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EXPERIMENTAL FAILURE INVESTIGATION OF AN AIRCRAFT NOSE LANDING GEAR

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ABSTRACT

In 1994, sets of aircraft were introduced into the Nigerian Aviation Industry for training of pilots. The nose wheels of some of the aircraft collapsed particularly during hard landings. The failure modes include complete fracture of the landing gear from the firewall and the buckling. This is the thrust for this study which is aimed at ascertaining the cause and mechanism of failure experimentally with a view to preventing future occurrence. Fractography of the failed samples was carried out and the fractograph showed high energy fracture – beach marks, initiation sites and the propagation area on the failure surface which indicates fatigue failure. Chemical analysis of the landing gear component showed medium carbon steel of the tough grade instead of spring steel. Experimental analysis entailed the characterization of fractured parts of the undamaged and failed nose wheel struts by determining the mechanical properties and examining the structural morphology of test samples. Fatigue tests revealed high cycle low stress fatigue in the failed material. Microstructural examination showed intermetallic inclusions within the microstructure of the material which acted as stress raisers causing crack initiation and eventually fatigue fracture.

KEYWORDS: Failure Investigation, Mechanical Properties, Metallography, Chemical Analysis

INTRODUCTION

Aircraft accidents are remembered by the public because of the unusually high loss of life and broad extent of damage that is typical of this type of accident [1]. Although flying is generally a safe method of transportation, accidents occasionally happen-whether through human error, mechanical failure, or criminal activity [2]. Landing gears, which are a major component in aircraft, are usually subjected to severe environmental conditions, such as temperatures, climates and operational situations such as runway conditions among others. Several works showed fracture in landing gear in parts such as cylinder attachment lugs manufactured from aluminium alloy, landing gear assembly manufactured in a die forging aluminium alloy and nose landing gear structure among others [3]. Defect and failure investigations on aircraft structural components have an important role in improving aircraft safety. Hence, the identification of the primary cause of failure and the subsequent analysis enable recommendations for corrective action to be made that hopefully will prevent similar failures from occurring in the future [4].

According to [1], failure can result, for example, from poor design, use of inferior material or fabrication methods, or from a phenomenon called *fatigue*. Fatigue design criterion of aircraft structures are usually one of the following: infinite-life, safe-life, fail-safe and damage-tolerant design. Because landing gear structures do not have redundancy in their means of support, the safe-life criterion is used. The safe-life includes margins for the scatter of fatigue results and for other unknown factors. The fatigue life consists of crack-initiation and crack-propagation stages. Landing gear materials usually show an initiation stage, consisting of 90-95% of the total life, and a propagation stage of 5-10% of the total life.

Because of this safe-life criterion, landing gears must have well-defined inspection techniques, frequencies and replacement times so that probability of failure due to fatigue cracking is extremely remote [5].

Another consideration in designing landing gear is material selection. Landing gear materials must be of high strength and stiffness, low cost and weight, and have good machinability, weldability and forgeability. They also must be resistant to corrosion, stress corrosion, hydrogen embrittlement, and crack initiation and propagation.

Because of the stringent requirements, landing gear components are fabricated from forgings. Castings have not been acceptable for landing gear structures due to poor fatigue-related characteristics such as grain flow and porosity [5]. This work aims at analyzing the failure of an ABT-18 aircraft landing gear in order to identify the cause of failure and hence forestall similar occurrences in the future.

The failed landing gear was the nose wheel component of the landing gear assembly for the ABT-18 aircraft. The ABT-18 aircraft is used in training of pilots in the Nigerian Aviation industry. Its basic design is a cantilever low wing monoplane with a single tractor engine, low mounted tail plane and elevator. The failed nose landing gear is underlain with wood and wrapped with fiberglass fairing. It was supposed to have been equipped with spring steel shock absorbers. Relevant layout of the nose landing gear is shown in Figure 1.

Figure 1: The Nose Landing Gear Assembly

Since the inception of training with the ABT-18 aircraft in 1994, several incidents have been recorded whereby the nose landing gear strut collapses particularly during hard landings. This resulted in severe damage of the propeller, engine, air frame and injury of pilots.

INVESTIGATION PROCEDURE

The failed landing gear was first inspected visually and macroscopically. The fracture surface of the gear strut was ultrasonically cleaned and examined under a Leica M400 electron microscope in order to identify the type of fracture.

The material in the vicinity of the fracture of the failed gear was then taken as samples for Brinell hardness measurement, impact tests and fatigue tests.

Metallographic specimens were prepared for optical microscopic examination. Chemical analysis of the landing gear material was performed in order to identify the type of steel used.

