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BONDED JOINT MONITORING OF THE COMPOSITE AEROSPACE STRUCTURES WITH THE USE OF NDE AND SHM APPROACH

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1. INTRODUCTION

One of the modern trends in aerospace community is the approach to integrate the sensors with the structure to create the so called 'intelligent – smart' structures[1]. This approach is known as Structural Health Monitoring (SHM). The use of integrated sensors may allow for monitoring of selected components and also for data comparison and damage development description.

In the article, the problem of the bonded joint monitoring will be presented. Moreover, the tests will be conducted and data from NDT and SHM (based on piezoelectric sensors and elastic wave generation) will be presented for the composite aerospace structures such as CFRP.

2. RESULTS

Adhesive joints are commonly used in the manufacturing of aerospace components (the so-called bondlines). In particular cases, the bonding technique is supposed to be more efficient than regular (for metal structures) joints, such as bolts, rivets etc. Moreover, it allows for the integration of different materials (composite-to-metal, skin-to-honeycomb, etc.), as well as the performance of a possible future repair. However, such joints may collapse because of the presence of manufacturing faults, operating cyclic loads and impact damage. Depending on a particular bondline and a type of structure, the inspection of adhesive joints may be accompanied by some problems. At the maintenance stage, because of a specific stress distribution and operating loading cycles, critical areas may propagate from bondline edges [2]. Based on information about typical ultralight aircraft structures, a specimen modeling the wing of the small aircraft has been designed [3]. The specimen contains sandwich skin (CFRP with foam core). Under the skin, the stiffener, which is a model of the spar has been bonded. Changes in the stiffener shape were designed to evaluate the sensitivity of the NDE techniques. This structure is characterized by strong attenuation of acoustic (ultrasonic) signals. Tests carried out on similar structures have shown the effectiveness of the MIA method [4].

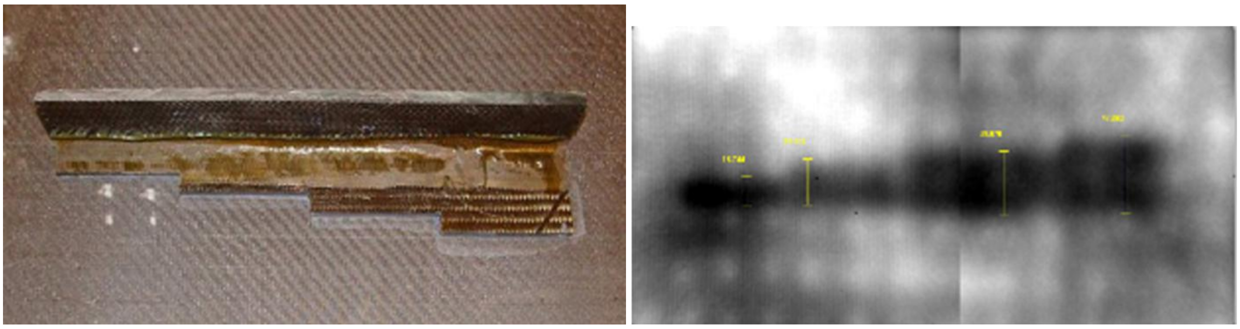


Fig. 1. Specimen of the wing skin (left) and thermography results (right)

The propagation of damage in the form of C-scan is illustrated in Fig. 2.

