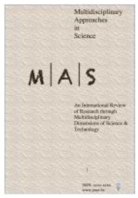
Journal of Multidisciplinary Approaches in Science (JMAS)

Journal homepage: https://jmas.biz/index.php



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Failure Analysis of Crashed Helicopter Main Components

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ARTICLE INFO

Article history:
Received 21 January 2019
Received in revised form 16 April 2019
Accepted 2 May 2019
Available online 13 May 2019

Keywords:
Failure Analysis, crashed helicopter, components, Non-destructive Investigation (NDI)

ABSTRACT

Many helicopter accidents are due to complications regarding flight operations, ground duties (mission planning and preparation), training and instructions. These are significant concerns within the existing global policies for momentously dropping the number of accidents in the years to come. Nevertheless, when accidents occur the successive investigations should include non-destructive inspection, for clarifications to eliminate possible causes like material defects, component and systems failures, and design deficiencies. To elucidate this, the present paper summarizes observations of non-destructive inspection (NDI) for clarifications regarding mechanics of fracture. Based on the results of visual, hardness, fractography, metallography, magnetic particle, x-ray radiographic, ultrasonic thickness and x-ray fluorescence observations, it is concluded that major components/assemblies of the crashed helicopter exhibited dynamic fracture modes consistent with failure due to overstress without any signs of slow stable fatigue crack growth. The non-destructive inspection observations have indicated no contribution of corrosion, stress-corrosion-cracking or any material deficiency toward final failure of examined components. The tail rotor control rod exhibited a typical triaxial-stress-state impact loading failure. The triaxial stress state was induced at the junction of inside reinforcement and the hollow rod making it the weakest site against impact or a dynamic stress condition.

1. Introduction

Helicopters have been significantly retained for various civil and industrial purposes in modern society [1–9]. Their adaptabilities come from the potentials of performing distinctive maneuvers including direct take-off, landing and hovering to fulfil exceptional needs during operations. Helicopters come in a variety of sizes and shapes, but most share the same major components [10-13] (Figure 1).

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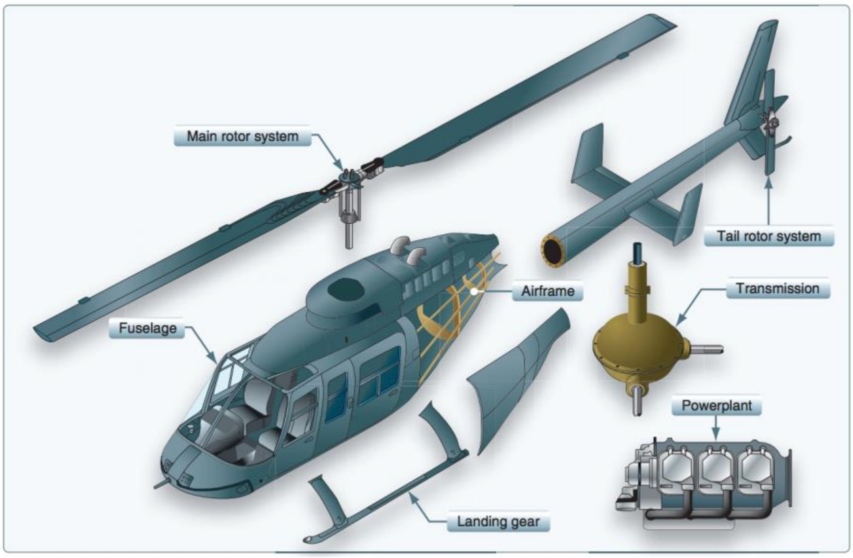

Fig. 1. The major components of a helicopter are the airframe, fuselage, landing gear, powerplant, transmission, main rotor system, and tail rotor system.

One of the helicopters came down and major components/assemblies were recovered from the crash site. It was desired to isolate the cause of failure of the crashed helicopter by characterizing fracture mechanisms of the main rotor blades, tail boom sections, tail rotor control rod, tail rotor driveshaft and tail pylon (Figure 2).

