Low Temperature Strength Deformation Failure of Turbine Shaft Produced with Rhus Fibre Reinforced Polyester Polymer Composite

CHIKE M. ATAH[1], KINGSLEY E. MADU[2]

[1, 2] *Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State.*

Abstract- Failure analysis on turbine shaft produced with RHUS reinforced polyester polymer composite was successfully carried out in this article. Previous research on shaft failure analysis was studied and knowledge gap established. The turbine blades are subjected to maximum tangential stress of 2.5 N/mm^2 at locations very close to the root of the blades; while displacements suffered at the tip of each blade on the account of 'attack' from nozzle jet have limiting value of 0.40 mm. Load vs. Deformation Simulation results reveal that, dynamically, both runner and shaft assembly of the turbine would survive design loadings under actual service condition.

Indexed Terms- FEA, Shaft Failure, Composite Material, Hybrid Shaft, Manufacturing, RHUS Fibre

I. INTRODUCTION

The turbine shaft connects the turbine to the generator, turning at the same speed as the turbine. It is essentially an item that is used in machine designed for producing continuous power. The system it is used in basically extracts energy from a fluid flow and then converts it into a usable form or medium. A shaft is an aspect of a spinning system that transmits power from one position to another. The power the shaft exhibits is as a result of a tangential force and the resulting torque (or twisting moment) inside the shaft enables the power to be distributed to different devices connected to the shaft. Usually bearings, flywheels, gears, clutches and other machine elements are connected on the shaft, and help in the process of power transmission. In fact, shafts are not know to have a standardized diameter and are stepped with shoulder braces where bearings, gears or other parts are placed. Based on the specification, shafts can be hollow or solid with various names such as Axle, Spindle, Countershaft, Jackshaft, Line Shaft etc. Mostly following properties are preferred when designing any shaft; high strength, good machainability, low sensitivity factor; good properties for heat treatment, high wear resistance. The shafts' loading requirements are very difficult, not only to withstand the wheel's vertical power, stopping power and reaction force, but also to withstand the line's impacting loads and moving device's pulling force and reaction force etc. In this article, the study of durability, replacement and fracture loss of turbine shafts was carried out.

II. RHUS FIBRE

They have stems with milky or resinous juice; simple or compound leaves; small flowers, with parts in fours or sixes and small dry, one-seeded, often hairy, sometimes highly colored fruits, usually in dense clusters.Syrian sumac (Rhus coriaria L.) is famously used in the Mediterranean region and Middle East as a spice, sauce and drink.

The Anacardiaceae (or sumac family) consists of trees,shrubs, or woody vines belonging mainly to the genus Rhus, with about 250 species, which occur mostly in the tropics and subtropics but also into the temperate areas of the world (Encyclopedia Britannica, 2008). The sumac name is derived from "sumaga", meaning red in Syriac (Wetherilt and Pala, 1994).

- Composite Material

A material composed of two or more constituents is called composite material. Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other.

The main difference between composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, whereas in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents.

Classification of Composites

- Polymer matrix composites
- Metal matrix composites
- Ceramic Matrix

The advantages of composites over the conventional materials are: High strength to weight ratio, high stiffness to weight ratio, high impact resistance, better fatigue resistance, Improved corrosion resistance, Good thermal conductivity, Low Coefficient of thermal expansion. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range, high damping capacity.

The common applications of composites are extending day by day. Now a day they are used in medical applications too. The other fields of applications are (Lee *et al.*, 2002): Automotive: Drive shafts, clutch plates, engine blocks, push rods, frames, valve guides, automotive racing brakes, filament–wound fuel tanks, fibre Glass/Epoxy leaf springs for heavy trucks and trailers, rocker arm covers, suspension arms and bearings for steering system, bumpers, body panels and doors. Space: payload bay doors, remote manipulator arm, high gain antenna, antenna insulators, Lighting poles, Fiber optics tensile members, etc. Sports Goods: Tennis rackets, Golf club shafts, Fishing rods, Bicycle framework, etc

III. AIM AND OBJECTIVE

The aim of the work is to investigate low temperature strength deformation failure of turbine shaft produced with rhus fibre reinforced polyester polymer composite. The objectives include;

- To create a CAD model of existing driveshaft
- To check the CAD model by using FEM with existing material and at normal operating conditions.
- To study the behavior of composite material

IV. LITRATURE REVIEW

So many works has been done before now on using composite materials to produce turbine shaft and other shafts of engines with positive results.

Zhanqi Zhang, Zhongjun Yin, Tian Han and Andy C. C. Tan 2013 analyzed the failure of Wind Turbine main Shaft, it was seen from their result that the failure in the shaft is as a result of stress concentration on the shaft surface close to the critical section of the shaft due to rubbing of the annular ring and coupled with high stress concentration caused by the change of inner diameter of the main shaft.. In addition, inhomogeneity of the main shaft micro structure also accelerates up the fracture process of the main shaft. In addition, the theoretical calculation of equivalent stress at the end of the shaft was performed, which demonstrate that cracks can easily occur under the action of impact loads. The contribution of this paper is to provide a reference in fracture analysis of similar main shaft of wind turbines.

