REPAIR OF AIRCRAFT STRUCTURES

Rezala Aicha

Department of Mechanical and Production Engineering, Mechanical and Process Engineering Faculty, University of Science and Technology Houari Boumediene (USTHB), B.P. 32, El Alia, 16111, Bab Ezzouar, Alger, Algeria
Email: *aicha.rezala@usthb.edu.dz*

Abstract : Composite materials are only one of the types of materials used in the aeronautical field, but their use has progressed dramatically over the last decades. Knowing that an aeronautical program is developed over an average of ten years, and a time necessary to study, test, and launch the industrialization of an aircraft, improving its aerodynamic quality, while increasing the performance of engines and especially reducing the weight of structures. On the other hand, non-destructive testing (NDT) plays a very important role in detecting or characterizing the defects existing in the composite structure, estimating the importance of damage as well as determining the quality of a repair. However, the purpose of this study is to characterize some existing defects in the composite structure commonly used in aeronautical manufacturing, by representing the less expensive repair methods, to reduce the overweight of the final repair.

Keywords : Composite, materials, aircraft, damage, and repair.

1. Introduction

The use of composite materials occupies an increasing place in the construction of aircraft, to which they bring their qualities of lightness, corrosion resistance, fatigue resistance, and ease of shaping. However, because of their structure, their sensitivity to certain aggressions (hail, shocks, lightning, etc.) requires a different approach from that of metallic materials. Manufacturers are conducting long-term exploratory studies, improving their aerodynamic quality, increasing the efficiency of the reactors and thus reducing the weight of the structures. The latter can only be achieved with a strong, light, and economical material.

Composite materials, because of their specific properties remarkable for aeronautics, have been progressively introduced in the constitution of critical parts for the structural behaviour of the aircraft. However, the use of these materials has introduced a new problem compared to metallic materials: their sensitivity to small shocks.

Implementing efficient and cost-effective technologies to repair or extend the life of aeronautical structures is becoming necessary in most countries. To this end, it has become inevitable to have a better knowledge of these materials, in terms of microstructure and mechanical properties, in order to be able to follow their evolution under the action of the solicitations to identify the phenomena of damage, their initiations and their developments until rupture [1].

The resolution of such damage phenomena by repair and the search for methods of reinforcement of structures are the subject of our study. Such solutions, or methods, allow to bring economic gains to construction companies, by avoiding the disposal of damaged parts by repair, and by recovering others by reinforcement.

2. Composite sandwich materials

Sandwich materials consist of skins (which can be UD laminates or woven) and a core. The bonding of these two components gives a structure that has great rigidity and lightness. The skins, generally, of a low thickness (0.3 to some millimeters) are constituted of metal sheets of stratified composite structure.

The core can be made of different materials and presented in different architectures depending on the industrial application. Indeed, sandwich materials are usually used for structures subjected to bending stresses because they allow to drastically improve their rigidity and their bending resistance by increasing the thickness of the core while minimizing the additional mass. Honeycomb cores (Nomex or Aluminium) are generally used for this type of application. However, a major interest in sandwich materials lies in the fact that it is possible to obtain multifunctional materials with interesting mechanical properties but also good acoustic properties (with foam cores), good wave transparency (with honeycomb cores), and good fire resistance.

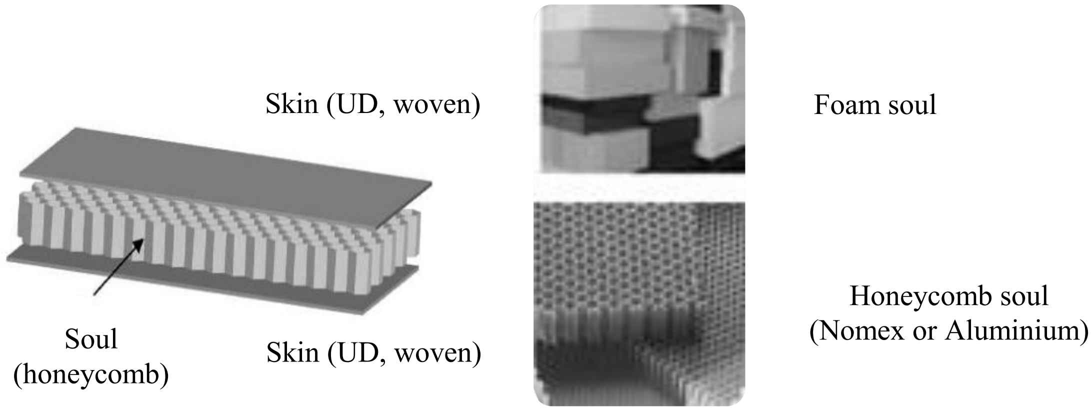


Figure 1. Presentation of composite sandwich materials.

