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NON-DESTRUCTIVE TESTING OF ELEMENTS OF TITANIUM HONEYCOMB PANELS BY SHEAROGRAPHY METHOD USING VACUUM LOAD

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ABSTRACT

The use of the modern method of non-destructive quality testing — electron shearography in combination with vacuum load for the study of elements of titanium honeycomb panels is considered. The effectiveness of the procedure for detecting inner defects of different location in the honeycomb panels, size and configuration is shown.

KEY WORDS: non-destructive quality testing, honeycomb panels, electron shearography, vacuum load

INTRODUCTION

Manufacture of modern products and structures, characterized by high quality and reliability, is associated with the use of new structural materials with set physical and mechanical properties. They mostly operate in the conditions of a complex mechanical load and temperature gradients. At the same time, even a slight concentration of stresses, that occurs in the zone of defects of structural elements, may lead to loss of their serviceability.

Providing high quality of created structures is one of the most important scientific and technical problems. In this regard, it is important to improve the well-known and develop new modern automated methods and means of quality testing of mechanisms and structures.

At present, in order to detect defects in materials and structures, a group of non-destructive methods is used, that include: radiological, acoustic, luminescent, method of eddy currents, etc. [1, 2]. Each of these methods has its own disadvantages and advantages, but none of them is universal and does not satisfy all the requirements for means and methods of non-destructive testing.

The group of the abovementioned testing methods successfully complement the methods of laser interferometry, especially speckle-interferometry. For engineering applications, the method of shear speckle-interferometry (shearography) is perspective [3, 4]. This method allows directly obtaining the value of derivatives from displacements and is effective in the analysis of deformations. The shearography method is not sensitive to displacement of the object as a whole, since such a displacement does not cause deformation and also does not require special protection against vibrations.

An intense development of computer and computational technology allowed a substantial improvement of the shearography method and development of the method of digital shearography [5–10]. An important characteristic feature of the method of digital shearography is the fact, that it allows observing a dynamic pattern of interference fringes in a real-time mode. The relative simplicity of this method allows applying it to solve significantly more complex problems associated with the analysis of deformations and quality testing of structures in laboratory and industrial conditions.

At present, digital shearography is intensively developing and has such advantages as visualization, contactlessness, high sensitivity, possibility of performing studies of objects of a complex shape and significant sizes in a real-time mode. In addition, an important advantage, as was mentioned above, is insensitivity to vibrations.

SHEAROGRAPHY SYSTEM FOR NON-DESTRUCTIVE QUALITY TESTING

Shearography quality testing is based on registration of difference during deformation while loading a defect-free element and an area with a defect, since in the defect zone, a decrease in rigidity is typical.

At the E.O. Paton Electric Welding Institute (PWI), an automated shearography system based on a modified Michelson interferometer with a variable inclination angle of the mirror in one of the optical arms was developed. The block-diagram of this system for non-destructive quality testing is shown in Figure 1.

Shearographic system (Figure 2) includes the following main components: laser illumination system (*1*, *2*), lens (*3*), interferometer (*4*), digital camera (*12*), laptop or computer with monitor (*13*), phase-shifting

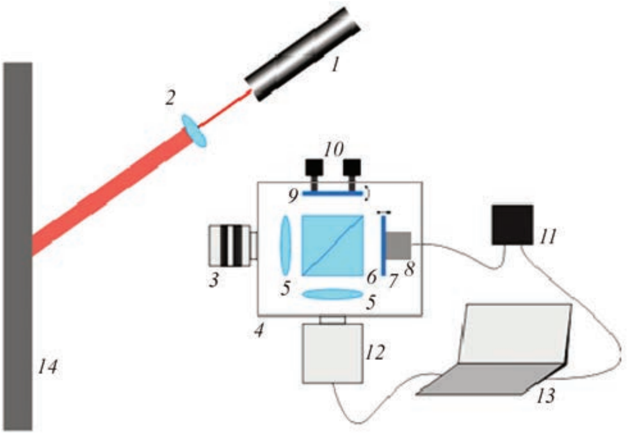

Figure 1. Block-diagram of shearography system: *1* — source of coherent radiation; *2* — laser beam expanding device; *3* — lens; *4* — shearography interferometer, which includes lenses *5*, dividing cube *6*, mirror *7*, fixed on piezoelement *8*, mirror *9*, which creates displacement of image using screws *10*; *11* — controller for piezoelement control *8*; *12* — digital camera; *13* — laptop; *14* — investigated specimen

