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Inspection of Surface Damage in Composite Materials with Different Techniques

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ABSTRACT

Due to their excellent physical properties and high strength and stiffness relative to density, aerospace industry research is producing high-performance structural materials, such as composites, which are used in many critical structural parts like airframes, wings, rotor blades, propellers, and other components. However, during flight, these materials may be damaged by impact, thermal stress, moisture, and ultraviolet radiation. One of the most prevalent issues with composite materials is their challenging nature in terms of flaw detection during both manufacturing and use. When they are employed in the crucial areas that were previously indicated, this becomes a very serious issue. When evaluating the structural integrity of composites and looking for any damage, microscopes are a very useful instrument. Effective methods for identifying and analyzing damage include microscopic procedures like optical microscopy, stereomicroscopy, scanning electron microscopy (SEM), scanning ion microscopy (SIM), and atomic force microscopy (AFM). A variety of methods may be employed with microscopes to examine and identify deterioration in composite materials. It is often possible to examine overt deterioration on the surface of composite materials under the microscope utilizing a number of different approaches and procedures. Determining the kind, extent, distribution, and impact of the damage requires these inspections. Often employed techniques consist of: SEM is a method for high-resolution imaging of surface damage. It entails shining an electron beam onto the sample's surface and capturing pictures. SEM is a useful tool for identifying erosion, delamination, and microcracks. It is also possible to measure things like the damage's breadth and depth. Optical microscopes have a large field of view and look at damaged regions. This makes it possible to find tiny fractures or cracks that are invisible to the unaided eye. Furthermore, details on the degree of harm, the roughness of the surface, and the breadth and depth of the fractures may be acquired. To see damaged objects, optical microscopy is utilized. Cracks and damage locations are visible with optical microscopy. Optical microscopes can identify different kinds of damage by looking at the surface of the material. Damage like delamination, fiber breakage, cracks, and deformations are a few examples of these. This study examines the efficacy of microscopic methods and non-destructive testing in assessing the different kinds of damage that can occur at the interfaces between holes in composite materials. Composite test materials were chosen from glass fiber reinforced phenolic matrix composites that were produced in compliance with aerospace standards. The measurements led to the conclusion that using microscopic techniques has benefits like speed and field suitability. However, the continuous development and improvement of new methods in this field will contribute to a better understanding of layered composite materials and the development of safer and more durable structures.