3. Damage to composites

Several researches have emerged in the last decades dealing with the problem of damage to composite materials, and their repair modes. We can quote the works of Erdogan and Arin [2] and Ratwani [3]. The interest of using a two-dimensional patch was first treated analytically by Rose [4], and also Soutis [5]. This repair technique has also interested other researchers such as Atluri [6], Bottega, and Loia [7]. Their contributions dealt with the design and analysis of repairs either by riveting, bolting, or gluing. Parallel efforts in the development of analytical methods for the repair of composite structures have also been made in the last decades, of which the works of Engels and Becker [8] and Oterkus et al [9] can be mentioned. Composite parts can be damaged when they are subjected to shocks, impacts that are often accidental in nature, in corrosive environments, or when they age, causing the appearance of cracks that reduce their service life.

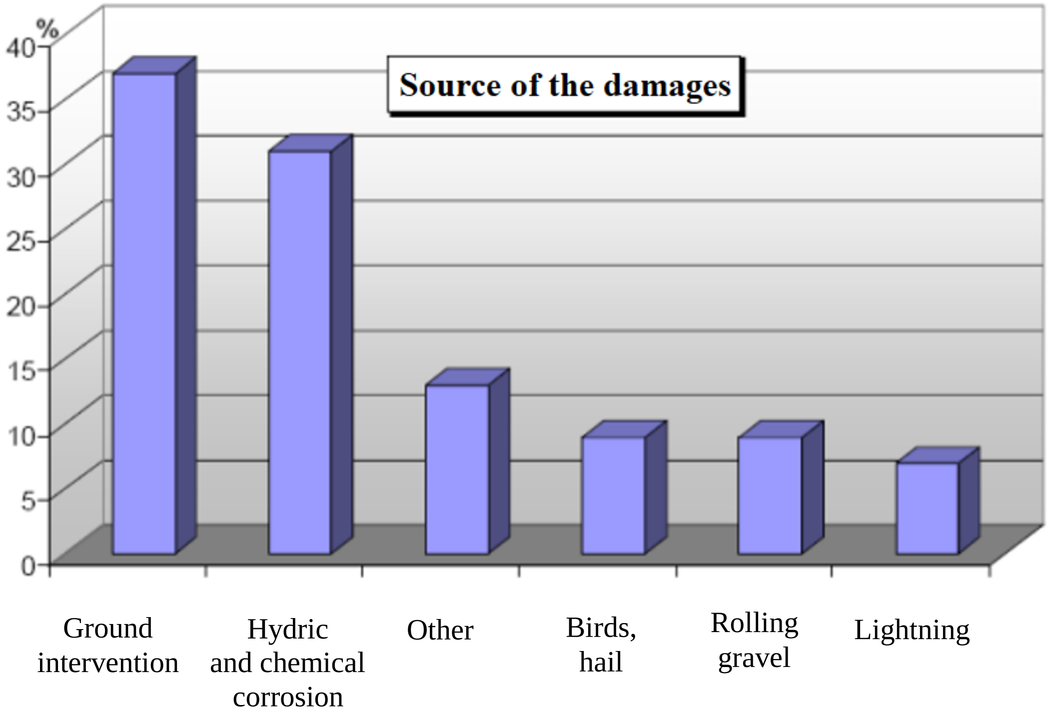


Figure 2. Nature of damage on civil aircraft from [10].

The phenomenon of modification of the mechanical and geometrical characteristics of a structure tends to decrease its capacity of resistance to the solicitations that it must normally support. The failure of composite materials is very often preceded by various types of damage, related to the constitution of the material. For laminated composites, the damage is manifested in chronological order: the appearance of microcracks in the matrix (cracking), localized rupture of the fiber-matrix bond, micro buckling of the reinforcements with the appearance and progression of delamination, rupture of the fibers parallel to the direction of the load and rupture of the structure. Environmental effects (temperature, humidity, radiation, etc...) other than lightning, hail, bird strikes, and various objects on the runway, are among the many sources of damage that some composite parts in the aircraft structure may encounter.