system (*7*, *8*, *11*). The piezoelectric phase-shifting element with the power source provides the required phase shift between the two wavefronts as a result of the mirror displacement in one of the optical arms of the interferometer to the value $\lambda/2$, λ, $3\lambda/2$, where λ is the length of the laser radiation wave. Shearography mirror *9* serves to create a shear. Varying the inclination angle of the mirror in the interferometer with the use of screws *10*, it is possible to set the required displacement value. In this case, the value of a shear affects the sensitivity of the measurement of the testing system. The laser is intended to illuminate the objects of investigations and the formation of speckle-structure on it. The replaceable lens *3*, mounted on the shear-module *4*, allows receiving and focusing the obtained speckle-patterns on the array of a digital camera *12* for their further digital processing. Replacing lenses, it is possible to adjust interferometer for studying regions of objects with a different area.

Figure 2. Appearance of shearography interferometer with laser modules

Studying the quality of objects requires specifying exactly what kind of surface deformations is better for registration — plane or out-of-plane, since different types of loading the specimen used in the process of shearography control causes different types of deformation. For example, during the use of thermal load or inner pressure, in the object out-of-plane deformations of its surface, and in the case of mechanical tension — plane deformations occur.

To obtain the sensitivity of the interferometer to different types of deformation (in the plane or out-of-plane) is possible by changing the mutual location of an object, illuminating laser radiation and observation direction through the interferometer lens. In order to achieve the maximum sensitivity of the optical scheme of the interferometer to out-of-plane deformation, it is necessary that the angle between the directions of illumination and observation was minimal. Therefore, lasers are fixed directly on the shearography interferometer.

The developed automated shearography system operates according to the following algorithm. A wave front from the laser, reflected from the surface of the investigated object, passes through the interferometer and focuses on the array of a digital camera, by means of which it is transmitted to the computer for further digital processing. Then the object is loaded (as a result of which it is deformed) and again the image of the studied surface is recorded. The images obtained before and after the load are processed before obtaining a shearogram with the use of the software developed by the PWI. Such a shearogram represents a pattern of alternating light and dark areas (fringes) that requires a further processing, namely, reducing the level of speckle-noise, intensifying contrast of fringes and some other. The software allows building a phase distribution field and a three-dimensional image of the deformation surface of the tested object, as well as recording the results in the form of documents.

The parameters of computer processing, except for standard operations (obtaining interference patterns, filtration and stitching) include additional filtration, since the pattern of interference fringes may be “noisy” and insufficiently contrasting. Too large number of interference fringes leads to a decrease in image contrast, which increases the time and reduces the efficiency of computer processing. A number of interference fringes is selected for a rapid and efficient processing of a shearogram. The change in a number of interference fringes is also possible by adjusting the value of the shear, i.e., by the change in the sensitivity of the interferometer.

Non-destructive quality testing of the elements of titanium honeycomb panels was carried out using the developed software, which allowed obtaining the interference fringe patterns of tested objects, filtering the received images, building phase fields and a three-dimensional representation of deformation surface of an object and recording the results into the file.

The developed software is used: to enter speckle-images from the digital camera to the computer; control the voltage supply on the piezoelement placed in one of the arms of the shearography interferometer; elaborate the shearography speckle-images for calculation and a three-dimensional visualization of the fields of the surface deformation of investigated objects; construction of diagrams of change in derivatives in a set direction along the selected cross-sections; storage of obtained results in the form of a file; outputting of shearography testing results to the printing device.

CHOICE OF OPTIMAL LOAD

In order to obtain a shearogram, it is necessary to record a reflected light wave in two states of an investigated object — in the initial and loaded one. Therefore, it is important to choose a method of loading, since the effectiveness and reliability of shearography control depends on it. The concept of an optimal loading of an object at shearography non-destructive testing consists in choosing such method of loading, which would allow causing stress concentration in the zone of a probable defect. In this case, researchers are trying to create such a stressed state that causes the largest difference in the distribution of deformation along the surface of a studied object on defective and defective-free areas.

