DOI: https://doi.org/10.37434/tpwj2025.02.06

DETECTION OF INTERNAL ULTRA-SMALL DEFECTS IN ALUMINIUM WELDED JOINTS BY THE SHEAROGRAPHY METHOD

L.M. Lobanov, O.P. Shutkevych, I.V. Kyyanets, I.L. Shkurat, K.V. Shyyan, V.V. Savitsky

E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

ABSTRACT

In modern industry, ensuring the quality of welded joints, particularly those made from aluminium alloys, is a crucial task for enhancing the reliability of structures. Special attention is paid to detecting internal defects that may lead to their premature failure. The aim of this work is to develop and apply a shearography non-destructive testing method in combination with thermal loading to detect ultra-small defects in welded joints of aluminium alloys. Loading was provided by an automated system that allowed the surface of tested specimens to be heated by 3–7 °C for 2–4 s. The studies showed that the advanced shearography equipment can detect defects as small as 0.3 mm in diameter, with a depth of up to 1.8 mm, both in the weld zone and in the base metal. The proposed parameters of thermal loading and the settings of the interferometer optical scheme allowed achieving a high sensitivity to ultra-small defects. The shearography method with automated thermal loading is effective for detecting internal defects in welded joints of aluminium alloys and can be used for non-destructive testing in production conditions.

KEYWORDS: non-destructive testing, shearography; aluminium alloys, ultra-small defects

INTRODUCTION

The production of modern parts and structures of high quality and reliability is associated with the use of the latest structural materials with specified physical and mechanical properties. Ensuring the high quality of the produced structures is one of the most crucial scientific and technical challenges. Therefore, it is important to improve the known and develop new modern automated methods and tools for quality testing of mechanisms and structures. Nowadays, various non-destructive methods are used to detect defects in materials and structures, such as radiographic, acoustic, luminescent, eddy current, etc. [1, 2]. Each of these methods has its own disadvantages and advantages, but none of them is universal and does not meet all the requirements for non-destructive testing tools and methods. In leading modern industries, especially in the automotive, shipbuilding, power and aerospace engineering sectors, new structural materials are widely used in the manufacture of thin-sheet structures. They mostly operate under severe mechanical and temperature conditions. Therefore, even a small concentration of stresses caused by defects in welds or structural elements can lead to their failure.

Hidden defects, which are undetected during manufacturing inspections, often cause reduced structural quality. A significant part of product failures at the initial stage of their operation is associated with the manifestation of such hidden defects. In most cases, they also cause the failure of assemblies and structural elements in the course of their further use. Therefore, in order to improve the testing and reliability of structural assemblies and elements, it is important to use modern methods of non-destructive testing [3–6]. A group of the above-mentioned quality testing methods is successfully supplemented by laser interferometry methods, especially speckle interferometry. The shearography method is promising for engineering applications [7, 8]. This method makes it possible to directly obtain the values of derivatives from the displacements and is effective in analysing deformations. The shearography method is insensitive to displacements of the object as a whole, since such displacements do not cause deformations and, therefore, do not require special protection against vibrations.

The intensive development of computing technology has made it possible to significantly improve the method of shearography and develop the method of digital shearography [9]. An important characteristic feature of this method is the ability to observe a dynamic pattern of interference fringes on a monitor in real time. Due to relative simplicity, this method can be used to solve much more complex problems related to deformation analysis and quality testing of structures in laboratory and industrial conditions.

Studies on the detection of fine defects in lamellar composites using thermal-loaded shearography are presented in [10, 11], and both experimental and numerical results on the detection of small defects are presented. In the given articles, a thermomechanical finite element model was created in Abaqus to evaluate different thermal loading schemes for flaw detection. The rational choice of reference and signal interference patterns from the heating/cooling sequence for reliable flaw detection was determined. Experimental and numerical results show that this approach