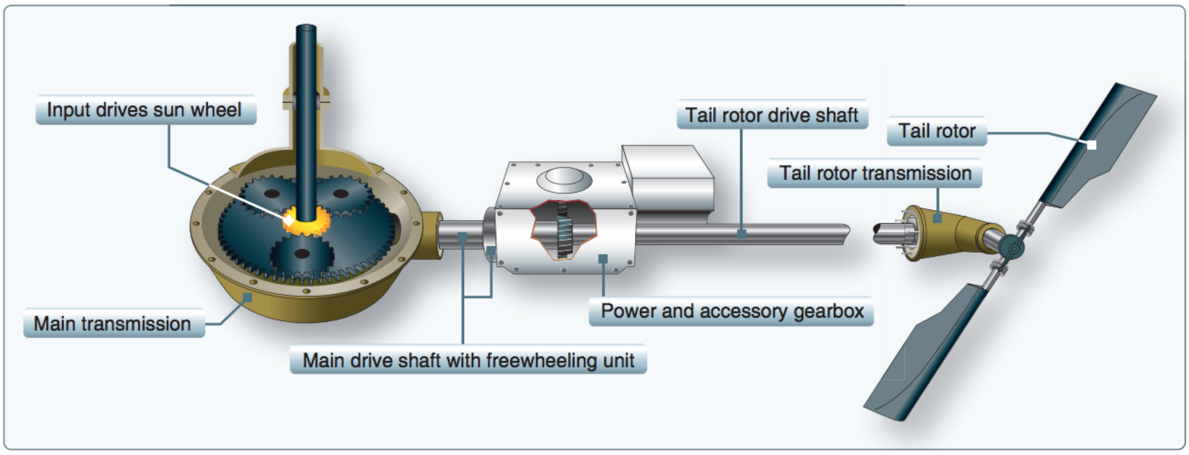

Fig. 2. The tail rotor driveshaft is connected to both the main transmission and the tail rotor transmission.

The Accident Investigation Board (AIB) aimed to isolate the cause of failure by characterizing fracture mechanisms of these components/assemblies. This research summarizes observations of non-destructive inspection (NDI) for clarifications as required by the AIB.

2. Details of Required NDI Data

NDI-based failure analysis for the main rotor blades, tail boom sections, tail rotor drive shaft and tail pylon was required with emphasis on the tail rotor control rod to clarify the following:

1. Mode of failure: Sudden impact or slow stable ductile fatigue.
2. Material failure as a root cause of damage.
3. Contribution of corrosion or stress-corrosion-cracking (SCC) in final fracture.
4. Type of loading in the case of the tail rotor pitch change rod.

3. Non-Destructive Tests Conducted for Study of Fracture Mechanisms

The essential non-destructive tests applied for collection of the NDI data required are given below:

3.1 Visual Testing

Visual examination of all fracture surfaces of the main rotor blades, tail rotor control rod, tail boom sections, tail rotor driveshaft and tail pylon were carried out with or without magnifying aids.

3.2 Hardness Testing

Hardness testing was carried out nearest to the fracture zone of the tail rotor control rod and tail rotor driveshaft by using a portable hardness tester. Hardness tests on an un-fractured tail rotor control rod of another helicopter were also conducted to obtain comparative data.

3.3 Fractography

Fractured surface of the tail rotor control rod was examined under a microscope at a magnification of 100x.

3.4 Metallographic Testing

Non-destructive metallographic testing was conducted nearest to the fracture region of fractured and un-fractured tail rotor control rods to investigate any contribution of SCC in the failure or any other material deficiency.

3.5 Magnetic Particle Testing

Fluorescent magnetic particle testing was carried out in the fracture zone of the tail rotor control rod for detection of surface or slightly sub-surface defects.

3.6 X-Ray Radiographic Testing

Radiographic testing of the un-fractured tail rotor control rod of a different helicopter was performed to check the inner geometry of the rod in the fracture region.

3.7 Ultrasonic Thickness Gauging

Thicknesses at various locations of the tail rotor control rod and tail rotor driveshaft were measured ultrasonically to check for any loss of thickness due to erosion or any other environmental effect.

3.8 X-Ray Fluorescence (XRF) Analysis

XRF analysis for the fractured and un-fractured tail rotor control rods was conducted for a comparative elemental composition.

