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Investigation Of Key Materials Selection Parameters For Drive Shafts Manufacture, Cost And Energy Economics

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Abstract- An Automotive drive shaft transfers power from the transmission to the rear wheels of automobiles. Automotive drive shaft materials traditionally made from steel are now made from different materials some of which are claimed to be lighter weight and sometimes safer than traditional materials. This study enables the investigation of key material parameters in the selection of drive shafts, their manufacture and performance over vehicles lifecycle. The Cambridge Engineering Selector (CES**) Eco Audit tool was applied in the selection of the best materials, costs and eco properties such as carbon dioxide creation, recyclability and production energy. In this study, advanced materials concepts have been applied to analyse some specific components of automotive drive shafts aimed at enhancing performance. The parameters of material for development of automotive drive shafts have been derived from a combination, like hybrid aluminium/composite giving higher torque transmission capability, higher fundamental natural bending frequency and less noise and vibration. In addition, co-curing layers of viscoelastic damping materials with composite materials can produce light-weight, stiff, highly damped structural components. The study shows that composite drive shafts are lighter in weight, weighing less than steel or aluminium with similar strength with flexible and lower modulus of elasticity such that in the event of torque peak occurrences in the driveline, it can function as a shock absorber by decreasing stress to save vehicle life. Disadvantages also exist with composites, such as high manufacturing and material costs.**

Keywords—Automotive drive shafts, composite materials, eco properties, Eco Audit, torque transmission.

I INTRODUCTION

The concept of sustainability, like a driving force, influences scientists and engineers in their quest for optimal reliability and safety standards not only in

the automotive industries but also in many other phases of life and issues affecting the environment. The work of the automotive drive shaft is to transmit mechanical power from the engine to the rear wheels (differential gear) of a vehicle. The need therefore to substitute for conventional metallic drive-shafts is rooted in the premise that greater efficiency and lightweight drive-shafts are derivable from composite materials with higher specific stiffness and strength.

The study finds that composites can be applied in the field of automotive industry as elliptic springs, drive shafts, leaf springs, and more [1]. Automotive drive shafts made from composites also have the advantage of being used interchangeably with OEM (original equipment manufacturer) parts. They are proven safer than metallic drive-shafts, reducing the amount of rotating mass with greater vibration dampening qualities. It has been found that for passenger cars the torque and fundamental bending natural frequency should be higher than 3500Nm and 9200rpm respectively to avoid rotary vibration [2]. The fundamental bending natural frequency of a one-piece drive shaft made of steel/aluminum is usually less than 5700 rpm at a length of about 1.5m. accordingly, studies have shown that advanced composites: graphite, carbon, kevlar and glass in combination with the appropriate resins show high specific strength and modulus [3], [4]. Material economics issues in composites such as high costs, fragility and unfavourable shock loading conditions attract further research as to their suitability in maintaining adequate drive-shaft safety standards. For instance, elastic properties of flexible matrix composite (FMC) can be tailored over much broader ranges compared to conventional rigid matrix composites (RMCs). FMCs are known for their torsionally stiff reinforcement combined with elastomeric polymer matrix materials, such as polyurethanes, silicones, natural rubbers, etc., strong and flexural composite drive-shafts [5].

Consequently, in RMCs materials like epoxy, the transition temperature of the elastomer glass is much under the service temperature. This work investigates some composite materials suitable for automotive drive shafts that can effectively replace conventional steel drive shafts. The report also examines the key parameters that are being used in selection of automotive drive shafts. The Cambridge Engineering Selector **(**CES**)** Edupack software was used to select the best materials and manufacturing methods and carry out an Eco Audit to determine which material is best for the environment.

IIDRIVE SHAFT MATERIALS AND THEIR CONSTRUCTION

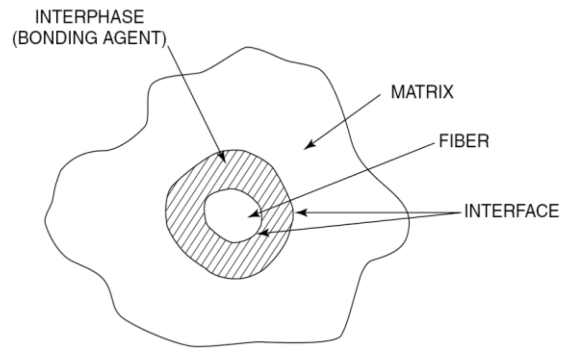
The Fig 1, shows that the constituents of a composite material does not lose their physical identity such that some kind of interfacial divisions relates them. The matrix constitutes its bulk form while its structural constituent known as reinforcement determines its internal structure. The inter-phase properties determine the ultimate properties of the bulk composite because it is where mechanical stresses are transferred between the matrix and the reinforcement. No particular material class dominates the chemical composing the composite constituents. In the automotive industry for instance, metal–matrix, ceramic–matrix, and polymer–matrix composites are relevant applications.

