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Search and Survey

Failure Analysis of Connecting Rods and Engine Blocks of Small Generators

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Abstract

Three small generators were selected for conducting the failure analyses. The generators tagged FG1(2.7kVA, SG2700), FG2(2.7kVA, TG2700, TIGER) and FG3(2.5kVA ELEPAQ, EC2500CXS) were first dismantled and the components inspected for physical examination. In all the three generators the Connecting Rods were found to have broken into pieces. Two of the engine blocks were pierced by the broken connecting rods. Chemical analysis tests were made on the Connecting Rods and Engine Blocks using XRFNiton analyzer. The tests revealed that all the components were made from Aluminum alloys. The Copper contents for the Connecting Rods were found to be from 1.77% to 2.37% which were below 4.0% minimum requirement for Connecting Rods and other components of high performance engines based on Aluminum Association (AA) and British Standard (BS) specifications. The Connecting Rods also contained up to 2.01% Iron but none of the Connecting Rods had Magnesium which is an important element for increasing strength of Aluminum alloys. The high content of iron coupled with lack of Magnesium resulted in low strength and increased hardness, making the Connecting Rods brittle and highly susceptible to fatigue failure. Hardness tests conducted on the Connecting Rods using Rockwell Hardness Testing machine gave 160,151 and 175 BHN which were much higher than maximum of 105 BHN for AA and BS specifications. Similarly, the hardness values of the Engine Blocks were found to be 128,160 and 140BHN respectively. The corresponding tensile strengths of the Engine Blocks were 167,149 and 152MPa which were lower than the minimum AA and BS specification of 170MPa.The results concluded that the Connecting Rods of the three generators failed due to excessive brittleness.

Key words: Generator, Chemical analysis, Copper, Magnesium, Manganese, Hardness, Connecting rod, Engine block.

1. Introduction

Failure analysis is a process for determining the causes or factors that leads an undesired loss of functionality. Generally, failure occurs when a system or part of a system fails to perform up to the expectation for which it is designed. Investigation for the chemical and mechanical properties of failed components is the most important part of failure analysis. Failure analysis on failed components may result in the rejection of such

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component by the user or the manufacturer may decide to improve the design or even stop producing it. Engineering branches from both design and manufacturing companies can utilize, failure analysis report in taking decision on where amendment will be made, that is from design up to final production. Furthermore, material selection and processing method can use failure analysis report especially when it is discovered that a component failed as a result of mechanical defect. This will be more in the industries where every year a new design or model will be out to the market. Another reason for conducting failure analysis on engineering components is to determine the factors responsible for the failure of the component or structure. This determination may be motivated by either sound engineering practice or legal consideration, in case of court cases. Machines or mechanical components such as shafts, fasteners and structures are not supposed to fail, but when they fail, we can determine why they fail through Failure Analysis. However, according to Mechanical Failure Prevention Group (MFPG) failure can be prevented by developing better design techniques, effective maintenance, improved diagnostic techniques, lubrication/ wear reduction and improved failure analysis. (Munz,1999).

1.1 Types of small generating sets available in the market:

A market survey was conducted for identifying the available types of small generators in Kano. The survey covered Muhammed Abubakar Rimi market, Galadima Road and Ibrahim Taiwo Road, which are the major markets for small generating sets. Table 2.1 gives the data obtained from this survey. Aluminium-copper cast alloys are recommended by AA and BS for producing pistons of high performance engines and castings requiring high strength and shock resistance.(Bolton, 2000). BS standards also recommended alloys of Aluminium-Silicon-copper/magnesium for general engine parts and components where high strength and pressure tightness are required including pump bodies, crankcases and blower house.

1 .2 Cases of Failure Analysis:

The Mechanical Failures Prevention Group (MFPG) made of Engineers and Scientists was established in 1967 to exchange information and innovative ideas on methods to avoid or predict mechanical failures in a wide variety of vehicles, equipment and structures. MFPG developed standard terminologies and established interrelationships among causes, modes and results of failure. The scope of MFPG not only covered machines but also methods of failure analysis and the application of lessons learnt from failure analysis results. (Zamanzadeh et al, 2004). Vander Voort, G. E. (2001), in his article on conducting failure examination, identified design shortcomings, heat treatment irregularities, material imperfection due to faulty processing or fabrication, overloading and other service abuses, improper maintenance and repair and environment material imperfections as the causes of failure in metallic components. He pointed out that all failures deserve the attention of the investigator because they reduce efficiency, cause waste of critical materials and, in some cases, cause considerable damage or personal injury which can result in costly litigations.