Keywords: *Aerospace, Composite materials, Microscopy*

Kompozit Malzemelerde Yüzey Hasarlarının Farklı Tekniklerle İncelenmesi

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ÖZ

Havacılık ve uzay endüstrisinin ticari ve askeri uçakların performansını artırmaya yönelik araştırmalar, yüksek performanslı yapısal malzemelerin geliştirilmesine yol açmaktadır. Kompozit malzemeler, mevcut ve gelecekteki havacılık ve uzay bileşenlerinde önemli bir rol oynayan bu tür malzeme sınıflarından biridir. Kompozit malzemeler, yüksek mukavemet ile sertlik-yoğunluk oranları ve üstün fiziksel özellikleri nedeniyle havacılık ve uzay uygulamaları için özellikle uygulanabilir bir malzeme türü olarak kullanılmaktadır.[1] Uçak gövdeleri, kanatlar, rotor kanatları, pervaneler ve diğer bileşenler gibi birçok kritik yapısal parçada kompozit malzemeler bulunmaktadır. Ancak, uçuş sırasında oluşabilecek darbeler, termal gerilmeler, nem, ultraviyole ışınları gibi faktörler nedeniyle hasarlar meydana gelebilir. Kompozit malzemelerin kullanımı sırasında sık karşılaşılan problemlerden birisi gerek üretim gerekse kullanımları sırasında meydana gelen kusurların tespitinin zor olmasıdır. Özellikle yukarıda değinilen kritik sahalarda kullanımında bu durum daha büyük bir problem olarak öne çıkmaktadır. Mikroskoplar, kompozit malzemelerin yapısal bütünlüğünü değerlendirmek ve potansiyel hasarları tespit etmek için kullanılan güçlü bir araçtır. Optik mikroskopi, stereo microskopi, taramalı elektron mikroskopi (SEM), taramalı iyon mikroskopisi(SIM) ve atomik kuvvet mikroskopisi (AFM) gibi mikroskopik teknikler, hasarların belirlenmesi ve analiz edilmesi için kullanılan etkili araçlardır. Mikroskoplar, kompozit malzemelerdeki hasarların tespiti ve analizi için farklı tekniklerle kullanılabilir. Kompozit malzemelerin yüzeyindeki açık hasarların mikroskopla incelenmesi, genellikle bir dizi teknik ve yöntem kullanılarak gerçekleştirilir. Bu incelemeler, hasarın türünü, büyüklüğünü, dağılımını ve etkisini belirlemek için önemlidir. Bazı yaygın kullanılan yöntemler şunlardır; SEM, yüzeydeki hasarları yüksek çözünürlükte görüntülemek için kullanılan bir tekniktir. Elektron demeti kullanarak numunenin yüzeyine odaklanır ve görüntüler elde eder. SEM, mikro çatlakları, tabakalaşma ve erozyonu tespit etmek için etkili bir yöntemdir. Ayrıca, hasarın derinliği ve genişliği gibi ölçümler yapılabilir. Optik mikroskoplar, hasarlı bölgeleri geniş bir görüş alanında inceler. Bu sayede çıplak gözle görülemeyen küçük çatlaklar veya kırılmalar tespit edilebilir. Ayrıca, hasar boyutu, yüzey pürüzlülüğü, çatlakların derinliği ve genişliği gibi bilgiler elde edilebilir. Optik mikroskopi, hasar bölgelerini ve çatlakları görselleştirmek için kullanılır. Optik mikroskoplar, malzeme yüzeyini inceleyerek hasar türlerini tespit edebilir. Bunlar arasında delaminasyon (katmanların ayrılması), fiber kırılması, çatlaklar, deformasyonlar gibi hasarlar bulunabilir. Bu çalışmada, tahribatsız muayene ve mikroskobik teknikler kullanılarak, kompozit malzemelerin delik ara yüzeylerinde meydana gelen çeşitli hasar türlerinin değerlendirilebilme etkinliği incelenmiştir. Kompozit malzeme olarak havacılık standartlarında üretilmiş cam fiber takviyeli fenolik matrisli kompozitler seçilmiştir. Ölçümler sonucunda; mikroskobik tekniklerinde, hız ve sahaya uygunluk gibi avantajları ile kullanılabilir olduğu sonucuna varılmıştır. Bununla birlikte, bu alanda sürekli olarak yeni yöntemlerin geliştirilmesi ve geliştirilmesi, katmanlı kompozit malzemelerin daha iyi anlaşılmasına ve daha güvenli ve dayanıklı yapıların geliştirilmesine katkıda bulunacaktır.

Anahtar Kelimeler: *Havacılık, Kompozit malzemeler, Mikroskopi*

I. INTRODUCTION

Composite materials are widely used in the manufacture of aircraft and spacecraft structural parts due to their specific mechanical and physical properties such as high specific strength and high specific stiffness.[2] Other properties of composite materials such as corrosion resistance, excellent surface profiles, improved fatigue resilience and special performance have also contributed significantly to the rapid increase in composite material applications. However, the defects and damages of composite materials and their subsequent repair requirements are currently challenging for composite material users.[3]

Defects and damage to structural components are common occurrences in materials processing, component manufacturing or in service. The impact of the defect or damage on the structural integrity of the composite component is crucial to understanding the defect.[4] Discontinuity, defects or damages are defined as any local change in the physical state or mechanical properties of a material or structure that may affect the structural behavior of the component. There are approximately many different types of defects that composite components are prone to or potentially exposed to. These range from microscopic fiber defects to large, severe impact damage.[5] The damage types in layered composite material in macro and micro dimensions are shown in Figure 1. Also, the separation damage that can occur during drilling operations for layered composite materials is also illustrated in Figure 2.