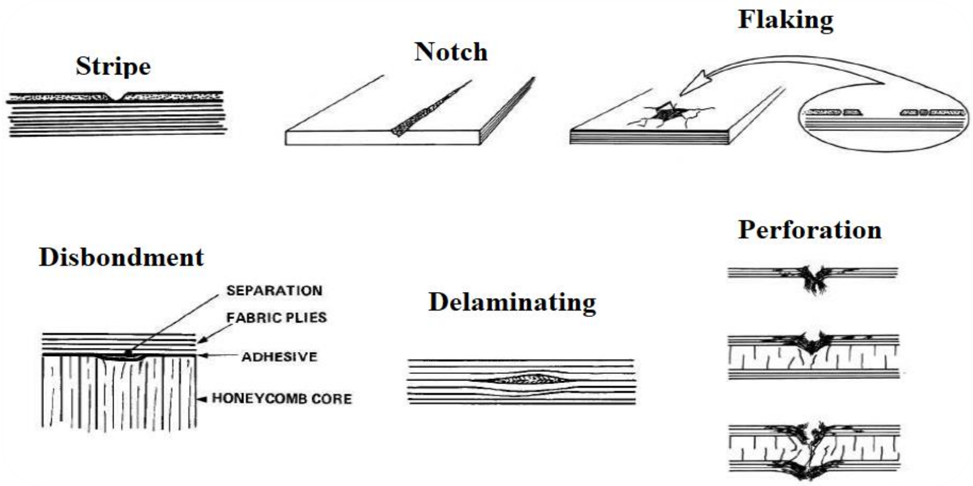
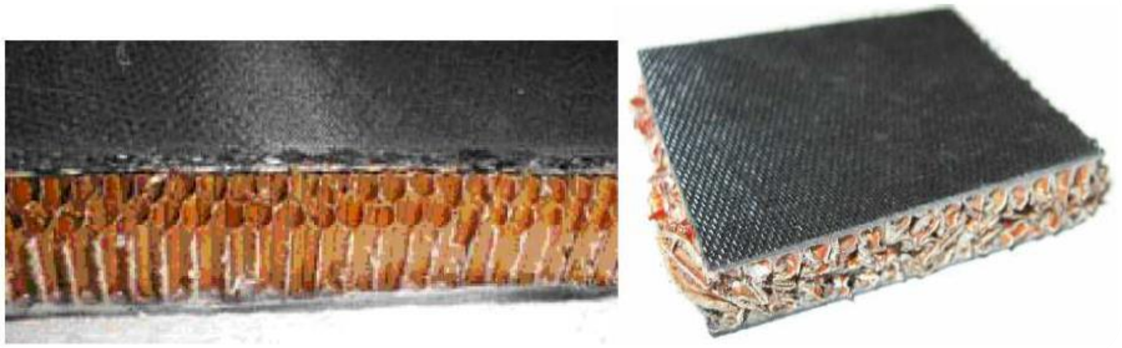


Figure 3. Different types of damage encountered on composite parts [11].

4. Non-destructive testing

The control allows the operator to know the state of possible damage to the composite structure without having to dismantle it or even immobilize the aircraft; to establish the diagnosis of loss of properties; to foresee the evolution in time; to choose the adapted repair technique and to validate the return to the initial performance. The final objective is to reduce maintenance costs.

In aeronautics, non-destructive testing is mandatory to ensure and verify the condition of the part without causing any damage. Knowing that the damage of composite parts is not always visible on the impacted side, but it is often more important on the opposite side. Non-destructive testing is used at several levels: detection of foreign body inclusion (separators), detection of early cracks, inter-ply delamination, bonding defects, control of fiber alignment, control of damage after fatigue, control after impact or static overload, control of environmental influence and detection of defect progression. In the visual inspection of composite materials, there are control methods such as tap tests, dye penetration, radiography, and ultrasound.



a) Before crushing. b) After crushing.

Figure 4. Sandwich structure with carbon-epoxy laminated skins and Nomex honeycomb core.

5. Repair techniques

Aircraft repair is intimately linked to the history of aviation and the material's constituents.