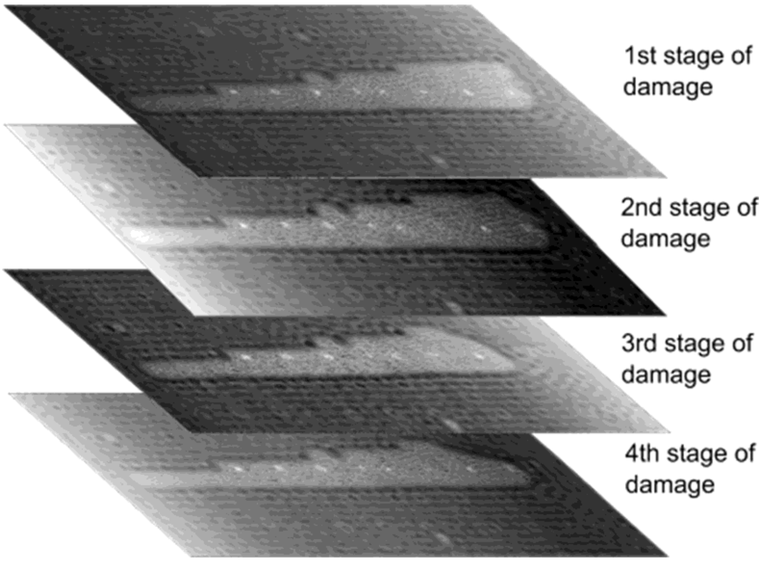


Fig. 2. Propagation of disbond

Figure 2 presents the results of the NDT tests. The damage growth was investigated with the use of the MIA method. However, some of the materials (especially wet ply stacking manufacturing) may be difficult for the inspection with the use of NDT. The signal attenuation and structure complication may be challenging for the NDT. Moreover, the inspection of large scale structures is time-consuming. For these reasons, the application of SHM may be interesting. The specimen presented in Figure 1 was instrumented with the piezo sensors array (shown in Figure 3) and analyzed with the acousto–ultrasonic approach [5].

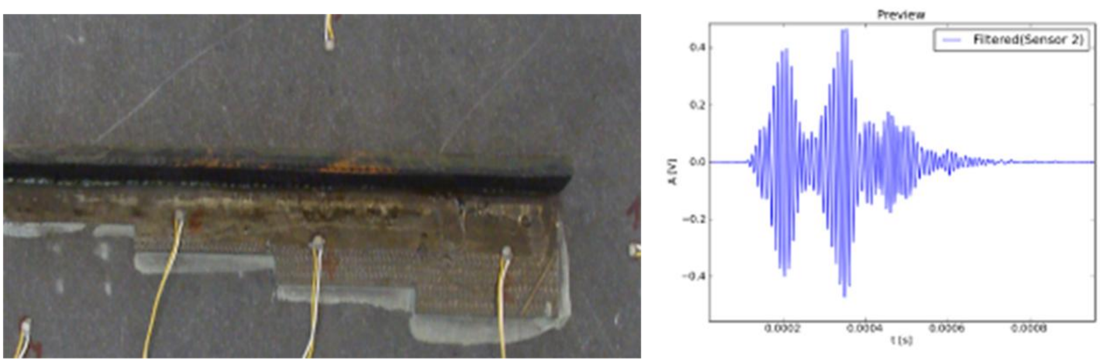


Fig. 3. PZT sensors layout and example of generated signals

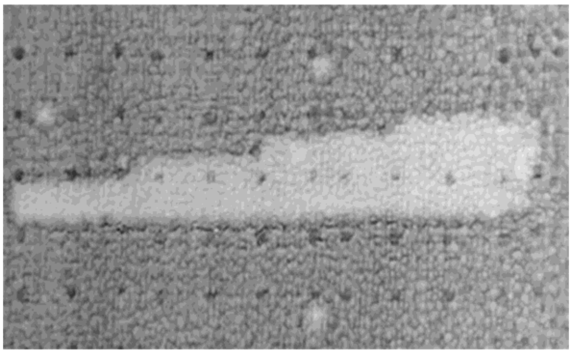
For such a layout of the sensors (Fig. 3), the disbond growth may be efficiently monitored. For the purpose of the damage growth monitoring the so called energy damage index was created. The measured signal (Fig. 3) is filtered with the use of the interactive filter (based on dedicated software created in AFIT). The algorithms are based on the FFT transform. For the purpose of further analysis the envelope of the signal is calculated in accordance with the following equation:

$$H[x(t)] = -\frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(r)}{t-r} dr \tag{1}$$