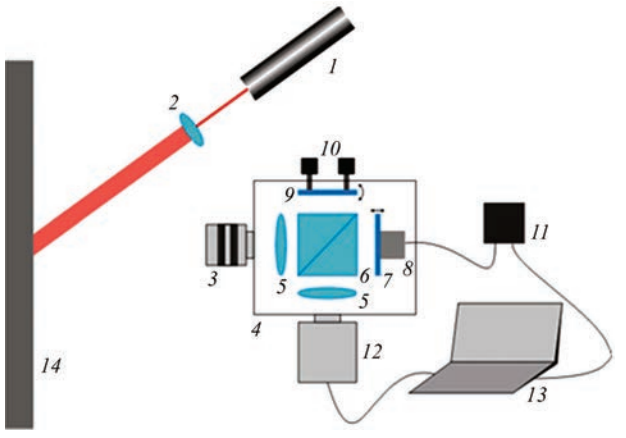

Figure 1. Block diagram of shearography system: *1* — laser; *2* — beam expander; *3* — lens; *4* — shearography interferometer containing lenses *5*, beamsplitter *6,* mirror *7,* mounted on piezoelectric element *8*, mirror *9*, which creates an image shear by means of screws *10*; *11* — PZT controller *8*; *12* — digital camera; *13* — laptop; *14* — tested object

allows detecting millimetre and submillimetre defects in carbon fibre reinforced lamellar composites.

In [12], a method of real-time phase processing with high-frequency synchronization of the digital camera, PZT-mirror and load is proposed to improve the quality of the phase pattern and the efficiency of protection against noise during the phase shift process. The method was applied to optical non-destructive measuring systems of shearography/ESRI to detect minor tear defects with a minimum size of 2 mm and to evaluate the interfacial adhesive strength of bonding layers, respectively. Currently, digital shearography is being intensively developed and has the following advantages: visualization, contact-free nature, high sensitivity and the ability to perform real-time studies of complex-shaped and large-sized objects.

THE AIM

of this work is to develop a technology for detecting internal defects of ultra-small sizes (less than 1 mm in diameter) in aluminium welded joints using the digital shearography method in combination with automated thermal loading.

METHOD OF SHEAROGRAPHY FOR NON-DESTRUCTIVE QUALITY TESTING

To conduct the NDT experiments, a shearography system based on the Michelson interferometer, which is sensitive to out-of-plane deformation, was used to conduct the NDT experiments, which is sensitive to out-of-plane deformation (Figure 1). The shearography experiments were carried out using the software developed by the authors, which contains additional options for control of the thermal load. It allows setting the time of recording the initial state, switching on and off the temperature load, recording the loaded state, as well as the time of exporting the initial and loaded states to the software for processing the received images.

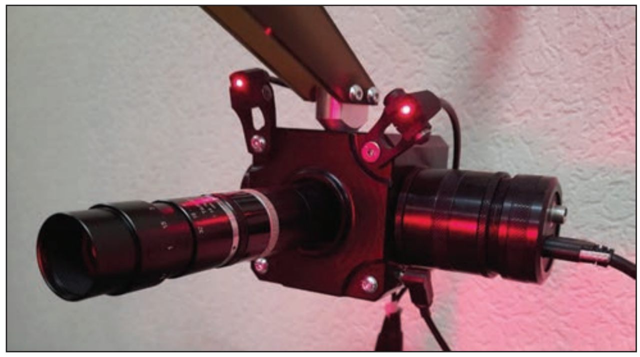

Figure 2. Appearance of shearography interferometer with laser modules and replaceable lens

NON-DESTRUCTIVE QUALITY TESTING OF ALUMINIUM WELDED JOINTS BY THE SHEAROGRAPHY METHOD

Experiments on non-destructive testing by the shearography method in combination with thermal loading were performed on welded aluminium alloy specimens. The specimens were planar and were made by friction stir welding. During the experiments, the specimens were fixed in a mounting frame, which allowed applying a thermal load (Figure 3). The loading was carried out automatically using the developed software. The shearography patterns were recorded both at the heating and cooling stages with a 10-fold optical magnification, which was achieved by installing a 75 mm focal length lens and an additional optical ring. The shear was chosen along the *OX* or *OY* direction and its value was 10 mm.

In the process of testing aluminium specimens, thermal loading with hot air was applied using an industrial hot air gun. The air heating temperature was set to 500 °C, the distance from the hot air gun to the specimen surface was ~20 mm, the heating lasted 2–3 s and the change in surface temperature was up to 10 °C.

Figure 5 shows the location scheme of the defect in the welded specimen. Figure 6 shows settings used for automatic thermal loading. In the first step (Step1), the initial state of the object is recorded. In the second step (Step2), the temperature load is switched on and off in the third step (Step3). In the fourth step (Step4), a speckle pattern of the deformed state of the object is recorded.