Figure 2: Failed Landing gear

Figure 3: Undamaged Landing Gear

Hardness measurement was taken using a universal testing machine and a Brinell reading microscope. Impact strength of the gear material was determined with Izod testing machine while fatigue data was obtained by applying reversed loads on the sample with the Avery Denison 7305 fatigue testing machine. Samples for these tests were correspondingly taken from an undamaged nose landing gear of the aircraft which was obtained from the aviation industry. These served as control for the experimental analyses.

RESULTS AND DISCUSSIONS

Visual Examination

The surface appearance of the failed landing gear is shown in Figure 4. Visual examination of the gear revealed a fractured strut surface with beach marks propagated from a point of crack initiation indicated by the arrow. This is a typical characteristic of fatigue fractures and particularly high cycle fatigue due to the well defined and closely spaced striations. The crack propagation can be seen by the flat plateaus joined by narrow regions of tensile tearing.

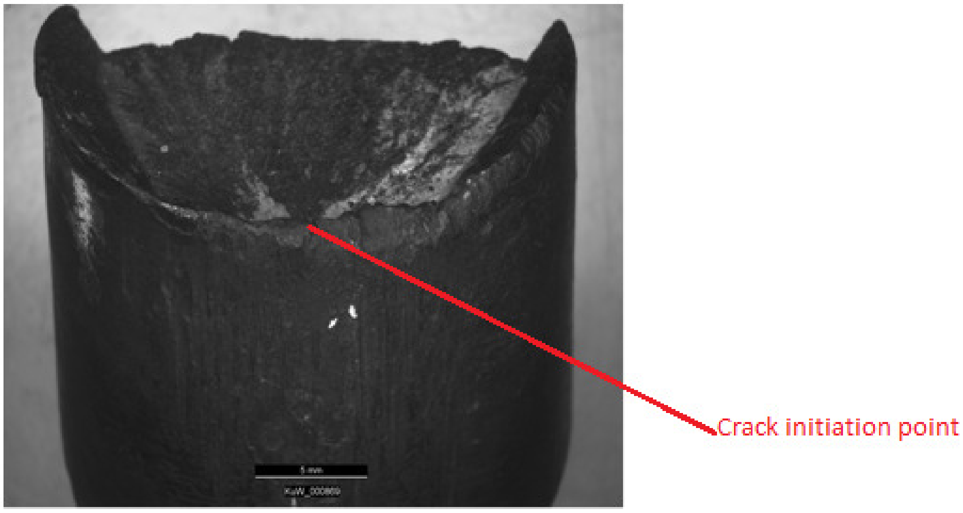

Figure 4: Fracture Surface of Gear Strut

There was also a measure of ductile pull which can be seen from the cone shape of the tear.

Hardness Profile

The hardness readings for the gear struts are presented in Fig. 5.

Fig. 5: HBR data for failed and undamaged gear struts

The failed gear's hardness differed from the undamaged by 92HBr. The marked difference may be due to loss of strength in the material as a result of fatigue. In each case, the hardness distribution across the gear surface was consistent. According to [6], the stronger (harder) the steel, the less likely it is that striations will be observable on the fracture surface. Hence, it can be inferred that the gears' hardness was probably not sufficient to prevent fatigue damage.

Composition Analysis

Chemical composition of the gear strut materials was analyzed using a spectrometer. The average values are shown in Fig. 6. Contrary to expectations, the compositions indicate that the material was made from medium carbon steel of the tough grade to SAE 0050 standard instead of spring steel. The strut ought to have been made from spring steel since the aircraft was designed without a shock absorbing mechanism. The spring properties are to enable the materials absorb shock on impact. According to [7], for spring effect, the percentage of Silicon in both samples should be in the range of 1.90% - 2.40%; with carbon content less than 0.65%, strength adequate for springs cannot be obtained.

