Classification of defects in honeycomb composite structure of helicopter rotor blades

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Abstract

The use of non-destructive testing methods to qualify the state of rotor blades with respect to their expected flight hours, with the aim to extend their lifetime without any risk of breakdown, is an important financial demand. In order to detect the possible defects in the composite structure of Mi-8 and Mi-24 type helicopter rotor blades used by the Hungarian Army, we have performed combined neutron- and X-ray radiography measurements at the Budapest Research Reactor. Several types of defects were detected, analysed and typified. Among the most frequent and important defects observed were cavities, holes and/or cracks in the sealing elements on the interface of the honeycomb structure and the section boarders. Inhomogeneities of the resin materials (resin-rich or starved areas) at the core-honeycomb surfaces proved to be an other important point. Defects were detected at the adhesive filling, and water percolation was visualized at the sealing interfaces of the honeycomb sections. Corrosion effects, and metal inclusions have also been detected.

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1. Introduction

The lifetime extension of helicopter rotor blades has an essential importance because of their high value. In the Hungarian Army, majority of the helicopters are Russian-made Mi-8 and Mi-24 types. Although their age is over several decades, the flight hours are below the allowed limit. Therefore, the use of non-destructive testing methods to qualify the state of rotor blades with respect to their expected flight hours, with the aim to extend their lifetime without any risk of breakdown, is an important financial demand.

In the last 3 years we have undertaken a complex non-destructive testing investigation to detect the possible defects in the composite
structure of helicopter rotor blades using combined neutron- and X-ray radiography (XR), and vibration diagnostics measurements at the Budapest Research Reactor [1].

Here, we give a short description of our radiography experimental work and some of the latest results obtained on several Mi-24 type helicopter rotor blades. Terms used in Ref. [2] for description of defects in helicopter composite structures were followed.

2. Experimental

2.1. Investigated objects

The investigated rotor blades of Mi-24 type helicopter are made of composite structures. Each one contains 18 sections of honeycomb construction and several bonded surfaces. The most important parts of a rotor blade, from our point of view, are marked in the schematic drawing in Fig. 1. The key part of the rotor blade comprises the aluminum alloy metal main holder (spar) bonded to the honeycomb structure. The blades are about 10 m long, 0.7 m broad and their width is between 3 and 60 mm. The weight is 110 kg.

For the radiography imaging each rotor blade was divided into four bands horizontally (A–D) and 53 columns vertically, as it is indicated in Fig. 1. ‘A’ band gives information mainly on the state of trailing edge and the backside stringer. ‘B’ band shows the state of the honeycomb structure. The quality of the bonded area at the aluminum-alloy spar is represented by ‘C’ band. The ‘D’ band shows the state of the anti-ice heater and leading (front) edge of the rotor blade. These identifiers were used as markers for segmenting the rotor blades. The radiography image of the whole rotor blade was reconstructed from 216 individual radiography images (146 mm × 140 mm) using a special software package [3].

2.2. Experimental facility

Measurements were performed at the radiography station at the 10 MW Research Reactor in Budapest using thermal neutrons [4,5]. At the sample position the diameter of the beam was 180 mm, the neutron flux was $10^8$ n cm$^{-2}$ s$^{-1}$. For XR a portable X-ray generator was used, adjusted to 150 kV and 3 mA. Scintillation screens were used for converting the beam into light, and the light images were detected by CCD camera.

Three types of radiography measurements were performed for each blade.

- In the first step neutron radiography (NR) was applied in the original state of the blades, called ‘dry NR’.
- In a next step the blade was watered on its entire surface, with the aim to simulate the effect of natural moistening (rain), and was radiographed by neutrons once again (called ‘wet NR’).
- In the third step XR measurement was performed in the wet state of the blade.
- Fig. 2 shows reconstructed whole-radiography images for the three different types of experiments.

3. Classification of the defects and results

Defects can be external or internal to the structure. External defects can be visually inspected, such as dimensions, finish, and warpage. Internal defects of most concern in composites are delaminations, inclusions, voids, resin-rich and

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**Fig. 1.** Schematic structure of the Mi-24 type helicopter rotor blade. A–D indicate the four bands of radiography inspection.
starved areas, fiber misalignments and breakage, and de-bonds, as tabulated in Table 1, including a rough view and a short description [2].

Following the classification of Table 1, we present some of the most important and characteristic defects visualized on the investigated rotor blades by our radiography inspection.

An important demand of the radiography inspection is, to visualize the resin-rich or starved areas (defects 4 and 5 in Table 1). These types of defects can be identified by the fact, that they are clearly visible in the NR images due to the high neutron attenuation coefficient of hydrogen containing materials (see Fig. 3), while for XR they are not visible. Another interesting aspect of this image is, the well-resolved double contour lines, as they reflect the tilted position of the honeycomb elements.

A fiber breakage (defect-type 7 in Table 1) of the trailing edge is detected both by NR and XR images, as it is illustrated in Fig. 4. Another type of defect was also detected in the same segment, namely, the slicing of the honeycomb structure nearby the stiffener. The adhesive material, however, can be detected only by NR.

