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ORIGINAL RESEARCH ARTICLE

INVESTIGATION OF CHEMICAL COMPOSITION OF A STEAM TURBINE SHAFT (A CASE OF KADUNA REFINERY)

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ABSTRACT

An investigation of the chemical properties of Original Equipment Manufacturer's (OEM) steam turbine shaft and that of locally produced shaft was carried out to determine the chemical composition of the shafts and determine the suitability of the locally produced shaft to replace the OEM turbine shaft that is in constant failure. The chemical analysis carried out on the samples revealed that the OEM turbine shaft is composed of 0.48C, 0.06S, 0.12Ca, 0.99Cr, 0.36Si, 0.71Mn, 0.07P, 0.12Ni, 0.15Cu and 0.39Mo and the locally manufactured steam turbine shaft is composed of 0.38C, 0.07S, 0.038Ca, 0.89Cr, 0.83Si, 0.63Mn, 0.04P, 0.04Ni, 0.16Cu and 0.20Mo. Manganese which was found to increase hardenability and tensile strength is lower in the locally manufactured shaft as compared to the OEM steam turbine shaft. The analysis also showed that carbon, Sulphur, chromium, phosphorus, Nickel and Molybdenum content of the original steam turbine shaft is higher than that of the locally manufactured shaft. The results obtained agree with the ASTM A668 steam turbine shaft requirement under class D standard of the chemical composition.

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1.0 Introduction

A steam turbine is a steam prime mover with continuous rotary motion of the driving element. It converts the thermal energy of steam into mechanical work. The steam flow proceeds through directing devices and impinges on curved blades mounted along the periphery of the rotor. By exerting a force on the blades, the steam flow causes the rotor to rotate (Nag, 2002). The chemical composition of a turbine shaft is essential for knowing the constituents that determine the hardness and other properties necessary for understanding the failure modes of the shaft (Mellinda and Rochim, 2015).

The steam turbine has proven to be a very convenient engine for driving rotating mechanisms, such as electric generators, pumps, blowers, and ship propellers. It operates at high speed and more compact, lighter, better balanced, and more economical than the reciprocating engines (Nag, 2002). In recent times development of steam turbines has witnessed improved output capacity and specialized turbines have been designed for various uses, (O'Connor and Roberston, 1999).

The turbine shafts generally operate at very severe conditions such as dust laden, corrosive, and high or low temperatures. Moreover, it is subjected to variety of loads such as tension, torsion, compression, bending, or combination of these loads and in some instances, they are often subjected to vibratory stresses. The turbine shafts usually fail at the keyways due to expansion. Wear by bearing and metal fatigue are the major contributor of shaft failure (Cots et al., 2003).

Not only the chemical composition, but the adjoining components also such as the bearing and gears could cause excessive vibration because of eccentricity or unbalance of the shaft (Trebuna et al., 2017).

The need is to look out for a material which can be effectively used as a substitution of the original steam turbine shafts. These materials should exhibit high tensile and toughness values. However, it is generally observed that both the tensile and toughness values are inversely related to each other. By increasing the tensile property, the toughness or impact value decreases and vice-versa. Hence, a judicious selection of an appropriate heat treatment process to maintain a good balance of these two properties is surely needed.

Heat treatment is an important operation in the final fabrication process of many engineering components. Only by heat treatment is it possible to impact high mechanical properties to steel parts and tools for sophisticated application (Energy and Environmental Analysis, 2008). Heat treatment is a very important tool of the metallurgist by which he can alter the properties of steel easily. The same steel can have a very wide range of mechanical properties if subjected to different heat treatment. Today, where science and technology are advancing very rapidly in pursuit of higher properties in materials, heat treatment plays a very important role (Whitaker, 2006). Heat treatment process as one of the methods of improving the performance of steel for specific use can be applied to enhance the performance of the locally produced steam turbine shaft. It is expected that the heat treatment will improve on the mechanical properties of the shaft to enhance performance and reduce the rate of failure.

Heat treatment is hence defined as a sequence of heating and cooling operation, timed and applied to a metal or alloy in the solid state in any way that will produce desired properties, that is, it is an operation or combination of operations of heating and cooling of a solid or an alloy metal to endow it with certain predetermined physical and mechanical properties (Leyzerovich, 2005). The changes in the properties of steel after heat treatment are due to the phase transformations and structural changes that occur during the heat treatment (Adewuyi et al., 2005).

Hardening is a heat treatment process in which material is heated to austenitising temperature, soaking at this temperature and then cooling at a rate faster than the critical cooling rate such that martensite is formed (Bob, 2003).

