamental natural bending frequency of the hybrid drive shaft was 9 100 rpm and the shaft rotated without whirling until 9 000 r-pm. The minimum static torque transmission capability Of 3550 Nm.The hybrid 107 cycles.the hybrid drive shaft was drive shaft was not failed until under a dynamic torque of (+500Nm)

2. Rotating bending fatigue was carried out for a hybrid aluminum/composite drive shaft. By increasing the number of composite layers would increase the fatigue strength for a hybrid aluminum/ composite drive shaft and there is no fiber breakage observed from the rotating fatigue tests, sometime, even when the delamination take place and the aluminum tube completely crack the specimen still can with stand the loading but becomes unstable.

3.By changing the stacking sequence of composite laminate may enhance the fatigue strength, aluminum shafts with laminates of a stacking sequence [+/45/_45] has the highest fatigue strength, up to 40% when compared to others. Process.

4. A finite element study was carried out using ANSYS software to predict the static torsion and bending fatigue capacity including the elasto-plastic properties for aluminum tube and linear elastic for composite materials. The comparisons between the experimental and predicted results carried out using ANSYS software gave good agreement.

5. From this discussion we can conclude that carbon/glass fiber-reinforced; epoxy composite automotive drive shaft is the best alternative today for replacing the steel dive shaft

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