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MEASUREMENT METHOD OF CRACK LENGTH IN COMPACT TENSION TYPE SPECIMENS MADE FROM THE Al/Ti LAYERED MATERIAL

Key words

Fatigue crack, fracture mechanics, compact tension specimen CT, digital image correlation, optomechatronics, FatigueVIEW system.

Abstract

This study presents a measurement method of fatigue crack length for compact tension specimens (hereinafter called as CT) used for the determination of a material fracture toughness and for fatigue crack growth rate tests. For this purpose, FatigueVIEW consisting of two high-resolution video cameras, completed with a dedicated software, has been used. In order to detect a fatigue crack in a specimen of the CT type and to monitor its length, in the function of the number of load cycles, a method of digital image correlation has been used. The applied research-measurement system enables the operation control of the machine for fatigue tests in relation to the crack length, e.g., through stopping the cyclically variable loading after the specimen reaches the intended length.

Introduction

The development of the aviation and aerospace industry is closely connected with progress in the production of structural materials. Service conditions of aviation structures involve the necessity to use materials characterized by many specific qualities including those that meet high standards in terms of mechanical properties to be accompanied with a simultaneously small mass. An additional problem is, in many cases, a wide range of operating temperatures affecting the structures. For instance, for materials used for aircraft skin, the temperature can range from -200°C to +400°C.

An example of an innovative approach to the development of structural materials designed for operation in challenging conditions is the application of composite materials [6], including multi-layer ones consisting of different metal alloys [1] or metals and ceramics [7] with categoricallydifferent mechanical properties.

New types of materials require a verification of its mechanical properties including ballistic resistance, fracture toughness, as well as fatigue strength. Tests of the two latter properties involve using compact specimens of the CT type when it is necessary to determine the length of fatigue cracks.

Fracture toughness tests involve the generation of a fatigue crack with a special length defined by the requirements of respective norms [2, 3, 4]. In turn, tests of fatigue crack growth rate need to be provided with the possibility of relating the length of crack with the number of loading cycles.

There is a variety of methods for the measurement of the length of fatigue cracks. They have been discussed in many publications, including works [8, 10, 12, 13]. However, only few of them provide the possibility of monitoring the crack during fatigue that includes methods based on optical measurement techniques [11, 14].

However, optical measurement of a fatigue crack length of a multi-layer material is difficult due to the non-homogeneity of the material and the image of specimens is often different on the opposite sides of the specimens.

Therefore, the presented method uses separate measuring systems for each side of the specimen. The operation of this method has been demonstrated with the use of CT specimens prepared for tests of the layered material fracture toughness.

1. Research object

The research object was an explosion welded Al/Ti layered material whose base components were AA2419 aluminium and Ti6Al4V titanium alloy. An image of a fragment of a metal sheet that was used for specimens for tests is shown in Figure 1a. The direct connection zone of materials is of a complex structure due to the used welding method, which is shown in Figures 1b and 1c. Figures 1b and 1c show additional material, which is supposed to improve the quality of the weld.

For this purpose, aluminium alloy AA1050 was used. The basic mechanical properties and the chemical composition of the base materials are shown in Tables 1 (aluminium alloy) and 2 (titanium alloy).

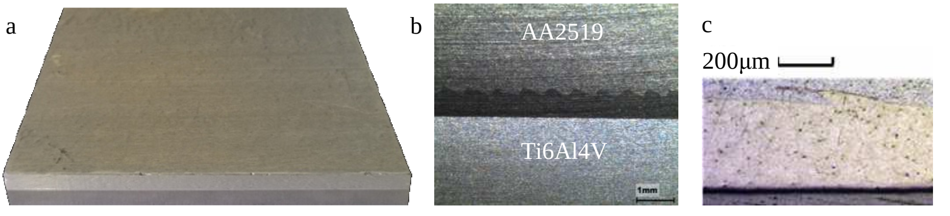

Fig. 1. Al/Ti layered material made by explosive welding: a) general view, b) microstructure, c) connection zone

Table 1. Selected mechanical properties and chemical composition of aluminium alloy AA2519 [9]

S_y	S_u	E	Hardness
MPa	MPa	GPa	HRC
460	485	73	23

Al	Fe	O	Ti	V	Cu
90	0.3	0.05	0.1	0.15	6.4

Table 2. Selected mechanical properties and chemical composition of titanium alloy Ti6Al4V after the high temperature treatment [9]

S_y	S_u	E	Hardness
MPa	MPa	GPa	HRC
950	1020	120	33

Ti	Fe	O	Al	V	Cu
90	0.25	0.2	6	4	0.05

The determination of the fracture toughness of the considered material was performed with the use of CT specimens. The dimensions of the specimens were consistent with the requirements of ASTM E 399 norm, although it needs to be noted that the ratio of metal sheet (B) thickness (10 mm) to characteristic dimension (W) was 0.25. Before specimens were cut out of the metal sheet, it was subjected to thermal treatment in order to obtain an optimal state of internal stress and an improvement in the aluminium alloy's mechanical properties. It should be noted that high temperatures had no effect on titanium at all.