4. NDI Results

The failed parts, including all fragments, were subjected to a thorough visual examination with and without a low-power microscope. All fractured regions exhibited an over-stressed dynamic fracture mode without any signs of slow stable crack growth due to normal loads, fatigue or SCC.

Results of non-destructive metallographic testing for fractured the tail rotor control rod at three different locations around the fracture are shown in Figure-3. No contribution of environmental degradation like SCC, or any material deficiency, to the final failure was observed in the microstructural evaluation. A comparative non-destructive XRF analysis conducted for fractured and un-fractured tail rotor control rods has shown elemental composition of Cr, Fe, Ni and Mo in the same range.

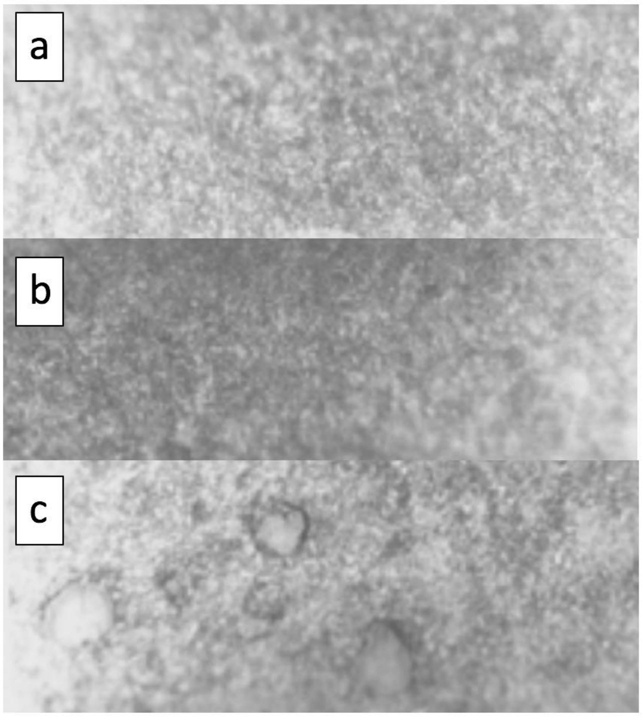

Fig. 3. Micrographs at three different locations around fracture surface

Hardness values of the fractured tail rotor control rod at the locations shown in Figure 4 lie in the range of 150-157 HB. These values are slightly higher the than harnesses of an un-fractured rod of a different helicopter as shown in Figure 5 indicating less resistance to impact failure. The hardness of tail rotor driveshaft is 285 HB.

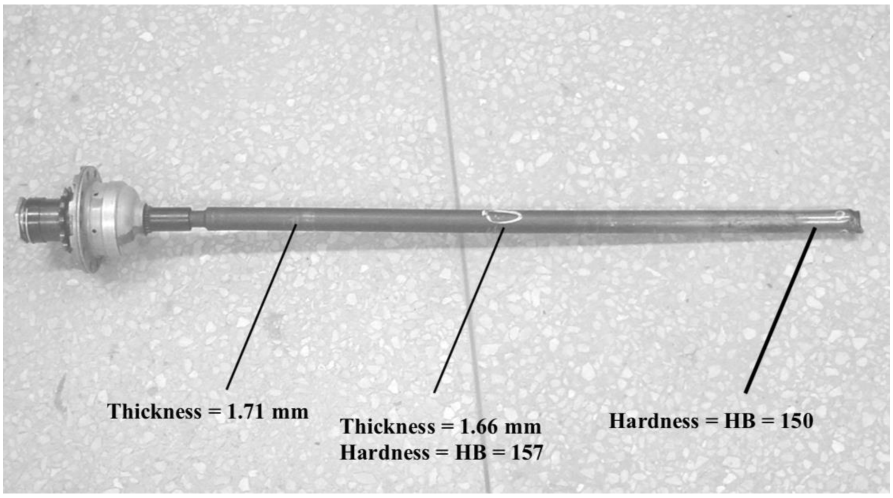

Fig.4. Hardness & Thickness Measurements of a Fractured Piece

The tail rotor control rod was fluorescent magnetic-particle inspected around the fracture, both outside and inside of the rod where accessible. The same location of an unfractured rod was also tested using the same technique. The presence of secondary fatigue micro-or macro- cracks in both tail rotor control rods could not be observed.