The optimal value of load is selected depending on mechanical properties of the material from which a studied object is manufactured. For example, if an object is made of the polymer material, the load temperature should not cause plastic deformation. In the process of shearography quality testing in most cases it is enough to create a small (several degrees) difference between the temperature of a studied object before and after heating.

During the use of mechanical load, pressure or vacuum, for all types of materials, the value of the load is selected in such a way that caused deformations remained elastic and did not reach the yield strength of the material. Usually a method of load and its parameters are selected experimentally.

NON-DESTRUCTIVE QUALITY TESTING OF HONEYCOMB PANELS

During the manufacture of modern structures of aerospace engineering, honeycomb panels (Figure 3) are widely used, which provides a significant reduction in the weight of products. Such panels consist of two outer skins, between which a honeycomb filler is located. In its turn, the filler is joined with outer sheets using welding, brazing or adhesion. Outer sheets can be manufactured both from metals and plastics or composites. A honeycomb structure has a high rigidity during bending and strength. Defects of a honeycomb structure, which reduce the strength during bending and compression strength include damages to the filler, surface defects, lack of continuity and incorrectly formed joint.

To use vacuum load during shearography non-destructive quality testing of honeycomb panels at the PWI, the equipment was designed consisting of a vacuum detachable chamber, compressor, by means of which vacuum is created, and pressure regulator in the chamber (Figure 4). The sizes of a vacuum detachable chamber can be changed according to the desired sizes and curvature of an investigated area of structural elements. An investigated area of the specimen is loaded uniformly, the process of experiments is automated and takes up to 2 min.

The elements of honeycomb panels, in which defects were detected by the shearography method, were made of titanium alloy. The panel skin had a thickness of 1 mm, the thickness of the sheet, from which the filler was made, amounted to 0.5 mm, and the diam-

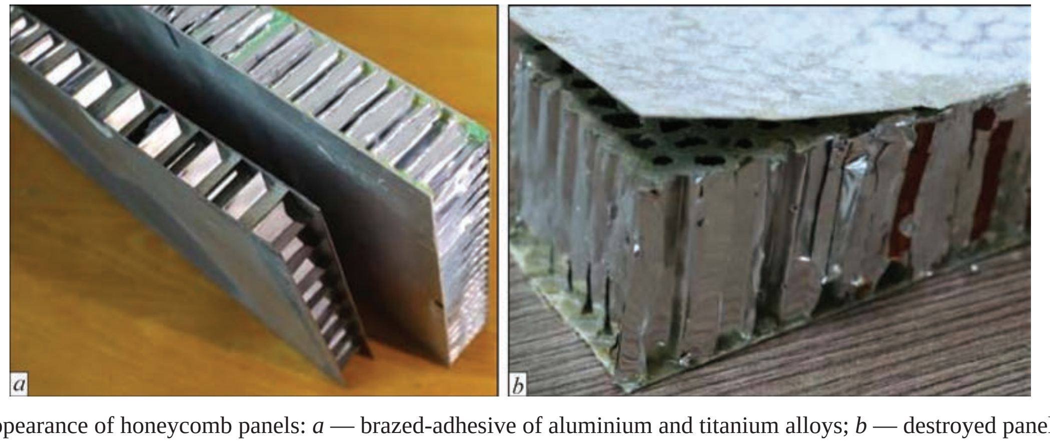

Figure 3. Appearance of honeycomb panels: *a* — brazed-adhesive of aluminium and titanium alloys; *b* — destroyed panel

Figure 4. Appearance of vacuum detachable chamber (*1*) and compressor (*2*)

eter of the honeycomb cell was 6 mm. The skin and filler were joined with each other by brazing. During such a method of joining, adjacent edges are sometimes in a state of adhesion, which leads to arising of defective zones in the form of lack of brazing. In the conditions of static or dynamic loads, on the area of such a defect, an opening of edges occurs that can lead to destruction of assembles and structural elements in the process of their operation.