Amol B Rindhe and S R Wagh 2014 analyzed and evaluated the failure of a composite material automotive driveshaft by using finite element methods (FEM). CAD soft ware was used to design the composite material automotive drive shaft which is made up of high modulus material and tested in ANSYS for optimization of design or material check and providing a best material.

Amim Altaf Baig, Dr. A.M. Langde 2015 designed and optimized the failure analysis of a propeller shaft for heavy duty vehicle. They found out that stress will concentrate in the smaller diameter portion, as consider to this change in shaft diameter according to the requirement we can optimize the shaft for better performance and make it more durable. In any case, one must determine the cause of failure and predict the fatigue life to prevent future occurrence and to improve the performance of the Drive Shaft.

Hariom, Prof. Vijoy Kumar, Dr. Chandrababu D. 2016 reviewed the fundamentals of shaft failure *analysis and select the best method to find out the root causes failure of heavy nip roller shaft used in textile industry.*

Shivanand, Shravankumar B. Kerur 2019 studied the Failure and Thermal Examination of Hybrid Materials for a Propeller shaft in Aerospace Applications. The suitability of the MATLAB results obtained from the previously selected composite material comprising of carbon steel + epoxy + S glass + T700 fibres using ANSYS software by creating a solid three-dimensional meshed model of the shaft was checked. Layerwise shaft theory and finite element analysis have been employed for developing the model. The load failure point was found to be 8.4mm from the delamination studies. From analysis it was understood that the chosen composite material could be used for the propeller shaft of an aircraft.

V. MATERIALS AND METHODS

The metallographic inspections of the fracture surface, chemical composition and mechanical properties of the material of the shaft were carried by means of electronic microscopes.

1. A theoretical calculation of equivalent stress of the shaft was also performed.
2. Investigation into the cause of main shaft fracture

For us to carry out a thorough investigation of the actual cause of failure on the turbine shaft we will have to study the failure analysis in the forms namely: (1) experimental analysis of the main shaft, and (2) theoretical stress calculations

Material Properties

Category: Natural Fibre Reinforced Plastics
Name: Rhus Fibre Reinforced Polyester Polymer Composite

Property	Value	Units
Elastic Modulus in X	19200	N/mm^2
Poisson's Ration in XY		N/A
Shear Modulus in XY		N/mm^2
Mass Density	1160 (approx.)	kg/m^3
Tensile Strength in X	190	N/mm^2
Compressive Strength in X	230	N/mm^2
Yield Strength		N/mm^2
Thermal Expansion Coefficient in X		/K
Thermal Conductivity in X	0.17	W/(m·K)
Specific Heat		J/(kg·K)
Material Damping Ratio		N/A

DRAWINGS

Fig.: 3D Realistic Model of the Shaft and Runner Assembly

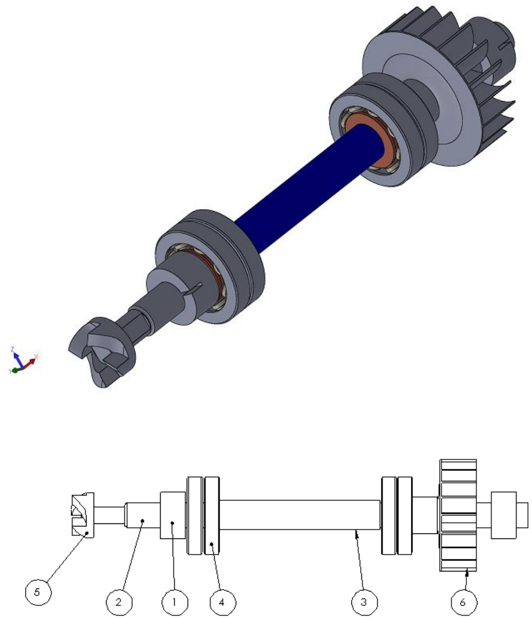

Fig.: Ballooned Drawing

Table: Part List

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Retainer		2
2	Shaft Model		1
3	Spacer Sleeve		1
4	Conrad Bearing		4
5	Jaw Clutch		1
6	Runner		1

DESIGN PARAMETERS

Generator Output Power (P)	3000 W
Head (H)	5.5 m
Flow Rate (Q)	0.75 m^3/s
Overall Efficiency) (η_o)	82 %

Calculation of specific speed, (N_s)

$$N_s = \frac{172.556}{H^{0.425}}$$

Calculation of turbine speed, (N)

$$N = \frac{N_s \times H^{1.25}}{\sqrt{P}}$$

Discussion of Load Simulation Results

Results for the static analysis carried out on the runner shaft of the cross flow turbine to ascertain its safety while in operation are shown on Figures 1 and 2; while those for the blades are depicted in Figures 3 and 4.