Turbine blades of a 210MW thermal power plant were made of 12% Cr steel with tempered martensitic microstructure. Micro structural analysis as well as hardness and tensile tests did not indicate any degradation in terms of microstructure and mechanical properties, but physical discontinuities were observed in the braze joint which might have been formed due to improper brazing operation. Failure of the joint was found to be due to improper brazing and corrosion. Fractographic evidence showed that the cracks were initiated from various points on the blade surface. Striations and beach marks were also observed which indicated the occurrence of high cyclic fatigue loading on the blade. The situation was aggravated by excessive vibration which facilitated the propagation of the cracks. (Wiley, 2002).

Araromi, (2009) conducted an investigation into the failure of ball bearings of a rotary furnace by collecting the grease of the bearings which was liquefied in a clean beaker with a petrochemical solvent. The wear particles were separated from the grease samples using a ferro-gram. The debris was later examined under a metallurgical microscope. Data analysis indicated that 18% of the bearing served their useful life before failure while 82% failed unexpectedly before their life span elapsed due to symptoms of acidic corrosion.

Xiao-lei Xu, et al (2011) also conducted failure analysis of a truck diesel engine crankshaft made from spheroidal cast iron which fractured after covering 13,656km of operation. The Fractures occurred on the 6^{th}, 5^{th} and 4^{th} crank pins. The cracks of the sixth and fifth crankpins are across the oil holes and a complete fracture occurred at the sixth crankpin. The results indicate that fatigue fracture is the dominant failure mechanism of the crankshaft. The fatigue cracks found in the crank pins initiated from a machining dent present in the wall of the oil hole which supplied the stress concentration responsible for the fatigue fracture.

In a similar work Xue-qin Hun, et al (2011) conducted failure analysis of ductile cast iron crankshaft in a vehicle engine. The crankshaft suddenly fractured as the vehicle engine was running normally on a highway. The failure was analyzed by using chemical and metallorgraphic examinations, evaluations of mechanical properties, observations of the fracture surface and measurement of the fillet radius. The report showed that crankshaft failure was as a result of fatigue fracture resulting from combined effect of bending and twisting. Several aspects such as chemical compositions, hardness and microstructure, yield strength and impact toughness were not up to the technical standard for production of crankshaft. Moreover, Xiao-lei Xu, et al (2011) conducted a failure analysis on a truck diesel engine crankshaft which fractured in service after 76,010km of operation. The fracture occurred on the first crankpin. The investigation identified fatigue as the dominant failure mechanism. The fatigue crack initiated at the fillet region of the first crankpin web due to absence of induction hardening case in the fillet region which decreased the fatigue strength.

2. Research Methodology

2 .1 Materials and methods

MATERIALS

The materials used for the Failure Analysis were the connecting rods and engine blocks from the three generators.

3. Experimental Methods and Equipment Used for the Research

The experimental methods used for this research work were as follows:—

(1) Physical Examination of dismantled generators

(2) Chemical analysis was conducted using NitonXRF analyzer, a high performance portable X-ray (XRF) elemental analyzer.

(3) Hardness test was conducted using Rockwell hardness testing machine (Avery Denison, Type6407) The scale used for the test was 60kgf using A as part of the mark.

(4) Tensile Strength Test was conducted using Universal Material Testing Machine (Model SM100TQ). Three samples from engine blocks were tested.

3.1 Data presentation

Physical examination

The three generators were first dismantled and examined physically (see Table 4.1) and photographs taken of the failed components. The photographs are given in Plates 1 to 5.

1- FG 1 (2.7kVA, SG2700) below is the first generating set selected for the investigation. It was narrated by the owner of this generator that it was purchased and commissioned in October, 2010 and failed in June 2012.After examining this generator, it was observed that the connecting rod broke into small pieces. The broken parts hit the engine block and made two holes on the side of the engine block. In addition, part of the piston was broken. Plate 4 shows the holes on the engine block.

PLATE 1 FG1 Connecting Rod

2- FG 2 (2.7kVA, TG2700, TIGER) is the second generator that failed about two years after commissioning while it was in operation. After it was dismantled, it was observed that, the connecting rod broke into four pieces and the piston was damaged due to the scratches over its surface. Similarly, the engine block was pierced with many holes.

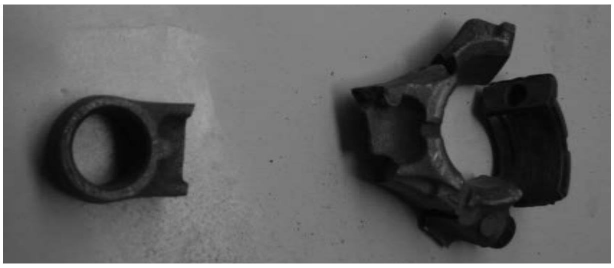

PLATE 2 FG2 Connecting Rod

3- FG 3 (2.5kVA ELEPAQ, EC2500CXS) is the generator that worked for twenty months before the failure. It was observed that, the connecting rod was broken into pieces. However, the engine block was not damaged. See plate 3forbroken connecting rod.