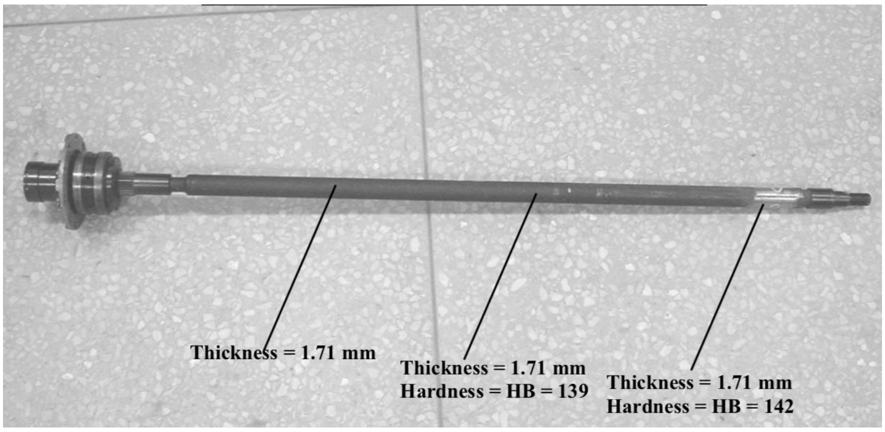

Fig. 5. Hardness & Thickness Measurements of an Un-Fractured Piece

Microscopic examination the of fracture surface of the tail rotor control rod indicated a typical triaxial-stress-state impact loading failure. Triaxiality is induced at the junction of the inside reinforcement and the hollow section of the control rod of 1.71 mm thickness as shown in the X-ray radiographic record of Figure 6, making it the weakest site against any impact or dynamic stress condition.

Radiographic testing of an un-fractured tail rotor control rod of a different helicopter was performed to check the inner geometry of the rod in the fracture region (Figure 6). The radiographic study revealed no gross defects observed in the un-fractured tail rotor control rod.

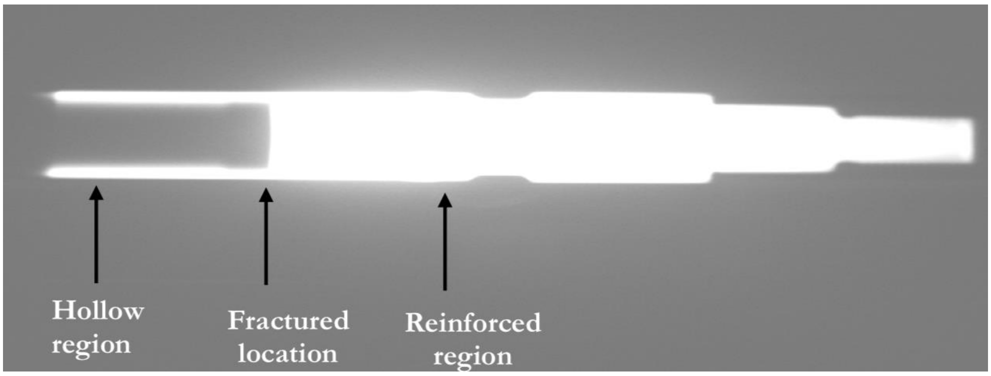

Fig. 6. Radiographic testing of un-fractured tail rotor control rod

5. Conclusions

Based on the non-destructive study of the mechanics of fracture outlined above, it is concluded that the major components/assemblies of the helicopter failed due to overstress. The fracture surfaces exhibited dynamic fracture modes without any signs of slow, stable fatigue crack growth. Contribution of environmental degradation like corrosion, stress-corrosion- cracking or any material deficiency in final failure was not observed. The tail rotor control rod exhibited a typical triaxial-stress-state impact loading failure because of triaxiality induced at the junction of the inside reinforcement and the hollow control rod resulting in the weakest site against impact or dynamic stress condition.

Based on the literature evidence [14-15] of fatigue cracking of helicopter-blade spindle at the fillet between shank and fork, along with the presence of a triaxial-stress-state in the tail rotor control rod, it was recommended that both these components of operating helicopters be subjected to periodical non-destructive evaluation.

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