Instructively, composite drive shafts made from advanced composite materials such as graphite, carbon, kevlar and glass are commercially important, and in combination with the appropriate resins can show high specific strength and modulus. Figs 2 & 3 show examples of rear wheel driving (RWD) conventional two-piece steel drive shaft showing the primary parts that makes it up. Drive shafts made for passenger cars, small trucks and vans usually have torque transmission capability larger than 3 500 Nm, and to dampen rotational vibration or spinning its fundamental natural bending frequency is designed to exceed 6500rpm. The speed at which the drive shaft becomes unstable and eventually crumbles is known as the revolution per minute (rpm) value describing its critical speed.

As a technical requirement of manufacturing, the length and diameter of a drive shaft directly affects its performance in the vehicle. The critical speed is defined by the length, diameter, wall thickness, and material module of elasticity. In many literatures, DOM (drawn over mandrel seamless tubing and chrome-moly steel) high performance steel is a very good drive shaft material which has 1,000 - 1,300 hp. However, studies have shown that this is considered better compared to the 350 to 400 hp OEM (original equipment manufacturer) steel material for drive shaft.

In view of the foregoing, it should further be pointed, that the torsional strength of Chrome-moly steel tubing can be raised up to 22, which implies that there could be an increase in the critical speed to 19%. In the same vein, it has been observed that Aluminum (900 to 1,000 hp), is the most commonly used material for driveshaft and has the advantage of being lighter than the heavy drive shaft load increasing steel. This weight advantage of Aluminum helps to reduce rotational mass, frees up engine horsepower and reduces parasitic losses associated with varying frictional transients. However, it should be pointed out that Aluminum lacks the strong strength and toughness of steel and therefore limited in the nature of application for which it can be deployed.

This study further observes that products of Polymer Matrix Composites are seen as the most common composite material for making drive shafts. The most common combinations are carbon/epoxy, glass/epoxy and carbon/glass/epoxy hybrids. A carbon fiber composite drive shaft has fundamental natural frequency that is about two times that of steel or Aluminum. The reason being that carbon fiber composite material is over 4 times the specific stiffness of steel or Aluminum, an important attribute which makes it possible to manufacture passenger cars drive shaft.



[1] Fig 1: Graphical display of fiber composite matrix with constituents [8]

III ADVANTAGES AND DISADVANTAGES

It should be thus observed that drive shafts made with composite materials have longer lengths and in comparison to steel drive shafts, composite drive shafts can operate at higher speed (in rpm) than steel with the same dimensions. Composite drive shafts are lighter in weight, weighing less than steel or aluminum with similar strength. These group of materials and their alloys possess superior properties such that they are one-piece construction, flexible and lower modulus of elasticity such that in the event of torque peak occurrences in the driveline, it can function as a shock absorber by decreasing stress to save vehicle life.

While the advantages are found to abound, it should be stated also that some disadvantages also exist with composites. These includes, high manufacturing and material costs and inventory considerations. For example, the strength of some composites and the cost of carbon is less and higher than steel respectively. Lots of examples of automobiles exist in production today that have gone towards composite driveshaft which uses a two-piece design where one driveshaft is steel while the other is composite; thus distributing frictional fatigue stresses and incidental shocks.

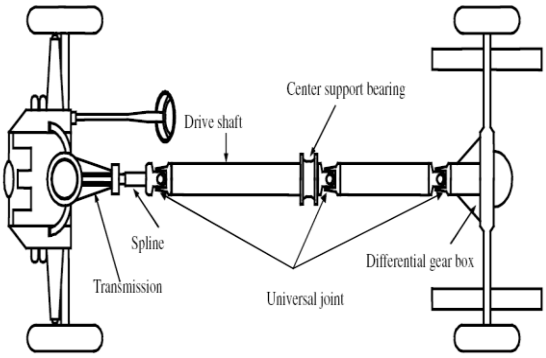


Fig 2: RWD conventional two-piece steel drive shaft showing compositions

IV DETERMINATION OF MATERIAL INDICES FOR DRIVE SHAFTS

The preference for composite draft shafts in spite of the high material costs is that combinations like hybrid aluminum/composite gives higher torque transmission capability, higher fundamental natural bending frequency and less noise and vibration. These are significantly important considerations. In addition, co-curing layers of viscoelastic damping materials can be successfully combined with composite material systems. This has the potential of manufacturing light-weight, stiff, highly damped structural components.