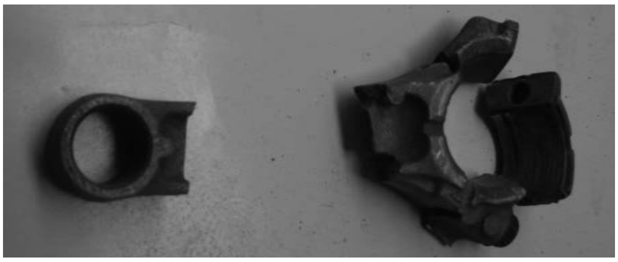

PLATE 3 FG3 Connecting Rod

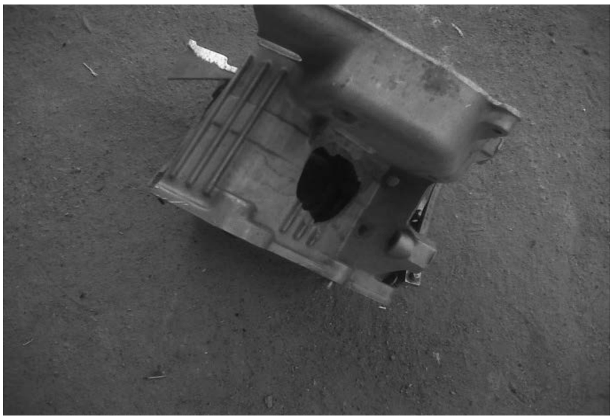

PLATE 4 FG1 Engine Block

PLATE 5 FG2 Engine Block

Table 4.1 Results of Physical examination of the failed generators

	CONNECTING ROD	ENGINE BLOCK	PISTON	REMARKS
FG1	Connecting rod broke into many small pieces.(See Plate 1)	Pieces of broken connecting rod pierced the engine block making two large holes (See Plate 4)	Piston was slightly damaged on the sides	Plate 4 shows one of the holes in the engine block.
FG2	Connecting rod broke into four pieces. (See Plate 2)	Engine block was pierced with many holes. (See Plate 5)	Intact	Plate 5 shows the two holes in the engine block.
FG3	Connecting rod broke into four pieces. (See Plate 3)	Engine block was not damaged.	Piston was slightly damaged	

3.2 Results of chemical analysis and hardness tests

From the tests conducted on each sample, chemical composition, hardness and tensile strength, tests the results obtained are summarized in Table 4.2

Table 4.2 Chemical analysis and Hardness results.

	Name-of Component	Major elements &their percentages						Hardness (BHN)
		Al	Cu	Fe	Zn	Mn	Ni	
FG1	Engine block	94,56	1.27	1.9	1.40	—	—	128
	Connecting rod	95.86	2.37	1.32	—	—	—	160
FG2	Engine block	95.47	2.01	1.56	0.62	0.12	0.05	160
	Connecting rod	95.05	1.93	2.01	0.59	0.24	0.02	151
FG3	Connecting rod	95.69	1.77	0.99	1.27	—	—	175
	Engine block	95.38	2.01	1.65	0.06	0.20	0.07	140

The detailed results of chemical composition tests are in Tables 3.3 to 3.6 inAppendix 2

3.3 Tensile Test Results

The tensile strengths of specimens made from FG1, FG2 and FG3 Engine Blocks were 167,149 and 152 kN/mm^{2}respectively. However, Tensile Test specimens could not be obtained from the broken Connecting Rods.

4.0 Discussion Of Results

According to AA and BS standards the percentage of copper in the Alloy for production of components of high performance engines should be between 4.0% and 10%. Corresponding tensile strength should not be less than 170 MPa(170 kN/mm^2) and hardness should be between 75 and 105 BHN. For example, Duralumin has the following composition of alloying elements which makes it as strong as steel but with one third of the weight:- Cu – 3.5 to 4.5% ,Mg – 0.4 to 0.7%, Mn – 0.4 to 0.7% and Si or Fe not more than 0.7% (Jain, 2009)

4.1 Connecting Rod & Engine Block Of Fg1 (2.7kVA, SG2700)

a) The failure of this generator was triggered by the catastrophic failure of the connecting rod which broke into small pieces. The broken pieces of the connecting rod pierced the engine block making a big hole. Chemical analysis of the Connecting Rod revealed that it was made of Aluminium alloy of 95.80% Aluminium, 2.37% copper and 1.32% iron. Most useful alloying elements for Aluminium are copper, silicon, manganese, magnesium and zinc. (Jain, R. K. 2009)The copper content is only 59% of the minimum AA and BS standards of 4.0%. This coupled with a high iron content of 1.32% made the connecting rod harder and therefore more brittle and more susceptible to fatigue failure because of the cyclic stresses on the connecting rod.

b) The Engine Block contained 94.56% Aluminium, 1.27% copper, 1.90% iron and 1.40% zinc. The copper content is only 32% 0f the minimum recommended in the AA and BS standards. This together with high iron content of 1.90% made the engine block very hard and brittle, even though the zinc content of 1.40% should have promoted the strength. The chemical analysis showed no trace of manganese or magnesium which could have improved the strength as in Duralumin.

c) Hardness of the Connecting Rod and Engine Block were 160 and 128 BHN respectively, much higher than the maximum 105BHN recommended by AA and BS standards which contributed to the brittle failure of the Connecting Rod and Engine Block.

d) Tensile strength of the Engine Block was found to be 167 kN /mm^2 (MPa) which was 1.8% lower than the AA and BS standards of 170 MPa.

