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Experimental and Numerical Modal Analysis of the Glass Composite Plate Damaged by Cut

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Abstract. The given paper is closely connected with the experimental and numerical modal analysis of the glass composite plate damaged by cut. In relation to the tested glass composite, modal analysis was performed by help of special measuring device Pulse 12. The mentioned device was supplied by company Brüel&Kjearand the experimental measurements were carried out using damaged and undamaged plate sample which were prepared from the mentioned material hereinbefore. The investigated and analyzed plates of glass composite were made of six layers of glassfibres and they were arranged under the angle 90º (it is like fabric material made off glassfibres). The layers arranged in the given way were joined by epoxide resin MGS 285. The experimental measurement of natural frequencies of glass composite plates was carried out using the undamaged and damaged sample with proportions 78 mm x 78 mm while ten measurements were performed for each one specified site of the sample. In relation to the damaged plate sample, there wascut length 20 mm in the centre border. The finite element method in the software system ADINA v.8.6.2 was used for numerical analysis of the natural frequencies.

1 Introduction

The motivation to perform a modal analysis of the glass composite plate was to determine the natural frequencies of the plate. Glass composite board is used in the automotive industry. The task of the analysis was to exclude resonant states during the movement of the car.

The motivation was also to find a new way to diagnose composite board damage by experimental and numerical modal analysis.

The experimental modal analysis belongs to Dynamics that is the special scientific field where so-called modal parameters of the object (e.g. natural frequencies, mode shapes of the vibrations, absorption or damping parameters) are investigated. These mentioned parameters can be obtained in an analytical way by help of finite element analysis (FEM) or they can be determined on the basis of the experimental analysis. The experimental analysis is connected with verification or completing of those results which were acquired on the basis of the analytical method. The given analysis is based on the principle which involves the usage of the process where the complex vibration process is divided into the simple modal constituent vibrations or parts. Each one of these constituent parts can be

characterized by its natural frequency or natural frequency as well as it has its mode shape of the vibration [1], [2].The sixties of last century can be understood as the beginning of the modern era of the experimental modal analysis (EMA) because of the introduction of Fourier transformation and development and progress relating to the computer technologies. Nowadays, experimental modal analysis (EMA) represents the scientific field which stands for some connecting point between signal adjustment and computational technology, theory of mechanics, vibrations, acoustics and signals processing [3], [4].
EMA can be also used for verification of the mathematical models and nowadays, it can help us to solve various technical problems including [5]:

- the determination of natural frequencies for any objects because if the excitation frequencies correspond to natural frequencies, it can lead to excessive vibrations of the construction (resonance) and it means the decrease of lifetime and reliability,
- the determination of the own or natural shapes of the vibration and control them by exciting actions of the system with the aim to find the critical site of the construction where the vibration is the highest,
- the verification of the authenticity relating to the mathematical models which were made by help of finite element methods and moreover, the change of models parameters can be done by help of experiments and measurements in order to obtain the mutual accordance (modal tuning),
- the modification and the change of construction geometry with the aim to eliminate the intervals or zones of in-service exciting actions (structural modification).

2 Experimental measurement of the natural frequencies

The experimental measurements were performed by help of special device PULSE 12from company Brüel&Kjear. The samples obtained from carbon composite material were used for measurement process. The mentioned composites were made of six layers of glass fibres and they were arranged under the angle 90° (it is like fabric material composed of glass fibres). Then, the layers arranged in the given way were joined by epoxide resin MGS 285.The experimental measurement of natural frequencies for glass composite was carried out using the undamaged and damaged samples with proportions 78 mm x 78 mm. In relation to the damaged plate sample, there wascut length 20 mm in the centre border.The samples were held around the whole circumference in special fixture and moreover, they were between two plates which were fastened by four screws. The testing equipment for experimental measurement can be seen in Fig. 1. For each one site, the frequencies obtained on the basis of ten hammer impacts were recorded and they were subsequently averaged, evaluated and displayed in the graphical way by Pulse system in graphs of the frequency response and coherency. The software which is supplied together with the measurement device is used for settings, controlling, and collection of obtained measurement data. The given software contains everything which is needed for measurement. The measurement process as well as setting of the required conditions is done by help of organizers and the user can make settings of software according to own requirements. The given settings can be saved and used as some pattern again during any other measurement. As can be seen in Fig. 1, the position of the accelerometer for the undamaged sample was in the centre and hammer impacts were performed for four sites – in the corners of the sample. The obtained natural frequencies for both types of samples are shown in Table 1.