For impact damage on a composite material, two solutions are possible: riveted patching and glued patching. In order to reduce maintenance costs and limit aircraft downtime, a range of repair techniques must be available, adapted to the different categories of materials and structures, as well as to the location of the damage.

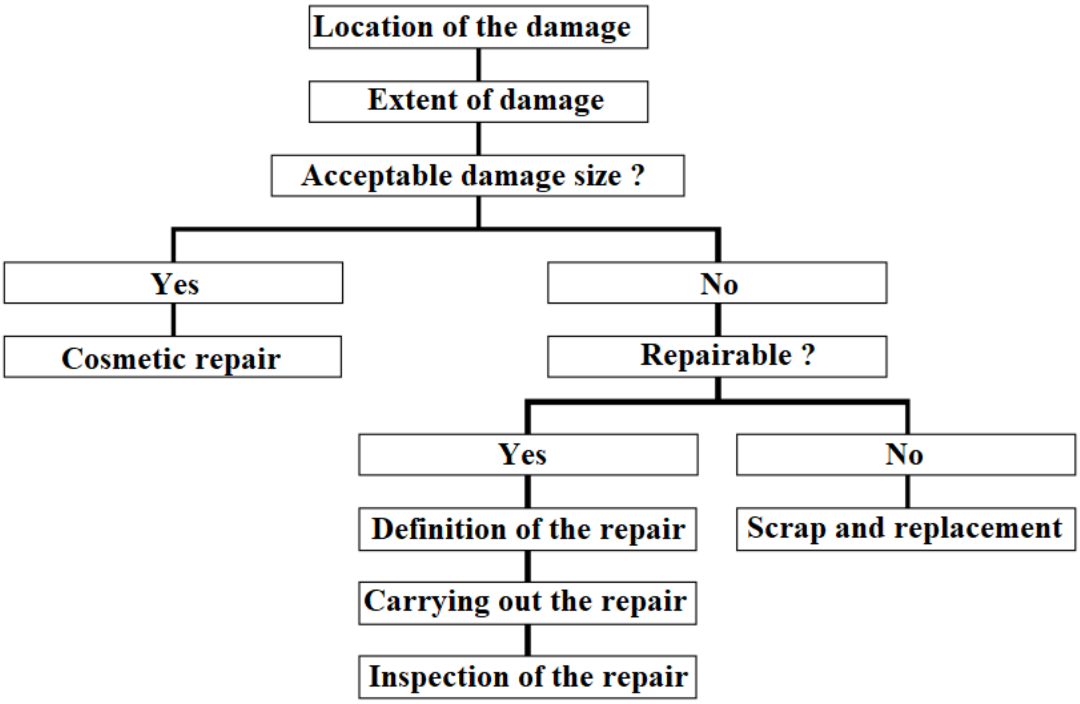


Figure 5. Repair process [12].

Various repair methods exist, including bolted or riveted patches. The disadvantage of these methods. However, is the singular field of stresses that occur in the connections. In order to avoid stress concentrations, a possible solution is to glue a composite patch on the defective area of the structure in order to better reinforce the damaged area and thus delay the failure phenomenon and increase the life of the structure.

Figure 6. Riveted patch repair on Boeing fuselage.

The structure can then be repaired with a composite patch, in order to transfer the loads from the damaged area to the patch. There are several alternatives depending on the level of damage:

- If the level of damage is too high, the part or structure is simply replaced. This is a very expensive solution, as the order of magnitude of the cost of a new wing of an Alphjet, for example, is about 1.5 million euros [13].
- If cracks appear in less critical areas, it is a matter of repair.

➢ If the cracks have not yet appeared, a prospective solution is considered. A composite patch can be glued in the damaged area to reinforce it in a preventive way. This case is called reinforcement.