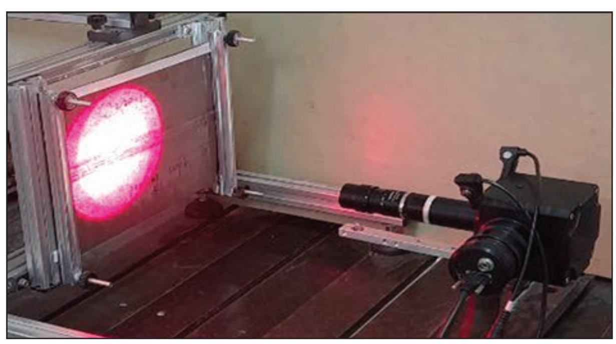

Figure 3. Appearance of shearography interferometer with a 10-fold optical magnification and test specimen fixed in a mounting frame

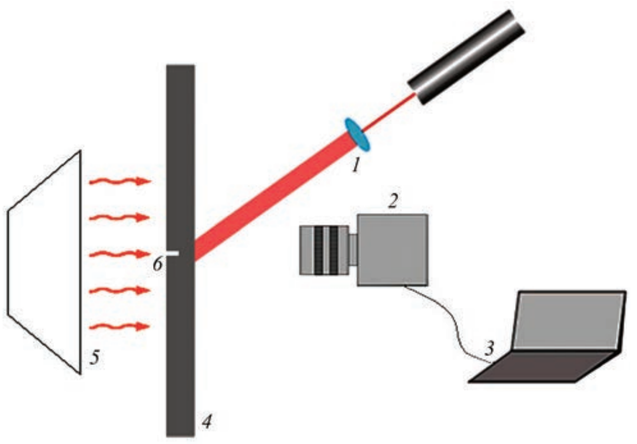

Figure 4. Scheme of the experiment: *1* — laser illumination; *2* — shearography interferometer; *3* — laptop; *4* — tested specimen; *5* — heating source; *6* — blind hole

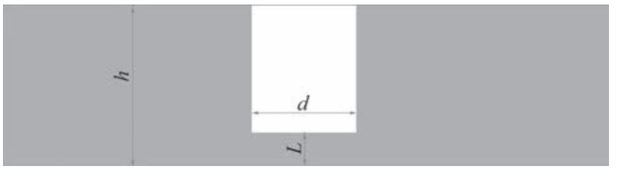

Figure 5. Scheme of defect location in welded specimen: *h* — thickness of specimen; *d* — diameter of hole; *L* — depth of occurrence (wall thickness remaining after drilling a blind hole with a diameter *d*)

In the fifth step (Step5), the initial and final states of the object are exported to a programme for processing.

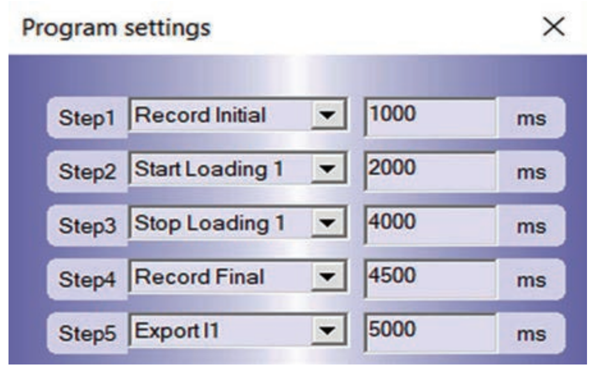

Figure 6. Settings of loading tested specimen in milliseconds

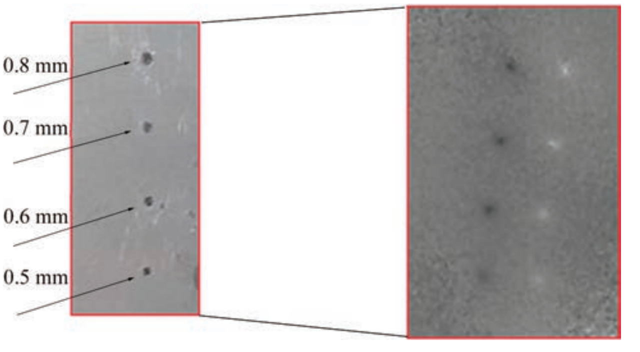

Figure 7. Shearography inspection of the test area of an aluminium specimen: general view of the area (*a*) and a typical pattern of detected defects with diameters $d = 0.5$, 0.6, 0.7 and 0.8 mm (*b*)

To develop the shearography testing procedure, blind holes with a diameter of $d = 0.5$–0.8 mm and a