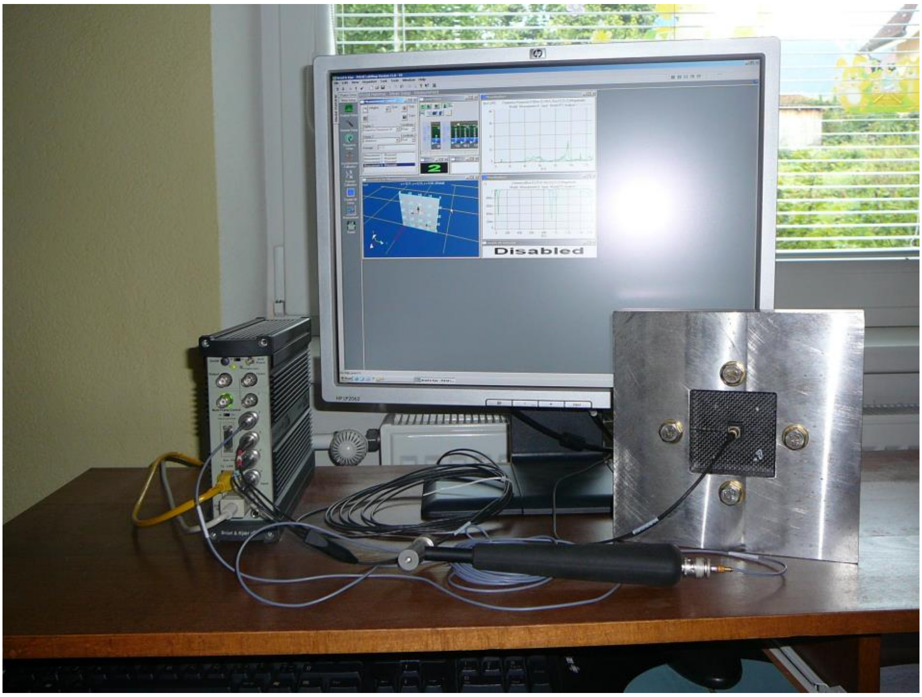

Fig. 1. Testing equipment for experimental measurements.

Table 1. Obtained values of natural frequencies for damaged and undamaged sample of the glasscomposite.

Obtained values of natural frequencies (Hz)		
Number of frequency	Undamaged sample	Damaged sample
1	3 795.71	3 772.18
2	6 111.82	5 712.64
3	8 459.74	7 779.64
4	9 284.23	8 773.23
5	11 062.70	10 397.00

3 Numerical analysis of the natural frequencies

The specific method, called “Subspace iteration“ method was used for calculation of natural frequencies in the ADINA 2.8.6program system. The material constant parameters were used for epoxide matrix L285 as well as for glass fibres and these constant parameters, shown in Table 2, were specified by the producer.

Table 2. Material constant parameters which were used for computational model.

Material constant parameter	Epoxide matrix L 285	Glass fibre
Young's modulus E [GPa]	3.45	73
Poisson's number μ	0.3	0.22
Density ρ [kg/m^3]	1200	2600

Numerical analysis was solved for two computational models:

- for undamaged sample with the proportions 78 mm x 78 mm and it was reinforced with six layers of glass fibres while the fibres were arranged under angle 90°-°-computational model was created by help of composite 8-node shell elements, while the number of elements was 17 600,
- for damaged sample the cut in the centre border of the sample the length was with 20 mm.