Cutting out specimens from metal sheets was performed by means of wire electro discharge machining EDM. The application of brass wire with a diameter equal to 0.2 mm made it possible to provide the notch root curve radius with a value not higher than 0.12 mm. Minimization of the notch root radius was supposed to provide the fatigue crack propagation with appropriate, from the point of view of the tests, direction, that is, along the line of the minimum cross-section and parallel to the specimen edge.

The basic dimensions of specimens used for the tests are presented in Fig. 2.

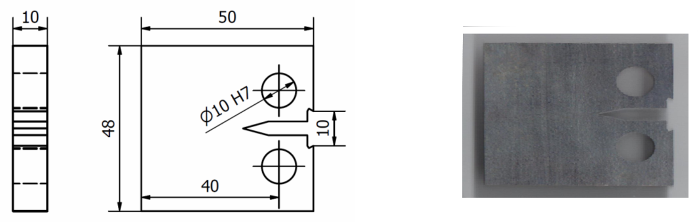

Fig. 2. CT specimen used in the tests

2. Research method

The generation of a fatigue crack in CT specimens was performed with the use of a hydraulic machine for fatigue tests, Instron 8501. The specimens were loaded with a force with a constant amplitude for the value of stress ratio R close to zero. In order to avoid 'loosening' of the specimen in the grips, the minimum force value was used which was not higher than 0.15 kN.

Two independent optical measurement tracks were used for the assessment of the crack. For this purpose, a FatigueVIEW system was adapted [5]. It was developed in the Institute of Maintenance Technology– National Research Institute in Radom in cooperation with the UTP University of Science and Technology in Bydgoszcz. In its basic configuration, the FatigueVIEW system makes it possible to observe the research object by means of two video cameras to observe the surface of the same fragment as developed for this purpose. Application of two video cameras is supposed to enable 3D analyses or increase accuracy of 2D analyses.

Hardware modification of the system involved an extension of the positioning system of one video camera that enables simultaneous observation of two sides of the specimen during a fatigue test. A modified FatigueVIEW system was integrated with a fatigue machine using special software, which enables an analysis of images of the specimen's surface, the control of the machine operation, and recording the tests results.

Measurement of the fatigue crack length is performed by an automatic analysis of displacement maps determined by the method of digital image correlation (DIC). Gradients of crack displacements in the direction of the force loading the specimen was used to make an analysis of the actual location of the crack tip.

A standard COD extensometer was used in the fatigue tests for the measurement of the fatigue crack opening. It was supposed to provide the possibility of a further analysis of the crack opening measurement results for the determination of the actual lengths of fatigue cracks.

A test stand with the tested specimen and extensometer is presented in Fig. 3.

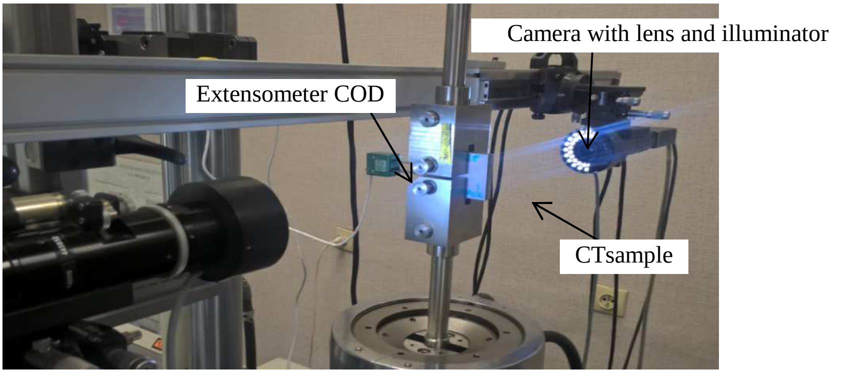

Fig. 3. Measurement stand

3. Crack detection

For tests whose aim was to generate a fatigue crack with a definite length in CT specimens, the research system operated in ‘detect’ mode. It involved indicating the location of a boundary line in the specimen’s initial image, which cannot be crossed by the crack. In Figure 4, it can be seen as a red vertical line. The system operator indicates the field of analysis in which the gradient of displacement is analysed and the actual position of the crack tip can be determined.