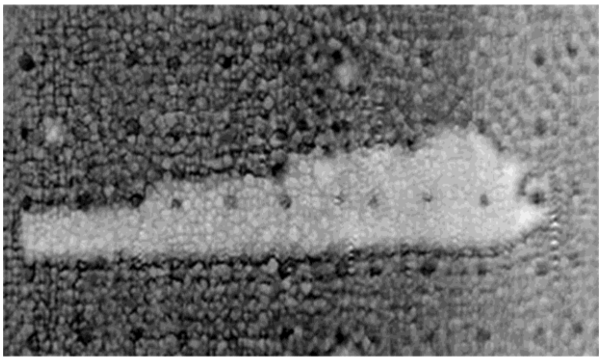
The use of the module of the signal calculated above may be used for the determination of the damage index called the "energy of the signal":

$$E_{Di} = \int_0^t \sqrt{x(t)^2 + H[x(t)]^2}\, dt \tag{2}$$

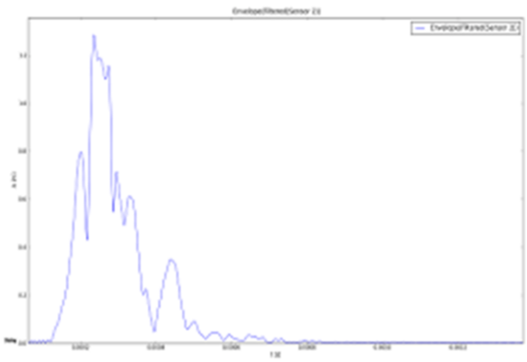
The graphical results of NDE with the use of MIA and time signals from the PZT sensors are delivered below.



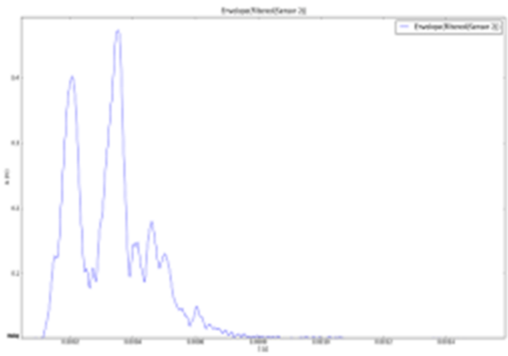
MIA result before the damage growth



MIA result after the damage growth



Envelope of the signal before the damage growth



Envelope of the signal after the damage growth

Fig. 4. Results of bond size monitoring with the use of NDE and SHM approach

The size of the bondline before the damage growth experiment was equal to 120 cm^2. At the last stage of the test the damage size was equal to 103 cm^2.

For the PZT sensors, the calculated ***signal energy*** was equal to 323,05 before the damage test and 52,78 at the last stage of the test. For the elastic waves generation, such reduction in the signal energy was connected with the location of the sensor over the disbonded area.