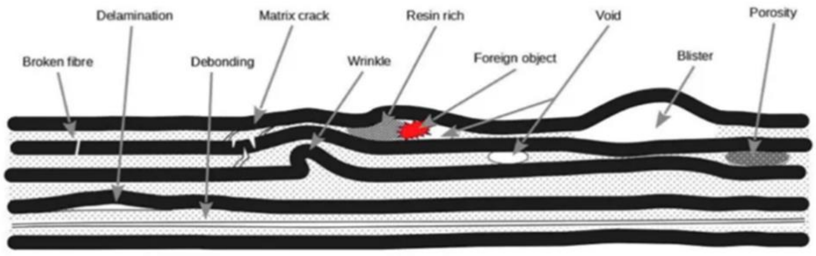

Figure 1. *Types of Damage in Layered Composite Materials* [6]

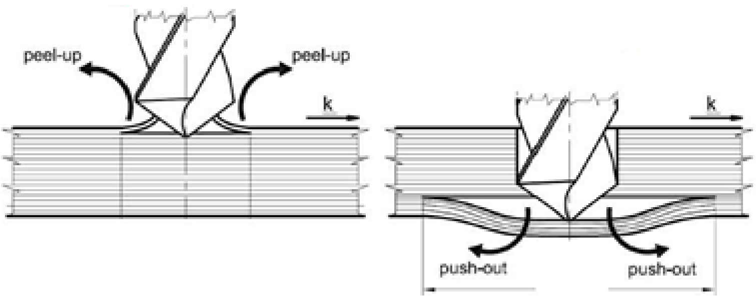

Figure 2. *Damages that can occur during the Drilling Operation*

Composites should be inspected at specified intervals during their production and service life. These inspections are carried out by destructive testing during production and usually by non- destructive testing during their service life. Non-destructive testing (NDI) is a crucial component in the service life cycle of critical structures in aircraft, spacecraft and transportation vessels.[7]

The investigation of composite material manufacturing defects using various control techniques is the focus of this study. Because of their complex behavior, composite materials are used in industries like aerospace and should be well-known.[8] In this study, it is aimed to non-destructively control the surface defects encountered in the drilling operations of polymer matrix glass fiber reinforced composite parts used in aerospace parts, which are pre-impregnated with resin and manufactured by autoclave process in layers, by visual and ultrasonic control methods and to examine the defects encountered.

II. MATERIALS AND METHODS

A. MANUFACTURING

For the selection of materials to be used for this study, glass fiber reinforced pre-resin impregnated materials used in avionic equipment covers, cockpit panels, antenna structures, in the interior and exterior structures of military and civil aircraft were selected[9]. Fiber glass is a special kind of industrial textile material because of its versatility. The fabric form of fiber glass provides an exceptional blend of characteristics, including fire resistance and high strength. The end user can choose the ideal blend of material performance, economy, and product flexibility thanks to the vast array of yarn sizes and weave patterns, which offer endless design possibilities. One engineering material that is dimensionally stable is fiber glass. It is not affected by changes in temperature, either in terms of stretching or shrinking. When exposed to water, it does not absorb moisture or undergo any physical or chemical changes. It is a better material in applications requiring high strength and low weight due to its high strength-to-weight ratio. This strength can be unidirectional or bidirectional in textile form, offering cost and design flexibility. Since it is inorganic, it cannot burn or facilitate combustion. At 1000 ºF, it has a strength of roughly 25%. For glass fiber, most chemicals have negligible or no effect. Glass textile fibers that are inorganic do not decay, rot, or grow mold. Strong alkaline compounds, hot phosphoric acids, and hydrofluoric acids all have an impact on glass fibers. It's a great material for insulating electrical systems. Fiber glass fabrics are perfect as an insulating varnish and printed circuit board reinforcement due to their low dielectric constant, high strength, heat resistance, and low moisture absorption. Compared to asbestos and organic fibers, glass fabrics have a low coefficient of thermal expansion and high thermal conductivity, making them dimensionally stable and able to dissipate heat quickly.

Hexcel HT93 pre-phenolic resin impregnated 7781 style E glass cloth was used as raw material for the production of test panel materials. The pre-impregnated glass fabric was assembled into layered assemblies by hand lay-up and vacuum bag methods in 100.000 class clean room conditions according to ISO 14644. Autoclave process was applied for curing of the phenolic resin and then cured test panel were obtained.