When the crack tip crosses the line, the software generates an announcement on the screen and stops the fatigue test.

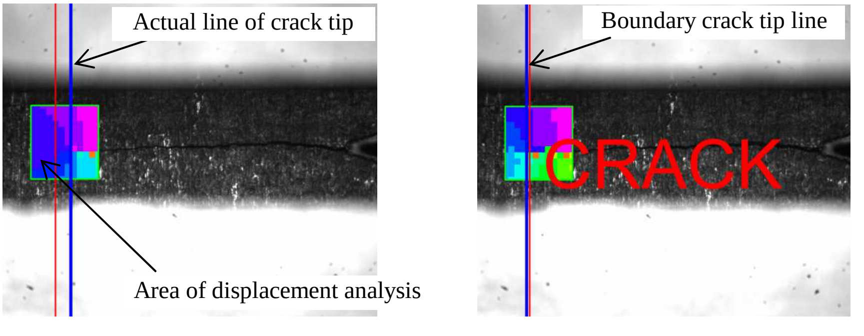

Fig. 4. Example images of the specimen in different stages of the test with a marked field of analysis and the positions of the actual crack and boundary line of the crack tip

Application of two separate measurement tracks enabled simultaneous analysis of the crack tip position on the side of aluminium alloy and the side of titanium alloy, which is shown in Figure 5.

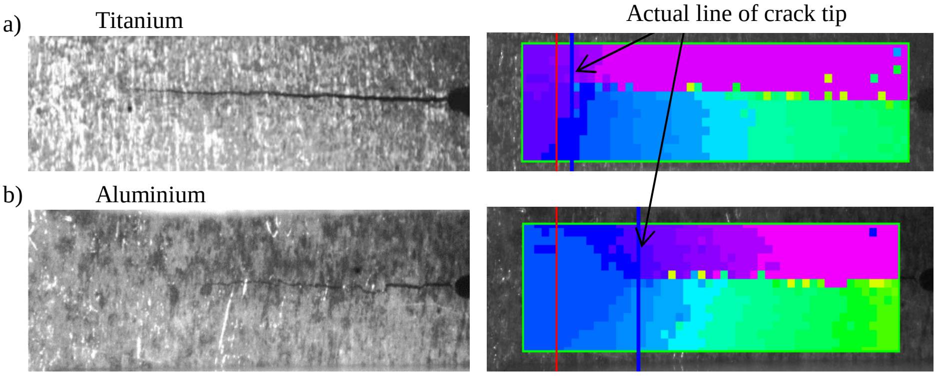

Fig. 5. Example images of the specimen with marked positions of the crack tip: a) on the titanium side, b) on the aluminium side

Application of the discussed method allows one to avoid situations when the crack length crosses the required length on one side of the specimen. The character and fatigue life to crack initiation for different base materials can result in crack lengths different on the side of titanium and the side of aluminium, which is depicted in Figure 6.

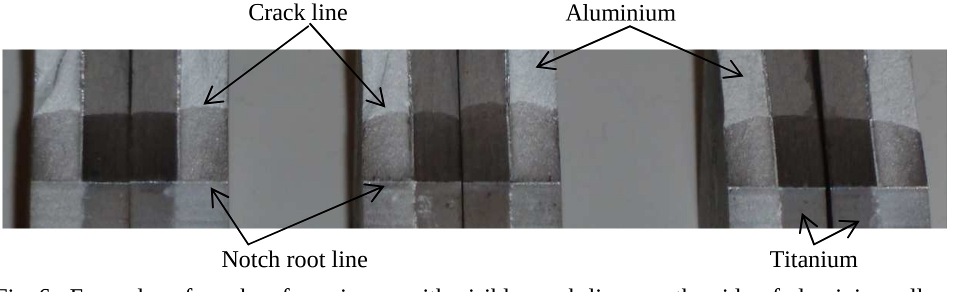

Fig. 6. Examples of cracks of specimens with visible crack lines on the side of aluminium alloy and titanium alloy

4. Measurement of crack length

Determination of the crack length as a function of the number of cycles can be performed in two modes: during a fatigue test and based on recorded images of the specimen surface after finishing the test. In both cases, the algorithm used for analysis of the images is the same as in the case of a crack detection.