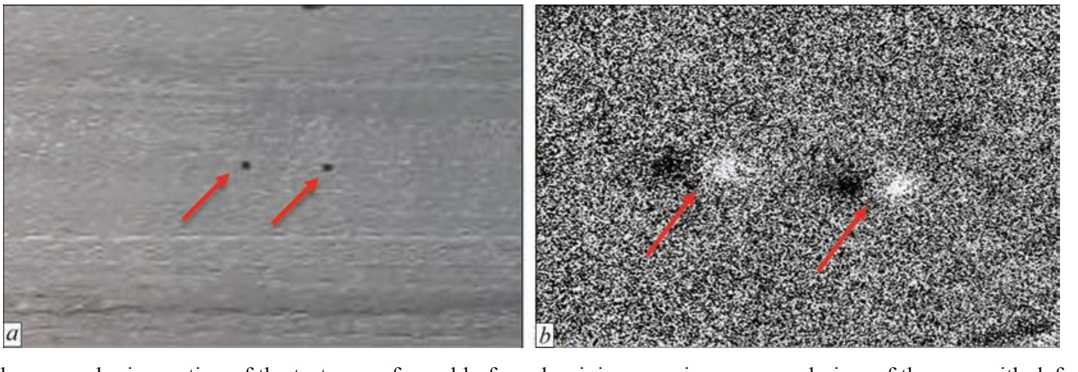

Figure 8. Shearography inspection of the test area of a weld of an aluminium specimen: general view of the area with defects (*a*) and a typical pattern of detected defects with a diameter of 0.3 mm and a depth of $L = 0.35$ and 0.85 mm (*b*)

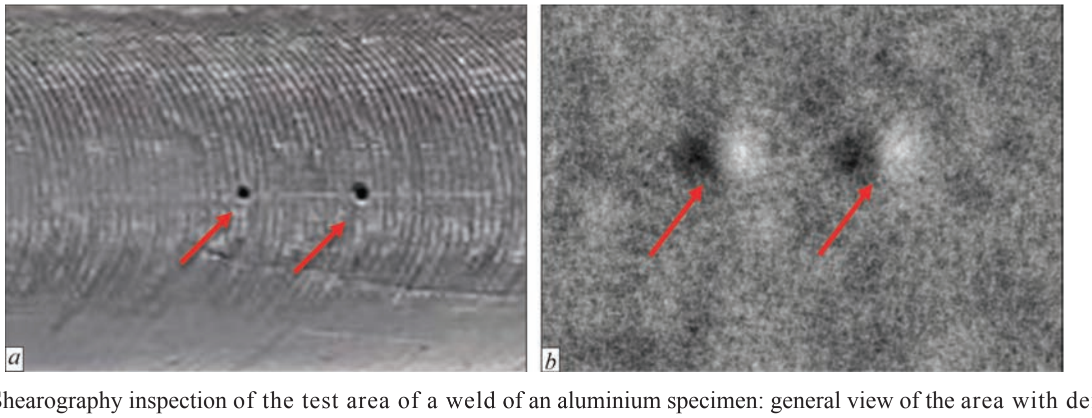

Figure 9. Shearography inspection of the test area of a weld of an aluminium specimen: general view of the area with defects (*a*) and typical pattern of detected defects with a diameter of $d = 0.3$ mm and a depth of $L = 1.8$ and 1.5 mm (*b*)

depth of $L = 0.1$ mm were drilled on the base metal of a welded specimen with a thickness of $h = 2.5$ mm (Figure 7, *a*). The results indicating the presence of defects in the studied area are shown in Figure 7, *b*. A local sharp change in the value and sign of the derivative characterises the presence of a defective zone. Since the shear is much larger than the size of the created blind holes, such defects are manifested against the background of uniform deformation as two separate areas in the direction and at a distance of the shear (dark and light).

Following the development of the shearography testing procedure, it was applied to inspect ultra-small artificial defects. The defects represented holes with a diameter of $d = 0.3$ mm and different drilling depths located in a weld made by friction stir welding. The results of testing defective areas are shown in Figures 8, 9.

The above shearograms clearly show local features that characterise the presence of embedded defects.

CONCLUSIONS

A procedure has been developed to detect ultra-small defects (<1.0 mm) located both in the areas of the base metal of aluminium welded joints and in the weld zone. This was achieved by using a shearography interferometer with a 10-fold optical magnification, selecting a shear that is larger than the sizes of a defect and automated dosed thermal loading. It has been experimentally confirmed that the proposed approach makes it possible to detect defects with a minimum size of 0.3 mm in diameter, which are located under the surface at a depth of 0.35–1.80 mm.