Consequently, fiber/resin composite bonds with interspersed metal layers that are called hybrid, with benefit of excellent fatigue, impact, and residual strength gains compared to conventional monolithic metallic alloys. They have also been shown to possess high specific strength and stiffness with the ability to resist corrosion and high temperature [6], [7]. They have low specific weight, compared to aluminum alloys with superior properties in terms of fatigue crack initiation characteristics and fatigue crack growth.

There is demand in both automotive and transportation industries for efficient composite material technology to enhance structural components construction of drive shaft. This is specially directed towards weight reduction strategies without compromising vehicle quality and reliability [9], [10], [11]. The two main parameters for power transmission rotating shafts associated to automotive drive and propeller shafts are the transmission of static and dynamic torsional loads, and the high fundamental bending natural frequency. This avoids the spinning vibration that may arise at some high rotational speed.

In addition to the foregoing considerations, Figs 4 & 5, are indicative of high Young's modulus and high tensile strength, density respectively specifying that aluminum alloys, steel and CFRP/Epoxy would be excellent choice for this application.

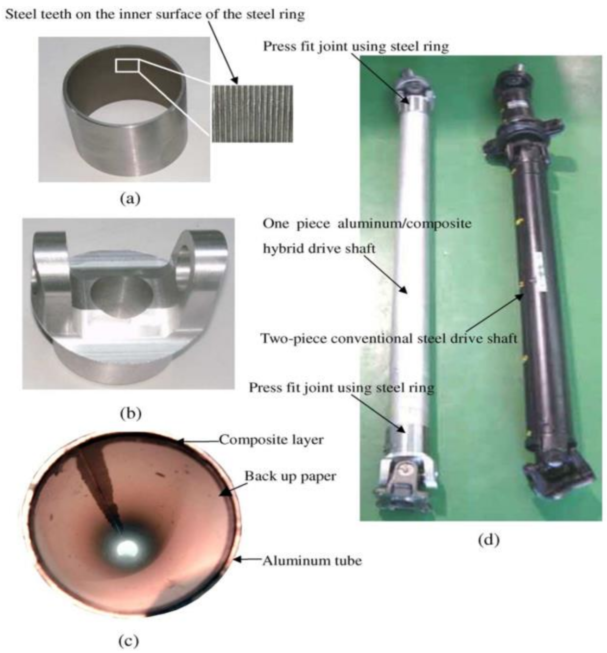


Fig 3: (a) Steel ring with inner surface having teeth in the axial direction; (b) aluminium yoke; (c) manufactured aluminium/composite hybrid tube; (d) manufactured one piece aluminium/composite drive shaft and conventional two-piece steel drive shaft.

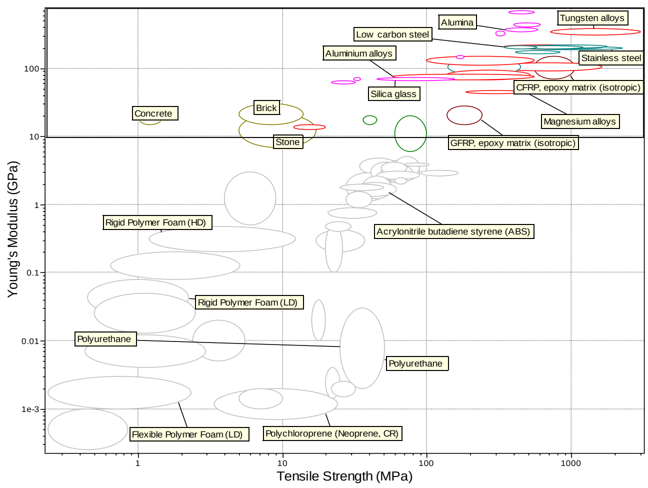


Fig 4: Materials selection chart pricing of Young's modulus against tensile strength