During tests of elements of titanium honeycomb panels, vacuum load was used, which, unlike the thermal method, allows providing a uniform and automated load of the entire investigated area of the specimen, as well as reduction in the time for diagnostics. During the experiment, a special chamber was applied to the surface of the investigated area and a vacuum of up to 0.7 atm was created and the initial state of the surface (speckle-pattern of the surface of the studied panel was recorded). Then, pressure in the chamber was reduced or increased by the value of 0.1–0.3 atm and the state of the honeycomb panel was recorded after loading. A reduction or increase in pressure caused a surface deformation, which allowed revealing and visualizing the deformation of each honeycomb cell. In the areas, where bonds between honeycombs are weakened (presence of a crack, absence of a welded joint, etc.), or other types of surface defects are present, a local abnormal deformation of the surface of studied elements appears.

During testing elements of honeycomb panels, a shear in the interferometer along a horizontal, vertical and diagonal directions was used. A shear determines the direction of optical differentiation of values of shears of the investigated surface and allows obtaining parameters of its deformation that arose under the action of applied load.

Figure 5 shows the results of shearography testing of the element of the titanium honeycomb panel using vacuum load and a shear in a diagonal direction. The images show a visualized honeycomb filler with approximately the same periodicity of change in defromation amplitude and a local defective area was determined, where violation of this periodicity in the form of "dumbbell" (indicated by arrows) is present, which characterizes the absence of a joint between the skin and filler.

The use of a shear in a vertical direction also allows visualizing the honeycomb filler and determining the defective local area (Figure 6). However, in this case, anomalous zones are manifested

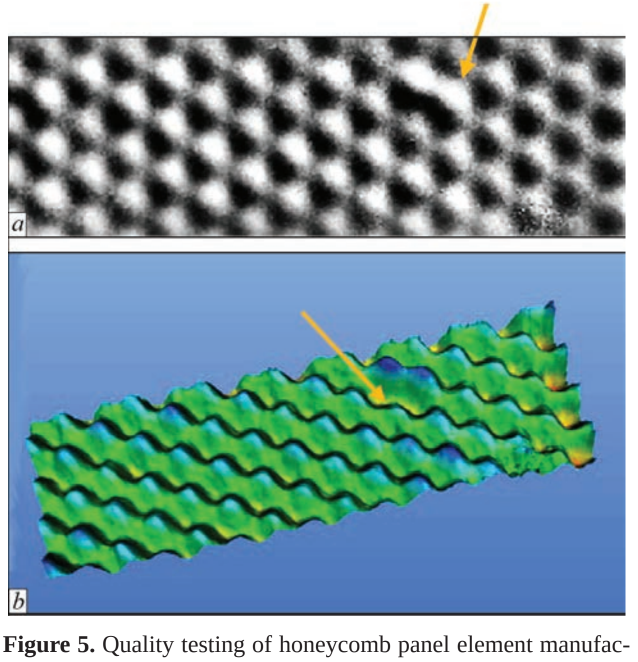

Figure 5. Quality testing of honeycomb panel element manufactured of titanium alloy, under vacuum load when using shear in a diagonal direction: *a* — shearogram of the investigated area; *b* — three-dimensional image of deformation of the investigated area

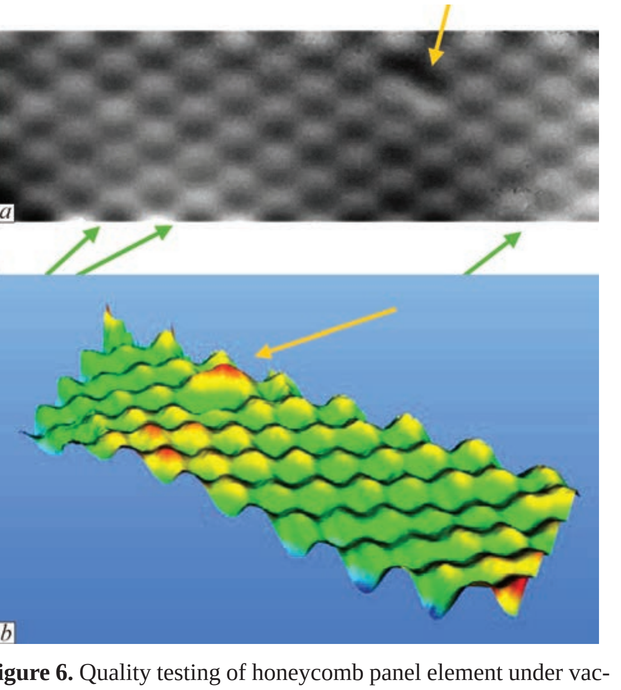

Figure 6. Quality testing of honeycomb panel element under vacuum load when using shear in a vertical direction: *a* — shearogram of the investigated area; *b* — three-dimensional image of deformation of the investigated area