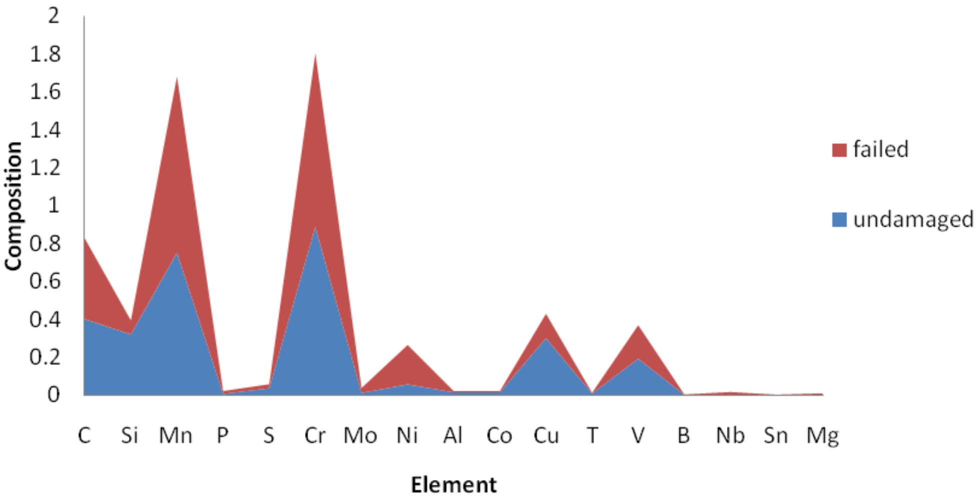

Fig. 6: Chemical compositions of undamaged and failed gears, the balance being Fe.

Molybdenum is required to increase the strength and toughness of the steel. Less than 0.60% cannot sufficiently provide this effect. Likewise, Nickel content should not be spared since Nickel improves the hardenability of steel. At least

0.50% is needed. Inconsistent design details may have caused the variations between the compositions of both samples. Also, improper material specification could have contributed to the failure of the aircraft's nose wheel strut.

Fracture Toughness

Test samples from the failed and undamaged gears were machined for impact tests according to the required specifications. Fig. 7 shows the fracture toughness of the materials.

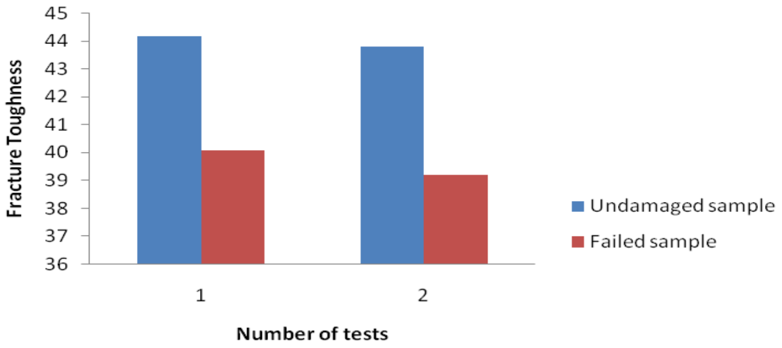

Fig. 7: Fracture toughness of failed and undamaged struts.

According to [8], the fracture toughness of materials to be used for axles, gears, drop forgings, buildings, bridges, washing machine and fridge bodies should be 60J. From the result above, it can be deduced that the gear strut materials may have had insufficient fracture toughness.

Fatigue Data

As a failure mechanism, fatigue involves initiation and gradual growth of cracks until the remaining section of material can no longer support the applied service load. The figure below shows the result of fatigue tests on undamaged and failed gear struts.

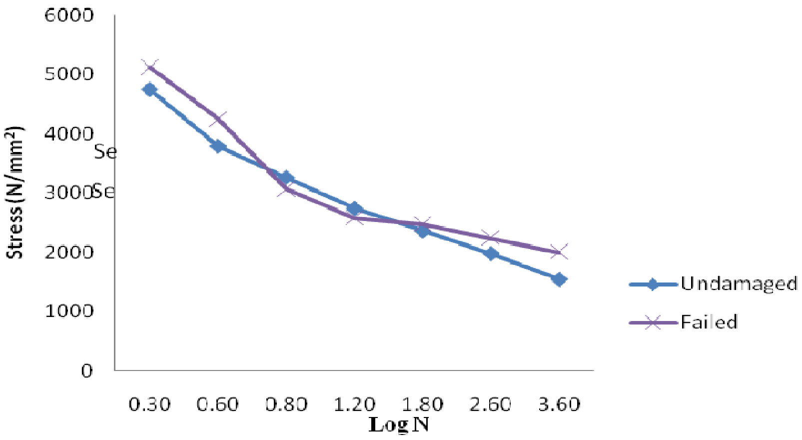

Fig. 8: Endurance Curves for Failed and Undamaged Strut Samples

The fatigue strength (S_e) of the undamaged sample is 3790N/mm^2 while the endurance limit (S_e) of failed sample is 3067N/mm^2. It is expected that below the endurance limit obtained for either of the samples, the material will not fail, that is, the structure is said to have an infinite life. The curve shows high cycle low stress fatigue strength of the materials. Furthermore, the beach marks (chevrons) characteristic of fatigue which propagates from the initiation site and the zone of fracture, being off-centre, is an indication that crack initiation was from a particular area on the strut. The low fatigue resistance of the samples and high stress to which the strut was subjected may have been the root causes of the fracture. This was also ascertained by visual examination where chevrons were seen on the surface originating from a point which could be the initiation site.

