

IDENTIFICATION OF IMPACT LOCATION AND FORCE ON UNIDIRECTIONAL CARBON/EPOXY COMPOSITE PLATE

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Introduction

Structures are exposed to number of loading states, events and influences of the environment during their lifetime cycle, which could degrade their capabilities for carrying their functions or damage them completely. One of such dangerous events is low-velocity impact on structure. Modern structures often include parts made of composite materials, which might be easily damaged by impact events. Impact on composite structures often causes damage which cannot be easily identified (e.g. laminates with failed inner layers or tiny long continuous crack between fibers etc). Therefore, it would be useful to perform a monitoring process, which will be able to recognize the impact event and evaluate the level of damage of the structure. The monitoring process of this kind performed for the composite structures should include the identification of impact location, identification of impact energy or impact force and failure analysis or failure identification with prediction of residual stiffness of the structure.

Presented work deals with the first two parts of the proposed monitoring process. It focuses on the identification of impact location and force on unidirectional carbon/epoxy composite plate and describes alternative methodology for identification of impact location and force to methodologies proposed e.g. in [1, 3]. Combination of optimization method and finite element (FE) analysis is used for the identification process. FE analysis is validated by experiment.

Experiments and virtual experiments

Experimental setup with drop test apparatus are shown in Fig. 1 (for details see [2]). Experiments were performed only for the validation of the FE model. It was performed with the use of unidirectional carbon/epoxy composite plate and glass sphere as an impactor. Subsequently, so-called virtual experiments were performed. Virtual experiments were dynamic contact analyses of impact events of steel bullet shape impactor or glass sphere on the composite plate. Advantage of the virtual experiments was the possibility of the calculation of the contact force

between the plate and impactor. Once they are known, they can be compared to the identified loading forces.

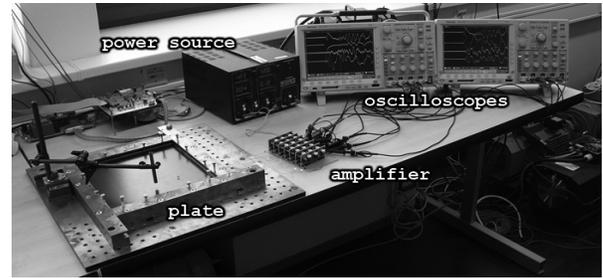


Fig. 1: Experimental setup.

Two distributions (rectangular and random) of the strain gauges were used. Strain gauge means node in virtual experiments, where the strain rate in the direction perpendicular to the fiber direction was measured. Dimensions of the plate with positions of two used distributions of the strain gauges are shown in Fig. 2.

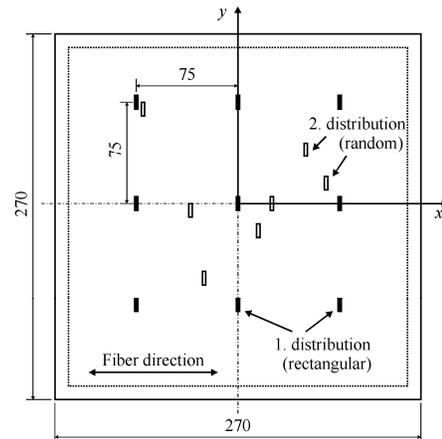


Fig. 2: Strain gauges distributions, dimensions of the plate and fiber direction.

Identification processes

Firstly, sum of square of differences of wave arrival times to positions of strain gauges is used as the objective function to be minimized within the identification of the impact location. Three parameters are identified, namely x

and y coordinates of the impact point and the time Δt (time-shift) when the impactor impacts the plate. Two loading forces (Fig. 3) were used with the combination of each of the strain gauges distributions within the identification process.

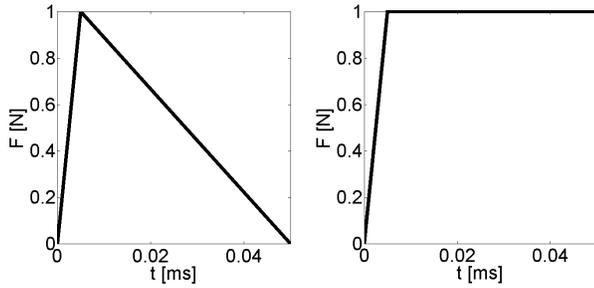


Fig. 3: Loading forces used for the impact location identification (left – triangle, right – “ramp”).