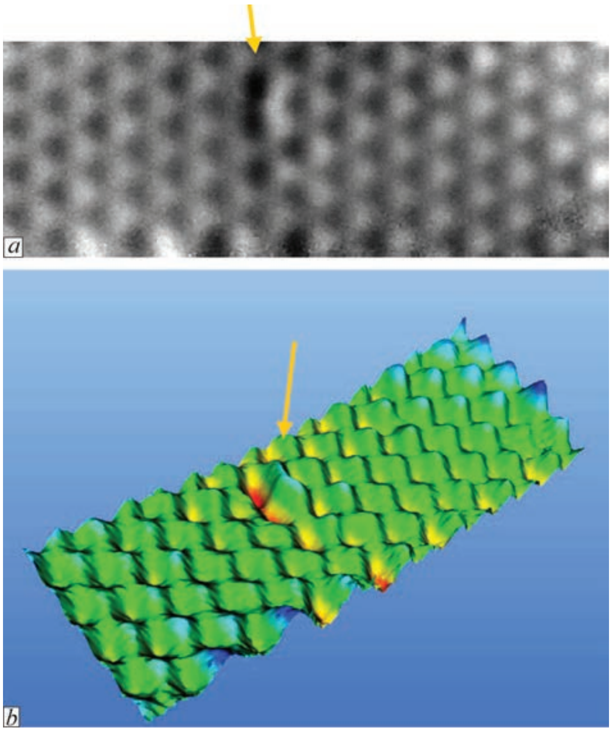

Figure 7. Quality testing of honeycomb panel element under vacuum load: shearogram (*a*) and a three-dimensional image of deformation of the investigated area (*b*) when using shear in a horizontal direction

along the edges of the surface of the honeycomb element, which is associated with the boundary effect of loading the vacuum chamber (indicated by green arrows in Figure 6, *a*).

Figure 7 shows the results of non-destructive quality testing of the honeycomb panel element by the shearography method using vacuum load and a shear in a horizontal direction. The local defective zone in the form of a “vertical dumbbell”, indicated by arrows, is clearly seen on the background of a visualized honeycomb filler.

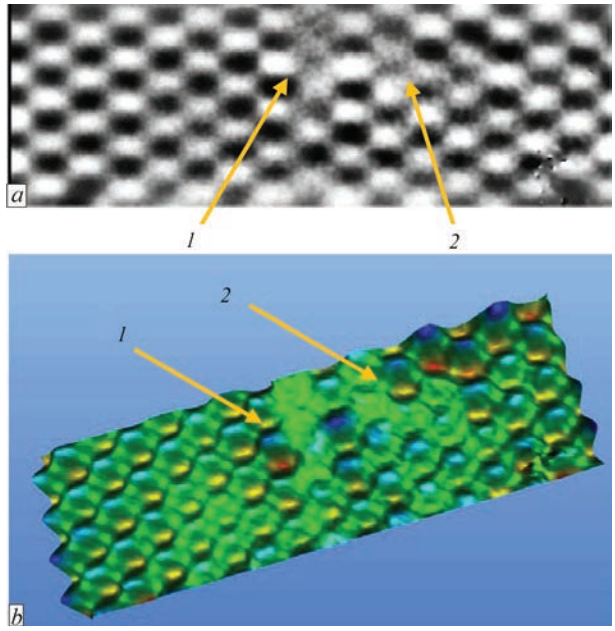

Figure 9. Quality testing of honeycomb panel element under vacuum load when using a shear in a vertical direction: shearogram (*a*) and a three-dimensional image of deformation (*b*) of the investigated area

The results of shearography control of defective areas, including more than two honeycomb cells, are shown in Figures 8, 9. On the images, local zones of the abnormal deformation of the studied surface on the background of a visualized honeycomb filler are visible, which makes it possible to evaluate the number of damaged honeycomb cells.