Figure 3. *Composite Test Panel Manufacturing*

B. MACHINABILITY OF COMPOSITE MATERIALS AFTER CURING

During the fabrication of polymer composites, it is more complex to create holes and slots without affecting the reinforcement, in such cases machining is the only technique of choice to create complex shapes and the necessary requirements.[10] Due to their inhomogeneous properties, composite materials show significant differences in machining compared to conventional materials.[11] Also, the cutting mechanism of composite material differs greatly from the cutting mechanism of conventional material.[12] This makes it difficult to analyze their machining performance. Machining of composite material can damage the material surface due to delamination, fiber orientation, fiber cracking and matrix flow.[13] Since it is not economical to process a composite material with most of the conventional processing methods. The performance of fiber-reinforced composites can also be affected by processing conditions, which concerns the lifetime and mechanical performance of polymer composites.[14] Recently composite materials utilize advanced processing techniques such as electrical discharge machining, ultrasonic machining, laser cutting and water jet and abrasive water jet machining.[15] In this study, an investigation has been carried out to understand the processing of composites, especially the drilling process. Our sample materials of layered composites made of glass fiber impregnated with phenolic resin Figure 4 holes were drilled and hole surfaces were examined with

1inç diameter HSS, carbur and seramic composite flat cutting tools, 500-2500mm/min feed rates, 1000-40000 rpm spindle rate and tool speeds on the 5 axes DMG DMU65 Monoblock and 3 axes Spinner VC1000 milling machines.

C. INSPECTION EQUIPMENT'S

Non-destructive testing (NDI) of composites is a crucial component in the service life cycle of critical structures in aircraft, spacecraft and transportation vessels.[7] Ultrasonic testing (UT) is probably the first method that comes to mind among the many NDI techniques beyond visual inspection and manual tapping hammer testing. Ultrasonic testing is based on the principle of making measurements on the material by using high energy and frequency sound waves. Detection of various defects and properties such as discontinuity, material thickness, etc. on the material is a very sensitive control method. In this study delamination inspection with the GE USN 60 ultrasonic controller and visual inspection up to 40x magnification with the WILD stereo microscope and for higher detailed images were obtained with the ZEISS Ultra Plus SEM.

Stereoscopic microscopes are used in various fields for tasks requiring three-dimensional imaging and fine detail observation. In surface inspection of composite structures, common in aircraft and spacecraft manufacturing, Stereo microscopes allow close inspection of the surface of materials. They can detect defects, faults and irregularities that are invisible to the naked eye.

Scanning Electron Microscopy (SEM) is a technique that uses a focused beam of high-energy electrons to produce various signals on the surface of solid samples. The electrons interact with atoms in the sample, producing a variety of signals that contain information about the surface topography and composition of the sample. SEM has many advantages over conventional microscopes, including a large depth of field, much higher resolution and the ability to image a relatively large area of the sample.[16]

III. INSPECTION AND RESULTS

Non-destructive control of the composite layered material was firstly carried out with General Electiric USD 60 ultrasonic tester using sound receiving and transmitting equipment. Unperforated and perforated surfaces were examined in detail. The sound frequency responses of the non-perforated surface and the perforated surface are compared in Figure 4a and 4b, and separations were detected around the holes machined at high speed and feed rate. Separation could not be detected visually, but all hole surfaces were examined in detail by SEM in Figure 5 and Figure 6, and layers, warping and warping arrangements, matrix and fiber fractures and voids were detected.