Afterwards, the identification of the impact force was performed. The impact force $F(t)$ is considered as two-parametric function with linear entering edge. Function is shaped by parameter F_0 , which characterizes amplitude and t_0 , which means time, when the force will decrease below $F_\epsilon = 10^{-16}$ N. The function is defined as

$$F(t) = \frac{F_0}{dt} t \quad \text{for } t \in \langle 0, dt \rangle, \quad (1)$$

$$F(t) = F_0 [1 - \tanh(T_F(t - dt))] \quad \text{for } t \in \langle dt, \infty \rangle,$$

where $T_F = \text{atanh}((1 - F_\epsilon)/t_0)$. Sum of squared differences of the signals is used as the objective function for the identification of the impact force.

Results

Surface of the residuals for identification of the impact location of the glass sphere with velocity $v = 0.5 \text{ ms}^{-1}$ on position $[x, y] = [50, 50]$ mm is shown in the Fig. 4. Fig. 5 shows identified force and one of the corresponding time dependencies of the strain rate for the mentioned impact event.

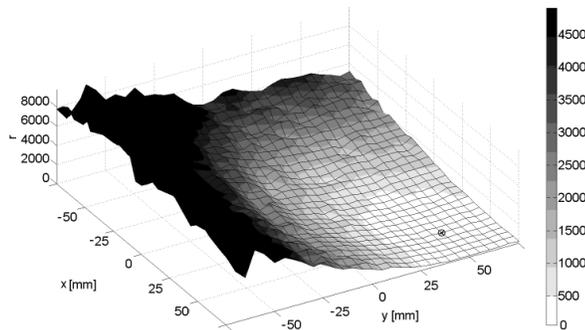


Fig. 4: Residual surface.

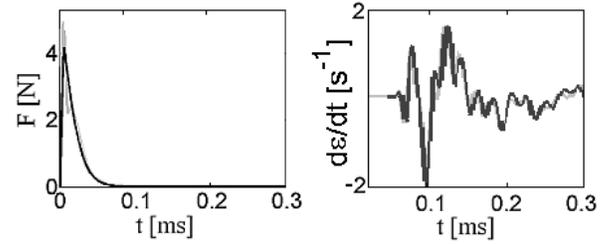


Fig. 5 Identified force (left) and corresponding time dependence of strain rate (right) from the sensor in position $[x, y] = [75, 75]$ mm, grey – virtual experiment, black – identification.

Maximal error in impact location identification was 3 edge lengths of FE model (15 mm). Nevertheless, four identification processes were performed (combinations of two loading forces and two distributions of the strain gauges) and 3 out of 4 processes found the exact impact location. Time-shift was not identified precisely for all of the impact events. Maximal difference of the identified time-shift from the time-shift of the virtual experiment was 5 time steps in FE analysis (e.g. $\Delta t = 25 \cdot 10^{-6}$ s).

Conclusion

The paper describes methodology, which combines finite element analysis and optimization algorithms for identification of impact location and force. It is successfully tested on impact events of steel bullet shape impactor and glass sphere, for number of impact velocities and locations and for two distributions of strain gauges. Impact location is identified with the use of two different loading functions. Subsequently the loading force is identified by proposed two-parametric function. In both cases, the agreement is very promising considering future identifications with the use of real experimental data.

Acknowledgement

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References

1. Advancements and Challenges for Implementation: Structural Health Monitoring 2005. Edited by Fu-Kuo Chang, DEStech Publications Inc., (2005).
2. Kroupa, T., Zemčík, R., Klepáček, J., Damage prediction of composite plate for structural health monitoring, 19th ICAST, Ascona, (2008).
3. Proceedings of the Third European Workshop: Structural Health Monitoring 2006. Edited by Alfredo Guemes, DEStech Publ. Inc., (2006).