The main objective of hardening is to induce high hardness and impact high wear and abrasion resistance to the material. In pearlite class of steel hardening is done to induce high strength along with good toughness and ductility (Dave, 2003). The temperature of tempering is decided based on the strength and toughness of the material required during the service period (Davis and Oelman, 1993).

This study is aimed at the enhancement of a locally fabricated steam turbine shaft that can have similar mechanical properties as the original shaft to eliminate the problem of constant failure and for optimum performance. The work was centred on the determination and evaluation of the chemical composition of the original and locally fabricated steam turbine shafts with a view to selecting appropriate method for the enhancement of the locally fabricated shaft.

2. Materials, Equipment and Methods

2.1 Materials

Samples for various investigations were taken from the failed OEM steam turbine shaft in Kaduna Refining and Petrochemical Company Limited and the locally produced shaft. The samples for the chemical analysis were then machined from both shafts.

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2.2 Equipment

The following were the major equipment used in carrying out the various tests and experiments conducted:

1. A SUI 40-50 lathe machine with an electric motor of 7.5kw
2. Minipal 4 model Energy Dispersive X-Ray Florescence Spectrometer (EDXRF)

2.3 Methodology and Chemical Analysis of Samples

Lathe machine was used to machine the samples in disc-like shaped samples having a diameter of 32mm that would fit perfectly in the sample holder of the X-Ray Fluorescence (XRF) spectrometer from the failed locally fabricated steam turbine shaft for chemical analysis as shown in Figure 1. The measuring surface of the metal sample was grinded and polished so as to have a smooth and mirror surfaces before been cleaned with acetone of the polished sample faces.

After positioning the sample on the X-Ray Florescent Spectrometer elemental compositions were analysed using a minipal 4 model Energy Dispersive X-Ray Florescence spectrometer (EDXRF) whereby the samples analysed were illuminated by X-rays or gamma rays, which resulted in the excitation of core-level electrons to excited states. The radiative decay of these electrons from the excited states back to their respective ground states resulted in the emission of fluorescent or "secondary" X-rays that are characteristic of the energy levels of each atomic species and thus serve as a spectroscopic fingerprint for each element present in the sample.

During the analysis, a power rating of 20kv, measuring time of 100 seconds, an air media and an Al-thin filter were used. The data for the chemical composition of the samples were obtained from the X-Ray Florescence Spectrometer (EDXRF).

Figure 1: Carbon Composition Test Sample of the Shaft

3. Results and Discussions

3.1 Results

Table 1 shows the result of the chemical analysis of the samples of the OEM and the locally produced turbine shafts as obtained using X-Ray Florescence Spectrometer (EDXRF).

Table 1: Chemical Composition of samples

Elemental Composition	%C	%S	%Ca	%Cr	%Si	%Mn	%P	%Ni	%Cu	%Mo
Original turbine Shaft (OEM)	0.40	0.06	0.12	0.99	0.36	0.71	0.07	0.12	0.15	0.39
Locally Fabricated Shaft	0.38	0.07	0.038	0.89	0.83	0.63	0.04	0.04	0.16	0.20

3.2 Discussion

The chemical analysis carried out on the samples revealed that manganese which was found to increases hardenability and tensile strength is lower in the locally fabricated shaft as compared to the original steam turbine shaft. The analysis also showed that carbon, manganese, chromium and phosphorus content of the original steam turbine shaft was higher than that of the untreated locally fabricated shaft with values; (0.48C, 0.06S, 0.12Ca, 0.99Cr, 0.36Si, 0.71Mn, 0.07P, 0.12Ni, 0.15Cu and 0.39Mo) and the locally fabricated steam turbine shaft (0.38C, 0.07S, 0.038Ca, 0.89Cr, 0.83Si, 0.63Mn, 0.04P, 0.04Ni, 0.16Cu and 0.20Mo) as shown in Table 1.

Comparing the chemical compositions of the original and locally fabricated steam turbine shaft as shown in Figure 2, nickel noted to induce strength, ductility and toughness in turbine shafts is lower in the locally fabricated shaft. Chromium characterized by their hardness and resistance to wear is also lower in the locally fabricated shaft, hence, renders the shaft less resistant to wear in service.

