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Quality assessment techniques in FRP Composites – a review

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Abstract — *Fiber Reinforced Plastics (FRPs) has been widely used in engineering application due to their significant advantages like high specific strength/stiffness, superior corrosion resistance, light weight construction, high dielectric strength, low moisture absorption, high fatigue strength and resistance to chemical and microbiological attacks. As a consequence of the widening range of applications, they are used in various parts of Electronic appliances, automotive, aviation and spaceships, medical components and marine ships. Machining of composite materials is a rather complex task owing to their heterogeneity, anisotropy, and high abrasiveness of fibers, and it exhibits quality related problems in machining such as delamination, fibre pull-out, shrinkage of hole, spalling, fuzzing and thermal degradation. This review aims at describing the various techniques to assess quality in FRP composites.*

Keywords – *FRP, Assessment methods, Microscopy, image processing, Ultrasonic C-scan, Interferrometry, Acoustic Emission, Radiography, X-ray computerized tomography.* .

INTRODUCTION

Fiber reinforced plastics are basically a composites; they are a macroscopic combination of two or more distinct materials which have a recognizable interface between these combined materials [1]. Fiber Reinforced Plastics are the materials composed of two or more distinct material constituents. In this form, both fibers and matrix retain their identical physical and chemical properties; still they produce a combination of properties that cannot be achieved individually. Generally, fibers are the main load-carrying members and the matrix surrounded the fibers keeps them in the desired location and orientation as well as acts as a load transfer medium and protects them from environmental damages against extreme weather conditions [2]. They provide high specific strength/stiffness, light weight construction, low thermal conductivity, and high fatigue strength, ability to char and resistance to chemical and microbiological attacks [1, 3]. In recent times, development and application of Fiber Reinforced Plastics increased very fast. Fiber Reinforced Plastic (FRP) have been widely used in engineering application such as electronics components, furniture, aviation and aerospace, marine boats, medical equipments, and automobile vehicle parts due to their significant advantages over other materials [4]. Fiber Reinforced Plastics can be further classified in many ways according to type of fiber and polymer utilized in matrix, but generally they are named by the type of fiber used as carbon fiber-reinforced plastics (CFRP), glass fiber-reinforced plastics.

For the machining of FRP manufacturing processes used are drilling, milling, turning, water jet machining, laser beam machining, ultrasonic machining. Drilling is probably the most broadly applied machining process to composites for the assembling of components made of fiber reinforced plastics. Machining of composite materials is a rather complex task owing to their heterogeneity, anisotropy, and high abrasiveness of fibers, and it exhibits quality related problems in machining such as delamination, fibre pull-out, shrinkage of hole, spalling, fuzzing and thermal degradation. Of all the cutting processes used in FRPs delamination damage is critical one. In the case of aviation industries' assembly related work, estimated 60 % rejection rate is reported as a result of these defects [5]. The deteriorating quality of the drilled holes may cause high stress on the bolt/rivet, which result into its failure. So, the quality of the holes is important for the life of the joints where the holes are used [6].

Methods of Quality assessment

There are many techniques for the quality assessment of defects, reported in literature for the assessment of defects generated due to drilling a hole or machining the FRP component. The methods for the assessment of delamination are as Microscopy, Image processing, Acoustic emission, Ultrasonic C-scan, Interferrometry, Radiography and X-ray computerized tomography.

Microscopy and Image processing

This is a convenient and economical assessment method to measure the damage using visual measurement by microscopes. It is pertinent that different techniques for the visual measurement were adopted by different researcher. Researchers' have used different versions of tools for the image capturing of the damage area like tool maker's microscope, optical microscope, scanning electron microscopes (SEMs), charge-coupled device (CCD) camera, digital camera and Flatbed scanner for the measurement of delamination and other damage occurred during machining of FRP composites [7, 8, 9, 10, 11, 12, 13, 14, 15, 16]. Magnification of the range 5 × to 30 × are used but some times Scanning electron microscopes are also employed to obtain images of high magnification. A powerful light source kept at back side of the component also helps visual inspection [7]. Visual assessment faces difficulty for the measurement of damage in non-transparent composites [7].

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In image processing, the assessment of damage is done using a personal computer, a scanner and image processing software. This is cheaper method compared to other available method. The entire process can be divided into following stages: (a) image acquisition (b) image processing or pre-processing (c) measurement and analysis of damage and conclusion. These stages are further described as:

(a) Image acquisition: In this stage, image of the damage area is captured by various ways like tool maker's microscope, optical microscope, scanning electron microscopes (SEMs), charge-coupled device (CCD) camera, digital camera and Flatbed scanner. This stage is important as it affects later stages.