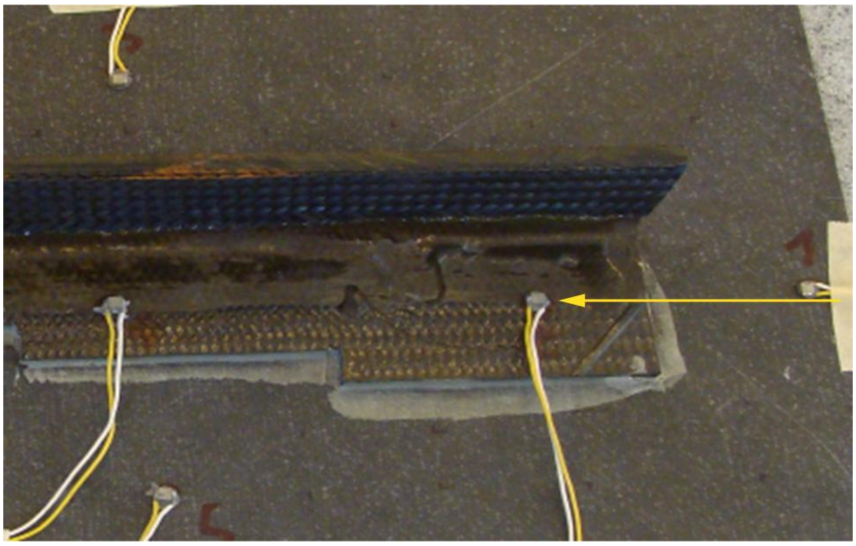


Fig. 5. Pathway of data collection (sensor 1->2)

Figure 5 presents the sensor layout. The area of monitoring uses the signal propagation pathway between the sensor 1 and 2 and data only from that pair of the sensors are delivered. The results of the collected signals are presented in Figure 6.

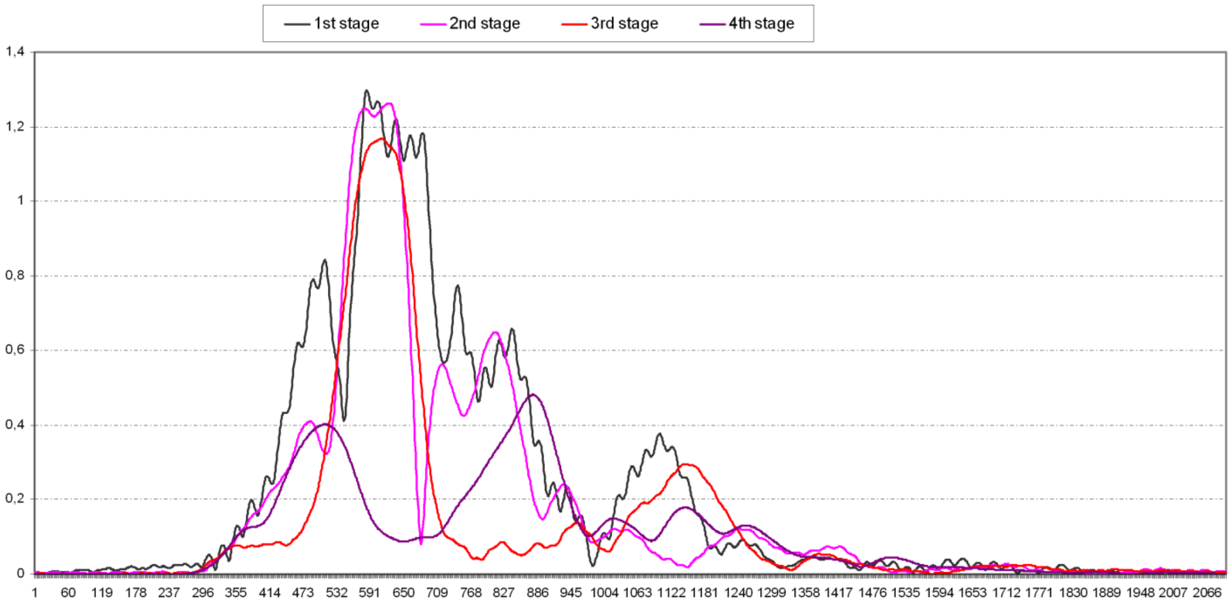


Fig. 6. Results of bond size monitoring with the use of PZT sensors

Figure 6 presents the results of the signals collected during the experiment. The amplitude 'shape' of the signals as well as the envelope are different, which is connected with the reduced amount of energy delivered to the sensor from the actuator. Most of the signal is reflected and dissipated in the disbond area. The similar results for the pathway 2->1 was observed. Further disbond propagation may be observed with the use of the consecutive pairs of the sensors. Additionally, the use of more that 2 pathways for analysis may enable more detailed location of the disband edge (by means of "triangulation").