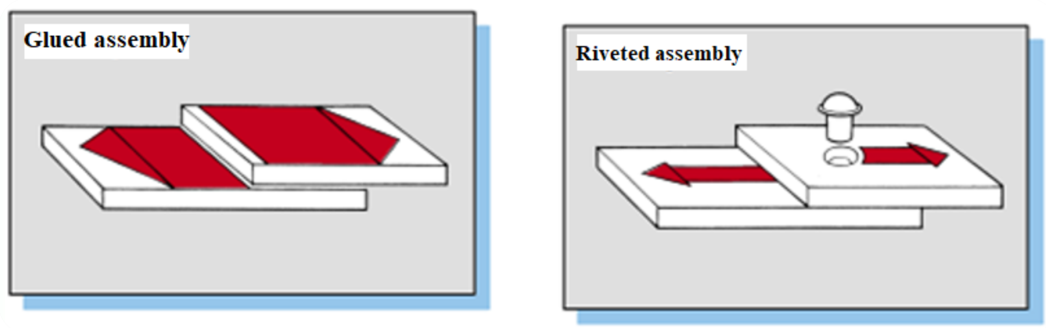


Figure 7. Gluing and riveting assembly.

It is therefore necessary to implement repair methods which are: hot repair, cold repair, and injection repair. The first two are permanent repairs, but their choice depends on three parameters: the damage tolerance, the type of material, and the repair time (cold repair from 24 to 48 hours and hot repair from 2 to 3 hours). On the other hand, the injection repair is a temporary repair whose choice depends on the damage tolerance.

Advantage of bonded repair : Once the decision is made that a defective structure must be repaired rather than replaced, the next step is the repair phase. The main techniques for fixing a repaired part of the damaged structure are mechanical fasteners (rivets or bolts), welding, and gluing. The latter technique has remarkable advantages over the others, including:

- Homogeneous stress distribution compared to bolting or riveting techniques which concentrate stresses locally.
- No change in the surface topography and texture of the assembled materials is observed: Welding can change the materials and thus the mechanical properties of the substrates. In addition, welding, riveting, and bolting affect the visual appearance of the parts.
- Weight saving: Adhesives are particularly suitable for lightweight constructions, where thin parts have to be assembled.
- Waterproof connections: Adhesives also act as a sealant, preventing the loss of pressure or liquid, blocking the penetration of water condensation and thus protecting against corrosion.
- Ability to take very complex geometric shapes.
- The ease with which the repair itself can be removed and replaced to facilitate future work.
- Joining different substrates and reducing the risk of corrosion: The adhesive forms a protective film to prevent corrosion. When different types of metals are joined, they can also act as electrical and thermal insulators.

6. Repair of aeronautical structures

The analysis of a damaged passenger floor of a Boeing 737-200 aircraft showed, according to a visual inspection, an impact in the coating and the honeycomb. This inspection is insufficient because it is not known how many folds exist in this coating, for that a non-destructive control by the method of ultrasounds is necessary. After this inspection, it was found that the impact has a diameter of 140 mm, a thickness of 5 mm and the coating contains three graphite folds.

1) **Prepare the repair area,** then carefully remove the coating in the damaged area and overlap with the sander around the damaged area, so that it has good adhesion with the replaced folds.
2) **The repair method :** according to the manual (SRM), the damage tolerance and the type of material allow us to choose a hot repair of 90°c.
3) **The repair material :** The repair material: we prepared four plies of reference graphite (BMS9-8type1, class 2) according to the (SRM): two plies of graphite with a diameter: of 140 mm, one ply of graphite diameter: of 190 mm and another ply of graphite diameter: 240 mm. Making a honeycomb cutout of 140 mm reference (BMS8-124), we can use a honeycomb with a thickness more or less equal to that of the original thickness.
4) **The control :** a last step of control allows verification that the repair of the part carried out corresponds well to the procedure of the manual (SRM) and does not present structural defects. This can be done by two methods: reading the recording tape of the machine "ANITA" and a non-destructive test (Tap Test).

7. Conclusion

The aeronautical sector is constantly looking for the best possible materials in order to further improve the efficiency and safety of its aircraft and people. However, the study of composite materials is still quite vast; knowing their behavior under the effect of the environment, various damages, and restorations, would enrich our knowledge in this vast field. In addition, they offer an interesting capacity to be repaired quite easily with simple tooling. However, many challenges remain to be met in order to reduce repair costs and development cycles.

Composite structures do not recover from damage, therefore the use of various reinforcement and repair techniques by riveting, bolting, and bonding has solved such problems. The repairs currently used are not well suited to low-energy impact damage and are very expensive.

The repair that has been developed is a direct application of this effort to provide a less expensive repair for the process and to reduce the overweight of the final repair. Ultrasonic inspection has emerged as the most suitable method for accurate detection of delaminated surfaces (mm^2 accuracy).

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