(b) Image processing or pre-processing: after image is acquired, quality of the image is to be improved by reducing the noise, improving the clarity and contrasts of the image and segmentation of the image is done. Different softwares like Image J, Analysis are used for image processing.

(c) Measurement and analysis of damage and conclusion: In this stage, required characteristics like perimeter, diameter, area, crack length are measured for the comparison, analysis and reasoning. After the analysis, conclusions are derived for the image.

Many researcher evaluated the delamination factor using the digital processing method [7, 17, 18, 19, 20, 21].

Acoustic emission

The acoustic emission is a release of energy in the form of sound waves which produced when damage occurs in material. This release of sound waves can be converted into root mean square (RMS) value which indicates the effect of machining on a material, and it can be utilized for damage analysis. According to ASTM standard E1316, acoustic emission is the class of phenomenon whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material or the transient waves so generated. The acoustic emission signals are monitored using acoustic emission sensor and signal data further processed. Different processing techniques are for the signal data and machining damage such as deformation, fiber cutting, matrix cracking and delamination is identified [7, 22, 23].

Ultrasonic C-scan

The ultrasonic waves (waves which have frequencies greater than 20 KHz) are passed through the test object and the echo signal are acquired by using oscilloscope which describe about any discontinuity or damage in the object. There are two variants of ultrasonic scan, one is the pulse echo method and the other is the through transmission method. The Ultrasonic system comprises the following component:

(1) An ultrasonic signal generator and echo acquisition system with a display,
(2) A probe for both the emission and reception of the ultrasonic beam,
(3) A probe arm fixed on a reference surface,
(4) A PC with a software that can allow operations like scan map plotting and image treatment.

A large number of high quality images can be obtained from each scanning by placing specimen between the sender and receiver. When the signal generator unit emits ultrasonic waves the receiver probe records the signals in computer. In ultrasonic C-scan, 2D images in a surface plane can be generated and using Back Reflection Intensity (BRI), all the internal defects can also be visualized because any defect at varying depth generates different reflection with varying Back Reflection Intensity (BRI). Ultrasonic C-scan images suffering from limitations of blurring effect and amplitude fluctuations due to discontinuous effect of the coupling gel [7, 24, 25, 26].

Interferrometry

The principle of this method was developed in the US Army Materials Technology Laboratory [7, 27]. In this method, master grating is inserted between the incident laser beam and test specimen. Level difference on the surface of the test specimen result of damage creates a dark and light fringe pattern development. A piezo-electric transducer is used to obtain phase shift in the optical path. 3D shape can also be measured by the phase modulation. This method has the advantage of being non-destructive and non-contact testing procedure [7].

Radiography

This is widely used non-destructive method for the assessment of the damage in FRP materials. In this method, a test specimen is directed with a collimated beam of X-ray which passes through the test specimen to a film. In this way, high resolution image is obtained. These images are correlated with the X-ray absorption density with the material density of the test specimen to measure the damage occurred during machining. These X-ray images are obtained prior to machining and after machining to eliminate pre-existing defects from the damage assessment [7].

X-ray computerized tomography

This method is useful for 3D non-destructive testing of FRP composites. Similar to X-ray radiography X-ray beam passes through the test object and beam is detected by the detectors at another end. The attenuated X-ray signals were recorded as a digital image and are stored in a computer. The difference from X-ray radiography is that the frame on which the X-ray tube and detectors are mounted, they are rotated in steps of 1^{o} from 0^{o} to 180^{o} to capture a series of images in the form of slices of the test object. This frame is afterward moved vertically to capture similar series of images for the slice. Thus in this method, it provides very accurate pictures defects by processing and analyzing in a computer [7].

CONCLUSIONS

As the field of application of FRP expands, task of quality assessment of defects has assumed pivotal role. Fast developing technology has provided means to assess the defects and damage more accurately at the same time very fast. Most of the above methods are non-destructive in nature. Digital image processing techniques are cheaper and with the

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development of portable image capturing devices, they are becoming popular. The different techniques were reported for the visual measurement of the damage in FRP, there is no consistent process or procedure which is followed for the quality assessment. Also there is not a common standard for the image acquisition for the quality assessment in the damage of the FRP composites.

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