Damage presence and damage development may be determined with the use of Damage Index description. Based on the experience gained during the research project O N504 418637, the following formula for the Damage Index was used [6,7]:

$$DI = 1 - \int_{u_0}^{u_1} Wf_t(u, s_o)\, du \Big/ \int_{u_0}^{u_1} Wf_b(u, s_o)\, du \qquad (3)$$

Where: $Wf_t(u,s_0)du$ – energy of the signal from the damage;
$Wf_b(u,s_0)du$ – energy of the signal from the so called baseline.

If there is a non damage condition, the index is equal to 0. If the damage develops, the Damage Index is equal to a value higher than 0 but never reaches a value greater than 1.

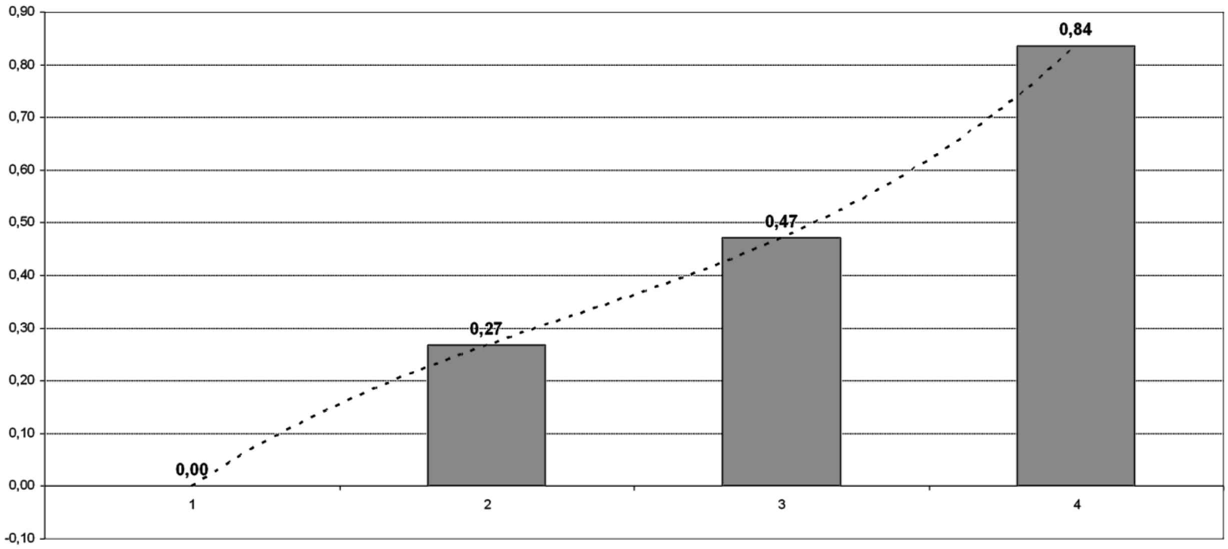


Fig. 7 Results of the damage index development for the experiment

Figure 7 presents the values of the Damage Index Development during the experiment. At each stage of the experiment, the growth of the index was observed. In the last case, the damage was nearly close to 1, which means the damage was located on the edge of the sensor 2.

At present, further work focused on the determination of the signals from the other sensors is being conducted.

3. CONCLUSIONS:

The paper presents an approach to structural integrity monitoring of composite structures for the disbond development monitoring with the use of NDT and SHM. As the example of the structure, the approach to the bondline monitoring in the small aircraft was presented. Durability of such structures is highly dependent on the quality of the bond manufacturing. In the article, the proposal of monitoring of the bondline which may suffer from the impact damage and cyclic loads was shown.

For that purpose, the PZT sensor layout as well as signal analysis techniques were elaborated. The results of the experiment were compared with the NDE and data analysis based on image processing. The correlation of the NDE results and SHM investigation was obtained. The purpose of further work is to deliver the large scale component and to perform impact and fatigue tests. Moreover, more extensive data analysis techniques will be developed, which will take into consideration self diagnostics techniques, signal normalization, effects of the wave reflection and scattering from the crack tip in the bondline.

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