Non-destructive evaluation of internal cracks in Glass fiber-reinforced polymers using digital shearing interferometry

Farzad Banakar[1], Davood Akbari[2*]

[1] Faculty of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran
[2] Faculty of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT

Shearography is one of the advanced methods of non-destructive techniques based on the interference of laser beams that have been reflected from the surface of the specimen. This method, which has high speed and accuracy, can evaluate the displacement derivative on the sample surface at once. In this paper, the possibility of sub-surface cracks detection with different lengths and angles in composite samples was investigated by shearography method and thermal stimulation system. For this purpose, in composite samples, controlled cracks were created with different lengths and angles. After calibration of the performance of the shearography setup, two heat sources of radiation were used to load samples. Loading quantity, the amount and direction of the shear, the cracks length, and their angles were chosen as the studied parameters. The results of this paper showed that the optimum loading amount plays a more critical role in the quality of the results than shear amount, and this value is related to the materials of the samples. To achieve the best results in crack detection on the selected specimens, optimum thermal loading was obtained between 12 and 15 seconds from in front of the specimen. Also, the optimum shear amount in the composite specimens was estimated about 0.1 image width that recorded by the camera. With the optimized values, all sub-surface cracks were identified.

KEYWORDS

Laser shearing interferometry, Shearography, Non-destructive test, Composite, Crack detection

* Corresponding Author: Email: daakbari@modares.ac.ir

1. Introduction

Recent researches show that many parts that suddenly break down, initially have small defects such as cracks and small holes in them. If these small and seemingly insignificant defects are not properly identified, they will spread and cause damage to the parts [1].

Laser shearography is a non-contact and full-field method to carry on non-destructive tests on different objects. It can directly measure the surface displacement derivatives in both cases of in-plane and out-of-plane [2]. This method is based on the interference of two light beams reflected from a surface of the samples [3]. To provide proper interference, a single-color laser light responsible for lighting up the surface is used. As a result, the spot patterns are formed on the surface. The spot patterns could be moved horizontally or vertically by the shearing device to create two identical but moved interfering patterns [4]. There are different methods for interfering and separating the light beam, which in this paper the Michelson interferometer is used.

The present paper utilizes thermal loading by two ceramic heaters in digital shearography to detect subsurface cracks with different lengths and angles in glass fiber-reinforced composites. The optimal values for loading magnitude and shear amount parameters were extracted in these samples. Also, the effect of each of these parameters on the quality of crack results was investigated.

2. Methodology

In the shearography configuration, a single-color laser with a power of 50 mW was used to illuminate the surface of the sample. Two flat mirrors, one fixed and the other rotating horizontally and vertically, were utilized to shear the images. A 3.2-MP CCD camera is utilized to investigate the sample surface. It should be noted that the location of the camera relative to the surface of the sample is such that it records an area of 90×90 mm^2. Loading on the samples was done by two ceramic heaters with a power of 500 W and a maximum temperature of 350-400℃. After loading, for all designed experiments, 20 images were captured from the surface of the sample at one-second intervals.

In this paper, the hand layup technique was used to prepare the composite panels. The LY-113 epoxy resin and RE-165 woven glass fibers are used to make composite panels with the layup configuration of $[0×90]_{12s}$. Six samples were cut out using water jet apparatuses with the width, length, and thickness of 100, 40, and 3 mm, respectively. After that, 4 vertical cracks with a length of 2, 5, 10, 15 mm on two samples and 3 angled cracks with 0, 30 and 60 degrees were created by a 0.3 mm thick shear blade on three other samples. The depth of each crack is about 1 mm from the surface.

Considering the Taguchi method, the three parameters of crack size, loading magnitude and shear amount in different modes were compared with each other. In this method, 4 levels were considered for each parameter, then 16 experiments were introduced to investigate the parameters, which the detectability of the cracks was introduced as the output. The levels of the examined parameters is shown in Table 1.