The computational model of the undamaged composite as well as its first five shapes of natural frequencies can be seen in the Table 3.The computational model of the damaged composite sample with the circular cut-out in the centre as well as its first five shapes of natural frequencies can be seen in the Table4. The given own or natural shapes represent the dynamic behaviour of the model or possible movement of the system vibrations and they are ordered from the lowest frequency to the highest one. In relation to the individual models, the own or natural shapes of the natural frequencies depend on the way of removal of the degrees of freedom and they also depend on size and shape of the defect as well as the location or site of the defect on the model. The first one shape represents the lowest frequency and the fifth shape represents the highest frequency. The calculated results of natural frequencies for the damaged and undamaged samples are introduced in Table5.

Table 3. Computational model of the glass composite undamaged sample and natural frequencies of its first five shapes.

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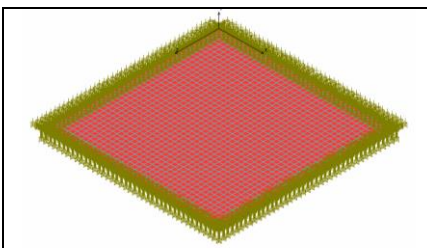
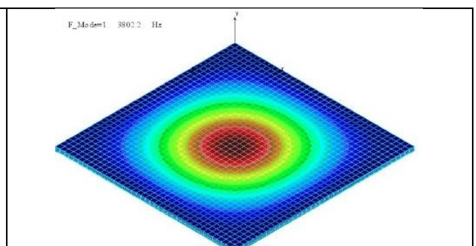
<tr><td></td><td>
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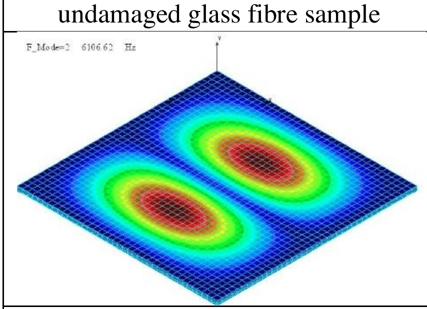
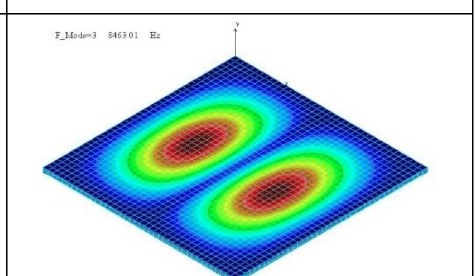
<tr><td>
</td><td>
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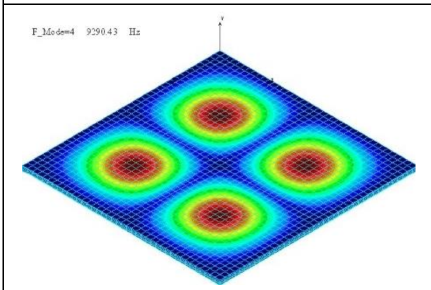
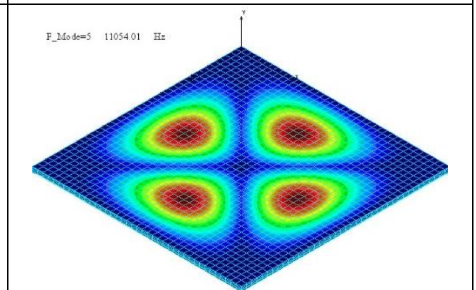
	
The fourth shape of the natural frequency	The fifth shape of the natural frequency

Table 4. Computational model of the glass composite damaged sample and natural frequencies of its first five shapes