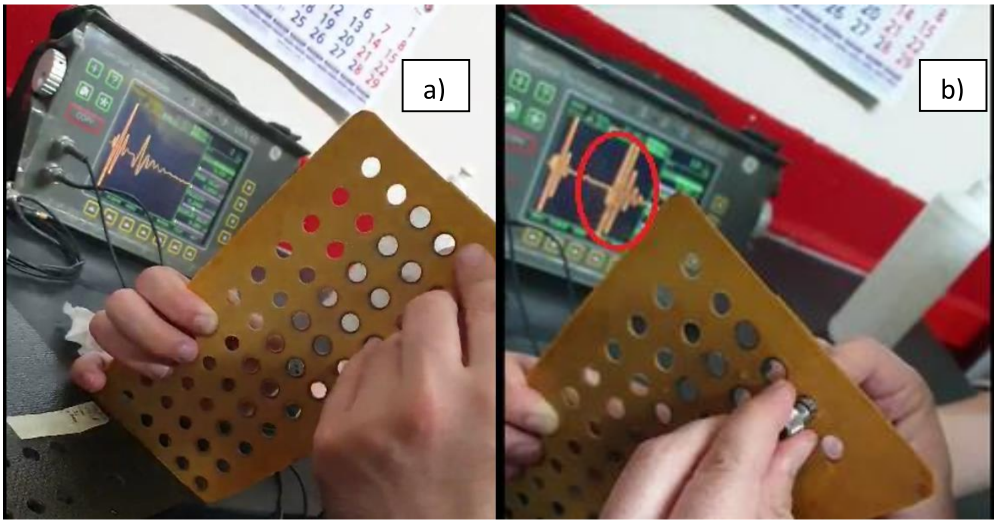

Figure 4. *Ultrasonic controls*

The surface of the hole was examined in detail with 6, 16, and 40 x magnifications in stereo micrograph. With the 6x image, the entire hole perimeter and the fibre openings at the entrance and exit during the milling hole process were detected. With 16x magnification, fibre cross-sections at the exit points of the hole process were detected and with 40x magnification, the arrangement of the layers at the interface, weave directions, matrix agglomerations could be examined.

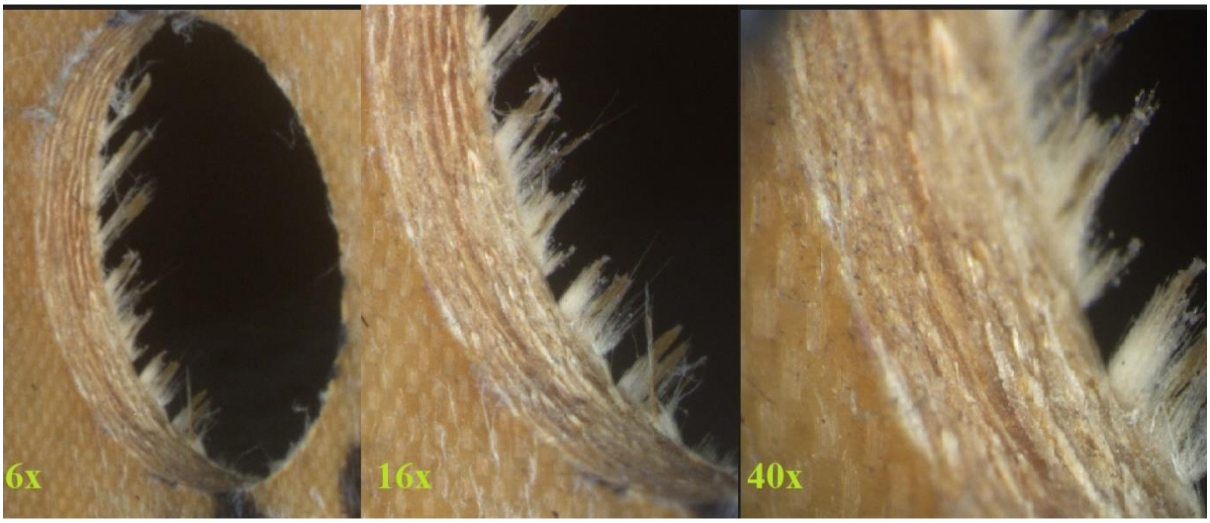

Figure 5. *Stereo microscopic images*

In Figure 6, the weft and warp image of the fibre yarns at the hole interface, the gap between the weft and warp and local regional fibre wrinkles were detected at 54x, 236x and 555x magnifications obtained by SEM.