One of the most dangerous defects is, when a de-bond (defect-type 8) in the adhesive surface is present between the honeycomb structure and the Al-spar. Such type of observation is illustrated in Fig. 5. The double contour lines are because of the tilted position of the honeycomb elements (similar effect like in Fig. 3).

In our case one of the most important family of defects was the presence of cavities, holes and/or cracks. The problem is caused by the fact, that water can penetrate into these places, and after freezing it can damage the surrounding due to the volume expansion of ice. Detection of these defects is very difficult because of the complex arrangement of the composite structure. Combined application of ‘dry NR’, ‘wet NR’ and XR experiments did make possible to discover and to make visual these defective areas. It was established, that the most frequent locations of water penetration are at the border sections or at the honeycomb-adhesive sealing joining surfaces. The first one is less dangerous, because the water settles in the stiffener cave (Fig. 6), and in a normal operational position, when the blade is in a horizontal position, the water easily flows out from the cracks through the venti gap of the stiffener. More problematic is, when the water penetrates into the honeycomb structure through the adhesive sealing elements on the interface of the honeycomb structure and the section borders. The origin of the water percolation is the insufficient sealing on the interface of the honeycomb structure with the Al-spar and the stiffeners. Fig. 7 illustrates water percolation through a horizontal and a vertical by-pass.

During our radiography inspection we have detected both types of these defects in the as received state of the blades. But in several cases, crack/hole type defects became visible only in the wet NR image (see Fig. 8) after the moistening procedure.

Damage of rotor blades caused by flinders may happen during flight missions (defect-type 2). We detected such type of defect caused during a gurnery practice. Although the defect had been mended, a small piece of splinter was not detected and thus not removed, as it may be seen in Fig. 9.
Table 1
Classification of defects in composite structures of helicopter rotor blades [2]

<table>
<thead>
<tr>
<th>Defect</th>
<th>View</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Delamination</td>
<td></td>
<td>Delaminations are separations within plies of a laminate, and caused by improper surface preparation, contamination and embedded foreign matter</td>
</tr>
<tr>
<td>2. Inclusions</td>
<td></td>
<td>Inclusions are foreign matter embedded in and between laminate</td>
</tr>
<tr>
<td>3. Voids and porosity</td>
<td></td>
<td>Voids and porosity are entrapped air and gas bubbles, and are caused by volatile substances, improper flow of resin and unequal pressure distribution. Voids are clustered in the resin, while porosity are pockets within the solid material</td>
</tr>
<tr>
<td>4. Resin-rich area</td>
<td></td>
<td>Resin-rich areas are localized, and filled with resin or lacking in fiber. This defect is caused by improper compaction or bleeding</td>
</tr>
<tr>
<td>5. Resin-starved area</td>
<td></td>
<td>Resin-starved areas are localized with insufficient resin evident as dry spots, or having low gloss or where fibers are exposed. This defect is caused by improper compaction or bleeding</td>
</tr>
<tr>
<td>6. Fiber misalignment,</td>
<td></td>
<td>Fiber misalignment is a distortion of the plies resulting in changes from the desired orientation, or in fiber wrinkling and buckling. These defects are due to improper lay-up</td>
</tr>
<tr>
<td>wrinkling, buckling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Fiber breakage</td>
<td></td>
<td>Broken fibers are discontinuous or misplaced fibers due to improper handling or lay-up</td>
</tr>
<tr>
<td>8. De-bond</td>
<td></td>
<td>De-bonds occur between different details of the built-up structure. Lack of bonding is due to contamination of the surface, excessive pressure or bad fit</td>
</tr>
</tbody>
</table>
In the NR image the resin-rich spots are as dark as the metal inclusion, while the XR image provides a dark contrast only for the heavy element with large X-ray attenuation.

Corrosion may also cause problems, leading to possible lifetime reduction. Corrosion was detected in some of the investigated blades inside the rotor blade tail elements, as it is shown in Fig. 10. Resin-rich area is also shown at the bond surface of the honeycomb structure and the last stiffener.

4. Conclusions

The most important points of our study have been the visualization of the possible imperfections in the honeycomb structure, like:

Fig. 3. Dry NR image of the honeycomb structure with a resin-rich area (dark spots).

Fig. 4. Fiber breakage and slicing of honeycomb by (a) XR, (b) NR. The letter visualizes the adhesive material as well.

Fig. 5. NR image of de-bond in the adhesive material between the honeycomb structure and the Al-spar.
• Inhomogeneities of the resin materials (resin-rich or starved areas) at the core-honeycomb surfaces;
• Defects at the adhesive filling;
• Water percolation at the sealing interfaces of the honeycomb sections;
• Quality control of resin-rich mended areas;
• Verification of the position of metal parts by X-ray;
• Corrosion effects.

Fig. 6. NR image of water percolation between two border near the stiffener.

Fig. 7. NR image of water percolation in the honeycomb structure.

Fig. 8. Hole-type defect in the honeycomb structure became visible in NR image after wetting procedure.

Fig. 9. Resin rich area due to reparation detected by NR, and metal inclusion visualized both by NR and XR.
Acknowledgments

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References


Fig. 10. NR image of the rotor blade tail: including two vertical columns (52 and 53) and all four horizontal bands (A–D).