4.2 CONNECTING ROD& ENGINE BLOCK OF FG2 (2.7kVA, TG2700 TIGER)

(a) (i) The connecting rod broke into four pieces which lead to the catastrophic failure of the generator. The broken pieces made two holes in the engine block. Chemical analysis of the Connecting Rod showed that it was made of 95.05% Aluminium, 1.93% copper, 2.01% iron, 0.59% zinc and 0.24% manganese with traces of nickel and titanium. The copper content is 48% of the AA and BS standards. The low copper content together with high iron content of 2.0% made the alloy hard and brittle causing premature fatigue failure

(a)(ii) The engine block was made of 95.47%Aluminium,2.01% copper, 1.56% iron, 0.62% zinc and 0.12% manganese with traces of nickel, tin, titanium and lead. The copper content is 50% of the minimum recommended content of 4.0%. The high iron content of 1.56% made the connecting rod hard and brittle prone to fatigue failure.

(b) Hardness of the Connecting Rod and Engine Block The hardness of the connecting rod was 151 BHN which was much higher than the maximum standard value of 105BHN making the component more brittle and therefore highly prone to fatigue failure.The hardness of the Engine Block was found to be 160BHN much higher than AA and BS standard values of 105BHN.

(c) Tensile strength of the Engine Block was found to be 149 kN /mm^2 (MPa) which was 12.4% lower than the AA and BS standards of 170 MPa.

4.3 CONNECTING ROD & ENGINE BLOCK OF FG3 (2.5kVA ELEPAQ EC2500 CXS)

Failure of the generator was caused by the breaking of the connecting rod into four pieces. However, the engine block was not damaged.

(a)(i) Chemical Analysis of the Connecting Rod showed that it was composed of 95.69% Aluminium, 1.77% copper, 0.99% iron, 1.27% zinc with traces of tin and lead. The copper content was 44% of the minimum recommended by AA and BS. Iron content of 0.99% and zinc content of 1.27% helped to increase strength but lack of manganese and magnesium probably encouraged fatigue failure.

(a)(ii) The Engine Block was made of 95.38% Aluminium, 2.01% copper, 1.65% iron and 0.20% manganese with traces of zinc, nickel, titanium, zirconium and lead.

(b) Hardness of the Connecting Rod and Engine Block. Hardness values of the Connecting Rod was found to be 175BHN whichwas much higher than the maximum value of 105 BHN specified in AA and BS standards. The Engine Block, however, had lower hardness of 140BHN.

(c) Tensile strength of the Engine Block was found to be 152 kN /mm^2 (MPa) which was 10.6% lower than the AA and BS standards of 170 MPa.

5.0 Conclusions

5.1 Connecting Rod for FG1 (2.7kVA, SG2700)

a) Chemical Analysis tests for the Connecting Rod revealed that copper content was below AA and BS specifications for 242.0/LM1Z Aluminium alloy recommended for the production of connecting rods of high performance engines. The iron content was almost three times that of Duralumin which made thealloy more brittle. Hardness tests revealed that the Connecting Rod was 30% harder than that recommended by AA and BS standards. This made the Connecting Rod more brittle and therefore prone to fatigue failure.

b) Engine Block was found to have higher hardness and slightly lower tensile strength compared to AA and BS standards.

5.2 Connecting Rod for FG2 (2.7kVA, TG2700 TIGER)

a) Chemical analysis of the Connecting Rod showed that the copper content was less than half of the amount recommended by AA and BS standards. Hardness of the Connecting Rod was 44% higher than the AA and BS standards.

b) Engine Block was found to have much higher hardness and slightly lower tensile strength compared to AA and BS standards.

5.3 Connecting Rod for FG3 (2.5kVA ELEPAQ EC2500 CXS)

a) Chemical analysis revealed that the copper content in the connecting rod was less than half that of the AA and BS specifications. The iron content was slightly higher than that of Duralumin but zinc content and lack of the magnesium lead to low strength of the connecting rod.Hardness tests showed that the connecting rod material was 67% harder than the AA and BS standards.

b) Engine Block was found to have higher hardness and slightly lower tensile strength compared to AA and BS standards.

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