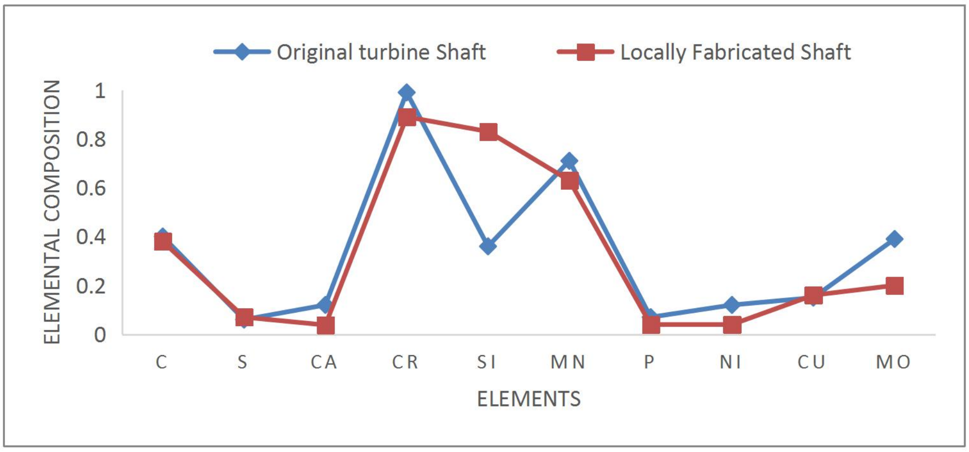

Figure 2: Comparison of elemental composition of original turbine shaft and locally fabricated shaft.

Comparing the chemical compositions of the ASTM A668 steam turbine shaft requirement under class D standard of the chemical compositions standards of steam turbine shaft, original turbine and locally fabricated steam turbine shaft as shown in Figure 3, Phosphorus contents of ASTM standard and locally fabricated shaft are the same which shows its effectiveness as a substitute to the OEM shaft. However, the Sulphur content which is detrimental to strength in the locally produced shaft is higher than in OEM which accounts for its lower strength. The carbon contents of both original and locally fabricated are in good agreement also.

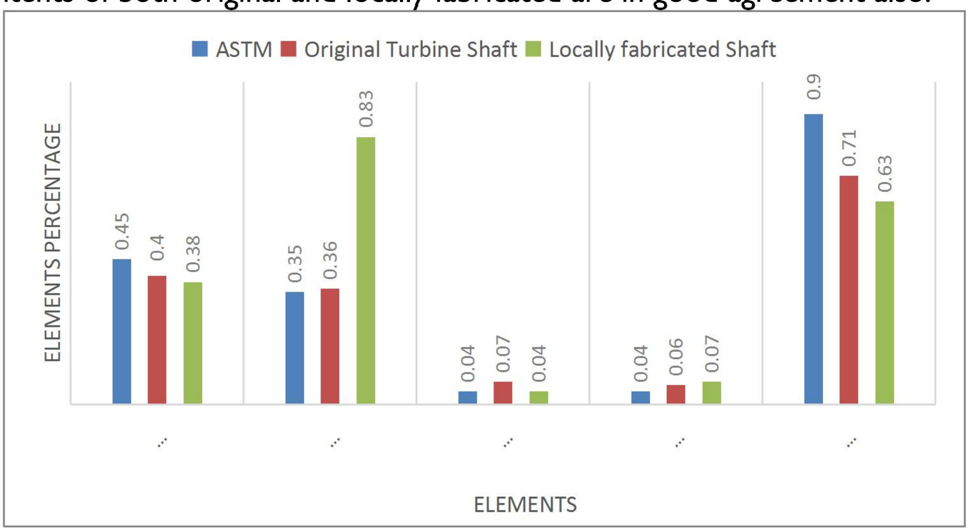

Figure 3: Comparison of elemental composition of ASTM standard, original turbine shaft and locally fabricated shaft.

4. Conclusions

The chemical composition of the original and locally fabricated steam turbine shaft was determined. The major alloying elements (Magnesium, Chromium, Silicon, Molybdenum and Nickel) in the original steam turbine shaft were found to be higher than that of the locally fabricated steam turbine shaft.

The Manganese content of the OEM shaft is higher than the locally produced shaft by almost double. The locally produced shaft is better with lower manganese content of 0.063% which gave better hardenability as the 0.07% of the OEM shaft is prone to brittleness which causes its failure.

The Phosphorous content of the OEM is also higher than the locally produced shaft. The locally produced shaft is better with lower Phosphorous content of 0.04% which gave better increased strength and hardness and increased corrosion resistance than the 0.07% of the OEM shaft which is subjected to high brittleness and increased tendency to crack that leads to its failure.

The Sulphur content in the locally produced shaft is higher which is not too good for steel, however the Silicon content of the locally produced shaft is higher than the OEM which is good but since the ductility, hardness, toughness, and strength elements are excellent in this service condition, the OEM is better than the locally produced shaft however, the locally produced shaft can be used as a substitute with appropriate treatment.

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