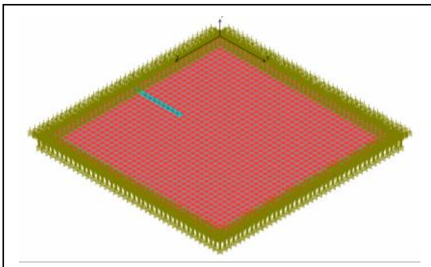
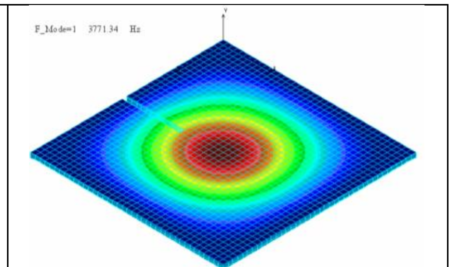
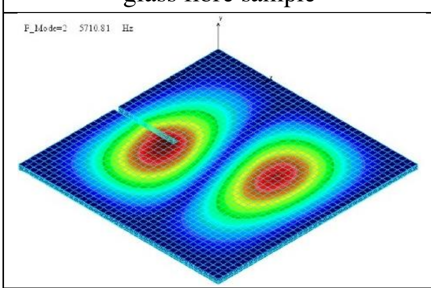
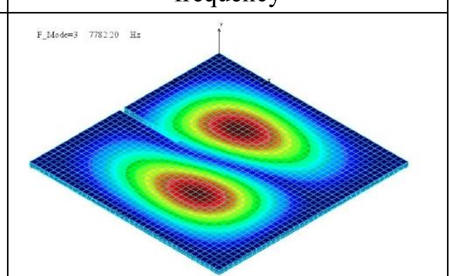
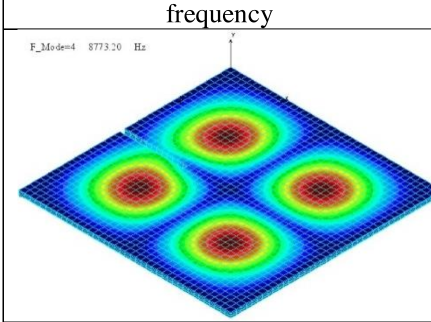
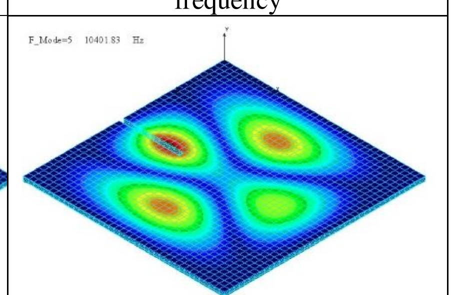
	
Computational model of the damaged glass fibre sample	The first shape of the natural frequency
	
The second shape of the natural frequency	The third shape of the natural frequency
	
The fourth shape of the natural frequency	The fifth shape of the natural frequency

Table 5. Calculation of the natural frequencies for damaged and undamaged sample.

Calculation values of natural frequencies (Hz)		
Number of frequency	Undamaged sample	Damaged sample
1	3802.202	3771.344
2	6106.620	5710.810
3	8463.012	7782.201
4	9290.430	8773.205
5	11054.01	10401.83

Table 6. Percentage deviations measured and calculated frequencies.

Percentage deviations (%)		
Number of frequency	Undamaged sample	Damaged sample
1	-0.17	0.022
2	0.085	0.03
3	-0.038	-0.032
4	-0.066	0
5	0.078	-0.046

4 Conclusion

As mentioned above, ten measurements were performed for the each one tested site of the sample. Table 1. shows the average value resulting from all ten measurements which were performed for four specified sites of the sample. According to the obtained results based on measurement, it can be concluded that the natural frequencies of the damaged sample are less than the natural frequencies of the undamaged sample. The same results were obtained in the case of the numerical analysis which was based on the finite element method and it is shown in Table 5.The measurement range of the natural frequencies was given up to 14 000 Hz. According to results which were obtained on the basis of measurement of natural frequencies Table 1. and results which were obtained on the basis of the calculation of the natural frequencies Table 5., it can be assessed that increase of the natural frequency leads to the higher value of the shift in relation to the comparison of the damaged and undamaged sample – the difference of the natural frequencies is noticeable.The percentage deviations between the measured and calculated frequencies can be seen in Table 6. We can state that the difference between the experiment and the numerical solution is minimal and the experiment confirmed the accuracy of the results of the numerical solution.

Acknowledgments

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