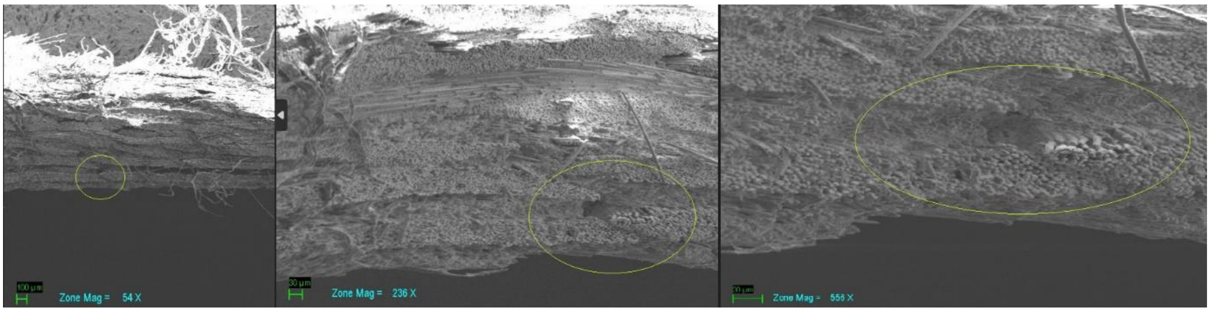

Figure 6. *SEM image of weft and warp*

In the regions marked in Figure 7, weft and warp images of the fibre yarns at the hole interface, fibre matrix fracture and separations were detected at 76x and 451x magnifications obtained by SEM. Fibre yarn thickness measurement can also be made with these images. The surface quality at the entire hole cutting interface can also be determined. The hole or process interfaces of composite materials layered from woven fabrics are not as smooth as metals and do not have the desired low surface roughness.

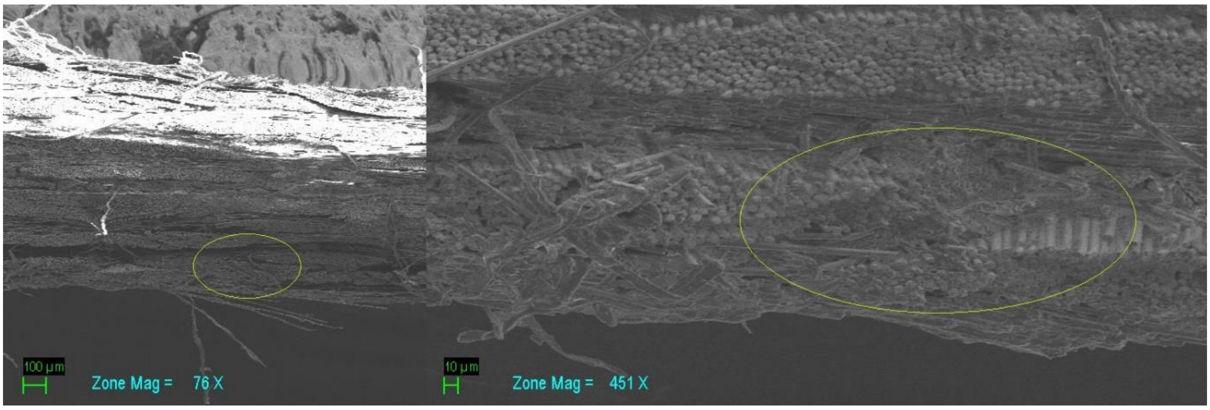

Figure 7. *SEM Matrix Fracture and Cavity*

IV. CONCLUSION

Composite materials are increasingly being researched and used in the manufacture of structural parts for civil and military aerospace structures due to their structural performance, increased efficiency and maintenance advantages. The FAA 20-170B Recommendation on composite structural parts in 2010 emphasized the importance of inspections and testing in the production and processing of composite parts and that requirements should be taken at the factory level. In this study, a detailed experimental study has been carried out on the hole processes required for the connection of composite parts with other structural assemblies with bonding elements, and the hole interfaces of test specimens produced with glass fiber fabric impregnated with phenolic resin were examined by ultrasonic non-destructive control methods and microscopy methods. It has been demonstrated that detailed interfacial controls can be performed successfully and effectively with the microscopy method for layered composite materials, and it is evaluated to be applicable in terms of optimization of hole drilling processes of composite materials and production quality requirements.

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