In Figure 8, *a* significantly reduced deformation amplitude along four vertically placed cells is observed. Such detection of features is usually asso-

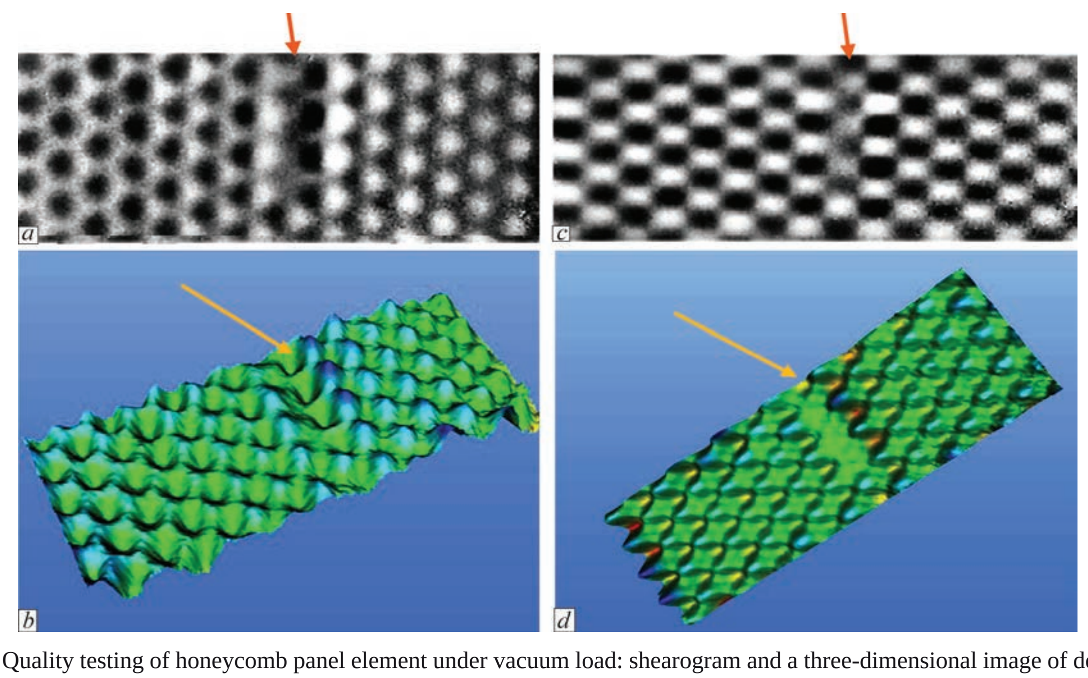

Figure 8. Quality testing of honeycomb panel element under vacuum load: shearogram and a three-dimensional image of deformation of the investigated area using shear in a horizontal (*a*, *b*) and vertical (*c*, *d*) direction

ciated with a higher rigidity of the local area of the specimen as compared to other areas. This defective zone is well visualized both in horizontal as well as in vertical direction of a shear.

Figure 9 shows the results of testing another area of the element of a honeycomb panel, where except of a vertical defective zone *1*, a defective zone *2* is present, which is indicated by a decrease in the amplitude of deformation of a larger area of the studied surface.

The use of a vacuum cover plate allows preserving the same conditions during experiments, which increases the repeatability of the obtained results and increases their reliability unlike a widely used thermal load, which requires testing of ambient temperature and heating and cooling time.

The obtained results showed that a defective zone is revealed the most clearly in the case when its area is less than 20 % from the total area of the tested area of the studied element surface.

CONCLUSIONS

The method of electronic shearography in combination with vacuum load is effective to detect inner defects of different sizes and configuration in the elements of honeycomb panels.

The created shearography equipment and vacuum load allowed increasing the efficiency of investigations by automizing experiments and reducing the time required to conduct them. The use of vacuum load allowed improving the repeatability of obtained results and increasing their reliability.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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