REFERENCES

1. (2001) *Non-destructive testing and technical diagnostics*. Ed. by Z.T. Nazarchuk. Lviv, PMI [in Ukrainian].
2. Rastorgi, P.K., Inaudi, D. (2000) *Trends in otical non-destructive testing and inspection*. Oxford, Elsevier Science B.V.
3. Nazarchuk, Z.T., Muravsky, L.I., Kuts, O.G. (2022) Nondestructive testing of thin composite structures for subsurface defects detection using dynamic laser speckles. *Research in Nondestructive Evaluation*, 33(**2**), 59–77. DOI: https://doi.org/10.1080/09349847.2022.2049407
4. Lai, W.L., Kou, S.C., Poon, C.S. et al. (2009) Characterization of flaws embedded in externally bonded CFRP on concrete beams by infrared thermography and shearography. *J. Nondestruct. Eval*., 28(**1**), 27–35. DOI: https://doi.org/10.1007/s10921-009-0044-x
5. Vandenrijt, J.F., Xiong, H., Lequesne, C. et al. (2019) Shearography inspection of monolithic CFRP composites: Finite element modeling approach for assessing an adequate strategy of artificial defects representing delamination. In: *Conf. Optical Measurement Systems for Industrial Inspection XI*, **11056**, 107–113. DOI: https://doi.org/10.1117/12.2527445
6. Menner, P., Gerhard, H., Busse, G. (2011) Lockin-interferometry: Principle and applications in NDE. *Strojniški Vestnik . J. of Mechanical Eng*., 57(**3**), 183–191. DOI: https://doi.org/10.5545/sv-jme.2010.169
7. Lobanov, L.M., Pivtorak, V.A., Savitsky, V.V. et al. (2005) Express control of quality and stressed state of welded structures using methods of electron shearography and speckle-interferometry. *The Paton Welding J*., **8**, 35–40.
8. Hung, Y.Y., Ho, H.P. (2005) Shearography: An optical measurement technique and applications. *Materials Sci. and Eng.: R:Reports*, 49(**3**), 61–87. DOI: https://doi.org/10.1016/j.mser.2005.04.001
9. Lobanov, L.M., Savytskyi, V.V., Kyianets, I.V.et al. (2021) Non-destructive testing of elements of titanium honeycomb panels by shearography method using vacuum load. *Tekh. Diahnost. ta Neruiniv. Kontrol*, **4**, 19–24 [in Ukrainian]. DOI: https://doi.org/10.37434/tdnk2021.04.02
10. Tao, N., Anisimov, A.G., Groves, R.M. (2024) Shearography with thermal loading for defect detection of small defects in CFRP composites. In: *Proc. of the 21st European Conf. on Composite Materials (ECCM21), 02–05 July 2024, Nantes, France*, Vol. 4: Experimental Techniques, 85–90.
11. Tao, N., Anisimov, A.G., Groves, R.M. (2022) Shearography non-destructive testing of thick GFRP laminates: Numerical and experimental study on defect detection with thermal loading. *Compos. Struct*., **282**, 115008. DOI: https://doi.org/10.1016/j.compstruct.2021.115008
12. Bin Liu, Shuo Wang, Mingming Zhan et al. (2022) Optical nondestructive evaluation for minor debonding defects and interfacial adhesive strength of solid propellant. *Measurement*, **194**, 111066. DOI: https://doi.org/10.1016/j.measurement.2022.111066

ORCID

L.M. Lobanov: 0000-0001-9296-2335,
O.P. Shutkevych: 0000-0001-5758-2396,
I.V. Kyyanets: 0000-0002-2559-8200,
I.L. Shkurat: 0009-0003-1888-4203,
K.V. Shyyan: 0000-0001-9198-6554,
V.V. Savitsky: 0000-0002-2615-1793

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

V.V. Savitsky
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.
E-mail: viktor.savitsky@nas.gov.ua

SUGGESTED CITATION

L.M. Lobanov, O.P. Shutkevych, I.V. Kyyanets, I.L. Shkurat, K.V. Shyyan, V.V. Savitsky (2025) Detection of internal ultra-small defects in aluminium welded joints by the shearography method. *The Paton Welding J*., **2**, 38–41.
DOI: https://doi.org/10.37434/tpwj2025.02.06

JOURNAL HOME PAGE

https://patonpublishinghouse.com/eng/journals/tpwj

Received: 14.10.2024
Received in revised form: 15.11.2024
Accepted: 31.03.2025