Load vs. Deformation Simulation results reveal that, dynamically, both runner and shaft assembly of the turbine would survive design loadings under actual service condition. Dynamic stability was investigated, and from the results of dynamic finite element analysis of the runner shaft and blades, it was evident that the induced stresses and deformations produced on the shaft and blades under various component loads were sufficiently within allowable values. The shaft didn't undergo plastic deformation from the results of both analyses.

Considering static conditions, portions of the components susceptible to localized deformations were revealed through a virtual experimentation with Solid Works Simulation 2014 add-in. Static nodal stress analysis for the shaft (Fig.1) generally indicates safe stress levels which occurs at the shaft end designed for fixtures and jaw clutch. Limiting values of stresses in this region is about 1.2 N/mm^2. From Fig.2, it is evident that maximum static displacement (deflection) corresponding to 0.66 mm over the entire length of 930 mm is considerably safe and within permissible limits, as par design. This deformation is seen to occur at the region where the rotor is mounted (about 175 mm from the RHS of the shaft). The maximum stress effect observed at points of location of stress-raiser and the concomitant deflecting position of the runner shaft as shown in Figures 1 and 2 are consistent in principle with the concepts of stress concentration factors and mass-moments.

From the simulation results, the turbine blades are subjected to maximum tangential stress of 2.5 N/mm^2 at locations very close to the root of the blades; while displacements suffered at the tip of each blade on the account of 'attack' from nozzle jet have limiting value of 0.40 mm. By all standards, these indical values are indicative that the runner-blade design for the water turbine, with the specified material, is functional. Bulk structural properties and morphological characteristics of the Rhus fibre impregnated Polyester composite promises to offer good fatigue endurance and excellent corrosion resistance.

VI. LOAD SIMULATION RESULTS

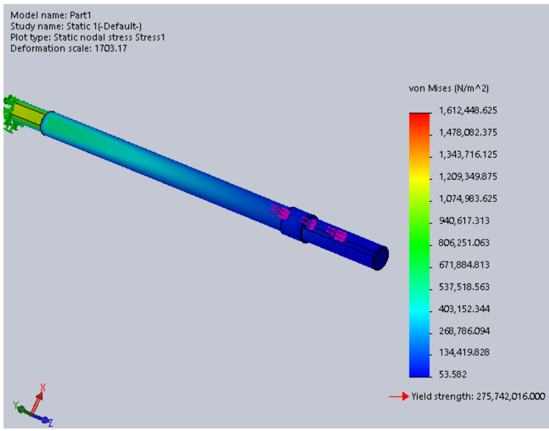

Fig.1: Stress induced in the shaft

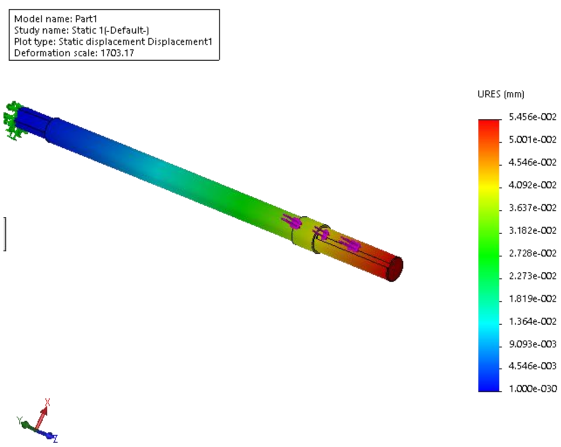

Fig.2: Displacement/deformation suffered by the shaft

CONCLUSION

The investigation of low strength deformation failure of turbine blade produced with RHUS fiber has been investigated and the following were observed

REFERENCES

[1] Amol B Rindhe and S R Wagh (2014), failure analysis and evaluation of a composite material automotive driveshaft by using fem—a review

[2] Lee D G, Kim H S, Kim J W and Kim J K (2004), "Design and Manufacture of an Automotive Hybrid Aluminum/Composite Driveshaft", *Composite Structures*, Vol. 63, pp. 87-99.

[3] Mohammad Reza Khoshravan (2011), "Design and Modal Analysis ofComposite Drive Shaft for Automotive Application", *International Journal of Engineering Science and Technology*

[4] Hariom, Prof. Vijoy Kumar , Dr. Chandrababu D. (2016) A Review of Fundamental Shaft Failure Analysis

[5] Shivanand, Shravankumar B. Kerur (2019) "Failure and Thermal Examination of Hybrid Materials for a Propeller shaft in Aerospace Applications"

[6] Zhanqi Zhang, Zhongjun Yin, Tian Han and Andy C. C. Tan " (2013), Fracture analysis of Wind Turbine main Shaft"