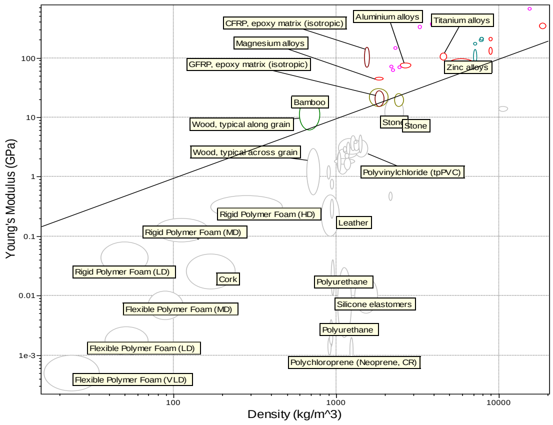


Fig 5: Materials selection chart of Young's modulus against tensile strength

V COST AND DETERMINATION OF ENVIRONMENTAL IMPACT ANALYSIS

The high costs of composite materials like that of carbon fiber epoxy composite materials could be contained if cheaper products such as aluminum can be used to form hybrids of aluminum/composite drive shafts. There are other methods that also that may reduce the effects of production and waste costs, such as mass production, reduction of machine time and shipping costs. From the materials selection chart (Fig 6) of specific elastic modulus the fiber-reinforced epoxy composites may have advantage over the steel and aluminum alloys due to their longer critical lengths. On the account that most medium-size automobile drive shafts are just about 1 meter in length, it is possible that by using composites a one-piece design can be used to develop a driveshaft. This is because the use of either of the alloys may involve costlier two-piece design [12] [13]. The graphite-fiber reinforced epoxy meets the minimum and maximum temperature use requirement and has the sufficient impact acceptable environmental resistance. The chart will show that carbon-fiber-reinforced polymers (CFRP) possess between good and excellent resistance against organic solvents.

This includes epoxies which also represent more resistant polymers. In addition, the cost of processing may also rise significantly (e.g. use of thermal equipment) because of the use of complex equipment.

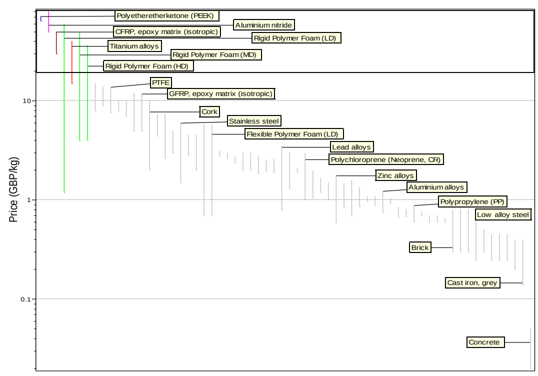


Fig 6: Materials selection chart of pricing per Kg of batch units

VI ECONOMICS OF OPTIMUM MATERIALS SELECTION USING CES AND MANUFACTURING METHODS

The CES tool for eco audit comprises production energy, carbon footprints, embodied energies, associated carbon dioxide and recyclable materials. During smelting operations carbon monoxide and carbon dioxide are produced where the metal oxides with carbon monoxide undergo reduction reaction. The materials selection chart (Fig 7) shows carbon dioxide creating materials at low melting point to high melting points. It identifies materials with high melting points relatively producing higher carbon foot print.

In line with the foregoing, this study is of the opinion that production energy and recyclability charts are crucial to the determination of parameters necessary for drive shaft and allied components manufacturing. They are represented in Figs 8 & 9 showing varying response relative to the respective materials. Product design in the 21st century put at the fore front eco awareness in almost all aspects of the material production phases and this concerns impact choice of materials and manufacturing. Incidentally, consumers are concerned about materials that are energy efficient and intensive, those with associated carbon footprints and high embodied energies. However, the industrialized world is also conscious of the fact that use of low-energy materials does not necessarily imply or mean a one-way path [14]. The decision people make in their choice of material influence manufacturing types, the weight of the product and its thermal and electrical characteristics. This therefore implies that the energy consumption during use do influence the recycling potentials and recovery at the end of life [15].