Figure 7 presents changes in the crack length for a CT specimen on each side, i.e. for the aluminium alloy and titanium alloy. Additionally, in Figure 7, there are changes in the crack opening measured by the COD extensometer.

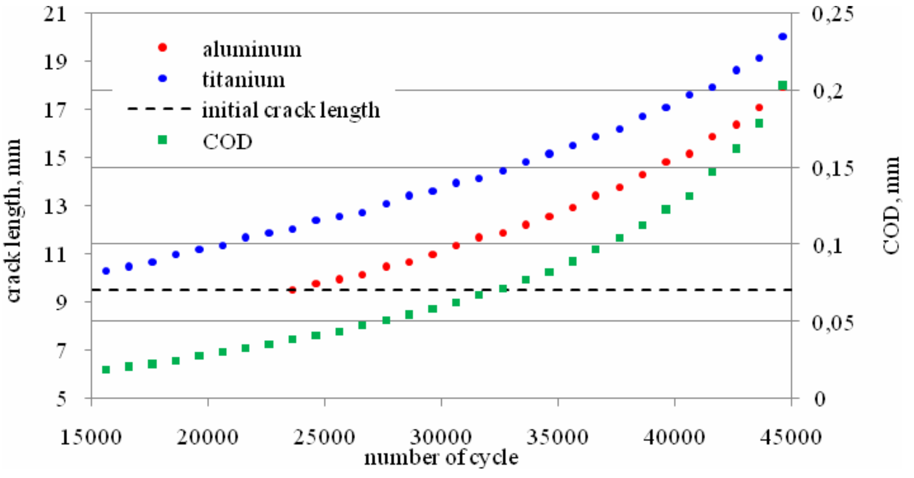

Fig.7. Changes in fatigue crack length as a function of the number of load cycles for titanium alloy and aluminium alloy

In Figure 7, the initial crack length is marked with a horizontal line, which is the distance from the centre of the hole in a CT specimen to the notch root where the crack is initiated.

A simple comparison of the changes in the crack lengths for the aluminium alloy and the titanium alloy allows one to indicate a different number of cycles needed to produce the specimen crack initiation in the notch root and different fatigue crack growth rates of its base materials.

The value of crack opening displacement can be used for crack length measurement by compliance method. Values of crack length determined with the use of described method will be a next step of analysis.

Conclusion

This work presents a method for an automatic analysis of fatigue crack lengths in specimens of the CT type used for tests of the fracture toughness and the fatigue crack growth rate of the Al/Ti layered material.

The developed method enables independent and simultaneous measurement and monitoring of the specimen crack length on both sides, i.e. for the aluminium alloy and for the titanium alloy.

The software which uses the developed measurement method allows one to control the operation of the fatigue testing machine, which enables, among other things, automatic stopping of the machine operation without the intervention of an operator.

Automatic control of the fatigue test allowed preparing specimens with very similar crack lengths. An analysis of the crack length on the fractures of CT specimens revealed that the expected crack length was 20 mm, and the standard deviation of the averaged length was 0.32 mm throughout their thickness.

Crack length measurement with the use of the optical method will be used for the calibration of the compliance method for crack length measurement in cryogenic conditions.

Acknowledgments

This work was supported by The National Centre for Research and Development of Poland under the grant No. PBS/A5/35/2013

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Metoda pomiaru długości pęknięcia w próbkach zwartych typu CT wykonanych z materiału warstwowego AL/TI

Słowa kluczowe

Pęknięcie zmęczeniowe, mechanika pękania, próbka zwarta CT, cyfrowa korelacja obrazu, optomechatronika, system FatigueVIEW.

Streszczenie

W artykule zaprezentowano metodę pomiaru długości pęknięcia zmęczeniowego w próbkach zwartych typu CT stosowanych do wyznaczania odporności materiału na pękanie i w badaniach prędkości pękania zmęczeniowego. Do tego celu użyto systemu FatigueVIEW ze zmodyfikowanym układem pozycjonowania dwóch kamer o wysokiej rozdzielczości, uzupełnionego dedykowanym oprogramowaniem. W celu detekcji pęknięcia zmęczeniowego w próbce typu CT oraz monitorowania jego długości w funkcji liczby cykli obciążenia zastosowano metodę cyfrowej korelacji obrazu. Zastosowany układ badawczo-pomiarowy umożliwia kontrolowanie pracy maszyny do badań zmęczeniowych w zależności od długości pęknięcia, np. poprzez zatrzymanie cyklicznie zmiennego obciążenia próbek po uzyskaniu przez pęknięcie założonej długości.