Microscopic Examination

Results are as shown in Figs. 9 and 10. Microscopic examination of the undamaged sample at magnification of X200 revealed few large inclusions with pearlite in ferrite matrix.

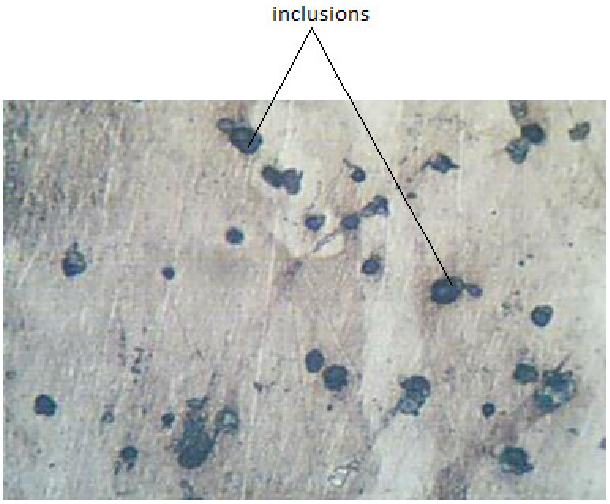

Figure 9: Optical View of Undamaged Strut Sample at X200

This defect could be a design problem since it is also present in the undamaged sample; hence there are equal chances of failure of this sample under fatigue loading. Microscopic examination of the failed sample at magnification of X200 revealed the inclusions more widely spread in the core of the material, resulting into pitting; with pearlite in ferrite matrix. Some are seen as degenerated inclusions. The inclusions acted as stress raisers and thus fatigue initiation sites resulting in cracks as shown in Fig. 10.

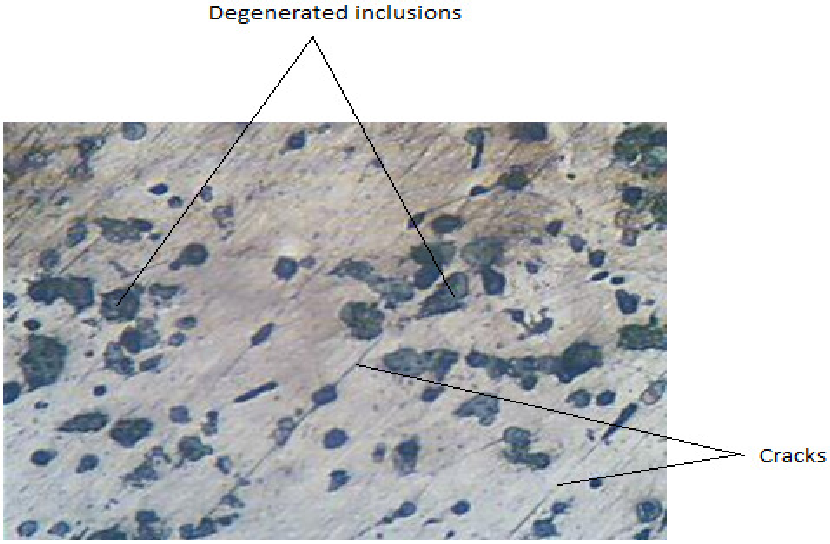

Figure 10: Optical View of Failed Strut Sample at X200 Showing Fatigue Cracks

It is worth noting that the thicker the inclusions in the longitudinal cross-section of a steel product, the higher the tendency for fatigue damage. Hence, the fatigue property of the landing gear can be effectively improved upon by ensuring that the average composition of these inclusions is minimal. Breakage starts from the inclusions if they are thick even though they are ductile. In other words, the width of the inclusions plays an important role in the improvement of the fatigue property of the gear materials. In essence, microstructural defects or inclusions are intrinsic latent defects which could initiate cracks and propagate failure.

CONCLUSIONS

Based on experiments and comprehensive analysis, the following conclusions can be drawn:

- Visual examination with the unaided eye and fractography revealed chevrons which indicate a brittle fracture associated with high cycle fatigue failures.
- From the compositional analysis, the as-received material was found to be medium carbon steel of the tough grade. It was below the standard requirements for high strength spring steel useful in aircrafts.
- The failure mode was impact fatigue failure initiated at the inclusions present in the microstructure resulting in crack propagation through the matrix and eventual fracture.
- Controlling the average composition of the inclusions present in the microstructure can effectively improve the fatigue properties of the steel.

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