Table1. levels of the investigated parameters

Parameters	Level 1	Level 2	Level 3	Level 4
Crack length (mm)	2	5	10	15
Thermal loading (s)	9	12	15	18
Shear amount (mm)	7	10	13	16

The output of the experiments is the ability of the method to detect different cracks. Signal-to-noise ratio was used to evaluate the results. This ratio was indicative of the sensitivity of the output to the examined parameters. The higher signal-to-noise ratio, means that better detection of cracks.

3. Result and Discussion

According to the results of parameter analysis, 15 and 10mm cracks were identified much more easily than the other two cracks. In the SNR diagram, the optimal shear amount is about 10 mm and the optimal loading magnitude is about 12 to 15 seconds. Fig. 1 depict the SNR diagrams for analysis parameters. According to the significant change of shear amount in SNR from 4 mm to 10 mm, it is clear that a small change in shear can greatly alter the quality of the fringes and the sensitivity of the method. Also, due to the greater difference in SNR in the loading magnitude diagram than in the shear amount, it is concluded that the change in the loading parameters plays a more important role than the shear amount in the quality of the results.

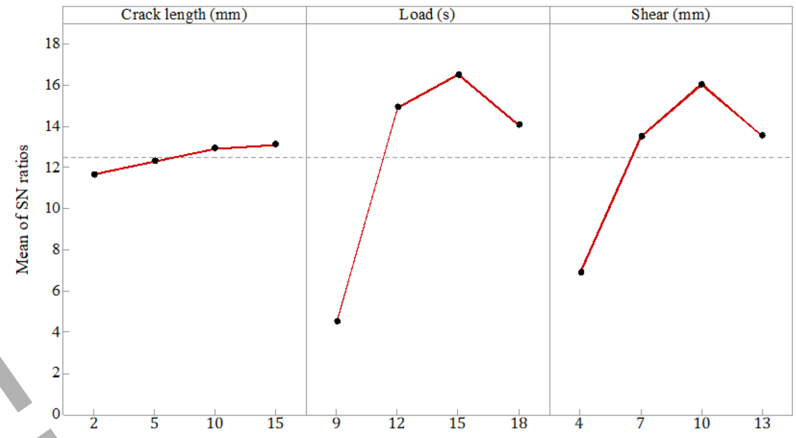

Fig. 1. SNR diagram for analysis of crack length, loading magnitude and shear amount parameters

As the load increased, the fringes became denser and more numerous, but there was no change in the location of the fringe center. Also, by increasing the shear amount at a constant load, the fringes became more interconnected and the best shear amount for crack detection was observed about 10 mm. As the amount of shear increased, the density of the fringes increased so that many fringes formed at short distances from each other. Also, by reducing the amount of shear from 10 mm, the number of fringes became less and it was difficult to identify the crack location. The reason for this is due to the main equations of shearography. In these relationships, with constant wavelengths and phase differences, increasing the shear amount, increases the out-of-plane displacement gradient. Similarly, with decreasing shear amount, the displacement gradient decreases. Therefore, the selection of the optimal shear is necessary to achieve the optimal out-of-plane displacement gradient and thus the best fringe patterns.

The shear amount in these samples was directly related to the width of the image recorded by the camera and it was concluded that the optimal shear amount of the discussed composites was estimated to be 10% of the image width recorded by the CCD camera. The best results were derived when the shear direction was perpendicular to the crack direction. To detect angular cracks, a combination of horizontal and vertical shearing was used. In this case, the shearing direction was measured at 30 and 60 degrees relative to the horizontal line.

4. Conclusion

In this paper, the method of digital shearography by thermal loading was used to detect cracks on samples of composite materials reinforced with glass fibers. Also, the parameters of loading magnitude, shear amount and direction, which are the basic parameters [5] in defect detection, were examined and the optimal value was obtained for them. Finally, thermal loading as a suitable method and efficient in detecting cracks on these materials, was introduced. The loading magnitude parameter has a more important role in the quality of the results than the shear amount. For the investigated composite samples, the best results were obtained at the loading time between 12 to 15 seconds (about 57-50 ° C). Due to the sensitivity of the shearography to the out-of-plane displacement gradient, the loading should be applied uniformly and smoothly on the surface to avoid excessive strain on the sample surface. Also, the best results were derived when the shear direction was perpendicular to the crack direction.

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