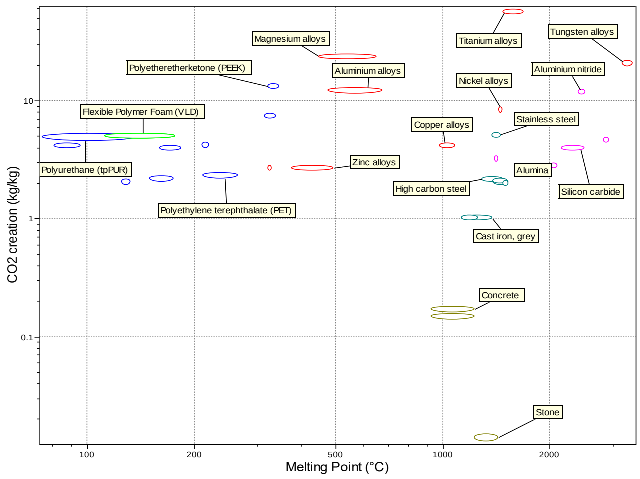


Fig 7: Materials selection chart of carbon dioxide creation

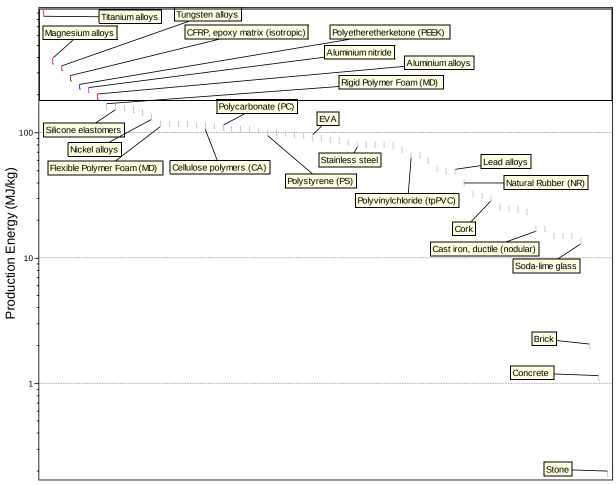


Fig 8: Materials selection chart of production energy of batch units

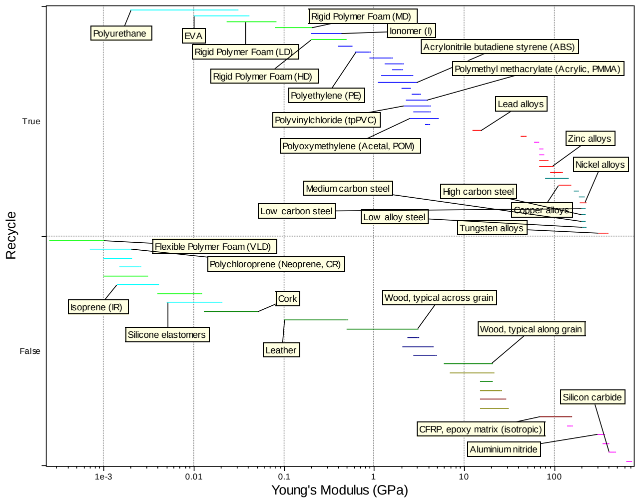


Fig 9: Materials selection chart showing recyclable and non-recyclable materials

VII CONCLUSION AND SUMMARY

In this study, advanced materials concepts have been applied to analyze some specific components of automotive drive shafts aimed at enhancing performance. The parameters of material for development of automotive drive shafts have been derived from a combination, like hybrid aluminum/composite giving higher torque transmission capability, higher fundamental natural bending frequency and less noise and vibration. In addition, co-curing layers of viscoelastic damping materials with composite materials can produce light-weight, stiff, highly damped structural components.

In view of the foregoing, fiber/resin composite bonds with interspersed metal layers are called hybrid, capable of excellent fatigue, impact, and residual strength gains compared to conventional monolithic metallic alloys. They also have ability to resist corrosion and high temperature [6], [7]. These materials show low specific weight, compared to aluminum alloys with superior properties in terms of fatigue crack initiation characteristics and fatigue crack growth. There is demand in both automotive and transportation industries for efficient composite material technology to enhance structural components construction of drive shaft.

It should be noted that weight reduction strategies without compromising vehicle quality and reliability is a crucial design consideration which significantly depends on proper selection of materials. Additionally, the two main parameters for power transmission rotating shafts associated to automotive drive and propeller shafts are the transmission of static and dynamic torsional loads, and the high fundamental bending natural frequency. This can avoid the spinning vibration that may arise at some high rotational speed. Composite drive shafts are lighter in weight, weighing less than steel or aluminum with similar strength with flexible and lower modulus of elasticity such that in the event of torque peak occurrences in the driveline, it can function as a shock absorber by decreasing stress to save vehicle life. Disadvantages also exist with composites, such as high manufacturing and material costs.

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