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Acoustic measurements to proof high-strength structures and joints

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Abstract. Due to increased product requirements, usual conditions for materials cannot be applied anymore. To reduce energy consumption, lightweight constructions are demanded but they cannot stand necessary mechanical stress. Therefore, local reinforced elements are applied for instance. According to actual research in material sciences, it is prerequisite to verify the position of this strengthening. Various physical principles can be used for non-destructive testing of this effect. In this article, an approach based on acoustic signals is presented. On the one hand a strategy could be to do comparative studies between nominal and sample and on the other to predetermine the place just by acoustic parameters like eigenmodes. In preliminary test, vibration characteristics of these innovative materials (e.g. bake-hardening plate and sandwich structure) are determined and reveal capabilities for acoustic methodologies. So, this approach could be a promising tool to localize reinforced elements.

Introduction

The development of structures and components with local variation of properties is necessary because of increasing product requirements. The creation of such components is done by either material transformation (i.e. structural change) or combining common materials in an innovative way (i.e. composite structures).

If the changed parameters optimize the mechanical properties of such structures, the acoustic transfer behavior is significantly influenced in many cases. Thus promising proposals to ensure proofs of property adaption within such structures can be made due to acoustic measurement techniques. Owing to this, the acoustic emission on the one hand and the vibration behavior on the other are of special interest. Therefore, the considered structures and components are examined systematically due to their effects on the acoustic transfer behavior.

The goal is to develop a method, which can detect property variations in a component with acoustic measurements and localize them.

Theoretical Aspects

To inspect novel material bonding for structures with local variation of properties, appropriate test procedures are needed in manufacturing.

Of particular importance are non-destructive methods, they can detect amongst others failures in the adhesive layer of sandwich components. If a basic calibration block is available, then comparative studies with samples are possible to determine their quality. The non-destructive methods can be distinguished by their physical principles [1], i.e. acoustic, electric, thermal and on radiation based methods. The outcome of this is a variety of techniques to detect material defects [2,3].

Because of the connection between strength and acoustic transfer behavior of material bonding, acoustic detection methods are very powerful. With this some exemplary questions can be answered like how the structure oscillates or how the oscillation pattern of a surface radiates sound respectively [4,5]. Answers depend on shape and material properties of the object. They can be determined by numerical simulation or experiments (see relevant paragraphs). An overview about state of the art research about vibration of structures especially plates can be found in the paper of Hambric [6]. Furthermore, the papers of Maysenhölder describe findings of acoustic insulations of sandwich components on the one side and acoustic properties of aluminum foam on the other [7,8].

Other acoustic approaches beyond the previous named methods are the statistical energy analysis (SEA) [9] and the structure intensity [10]. Which one of these acoustic methods is the best for the analysis this will be part of the future research.

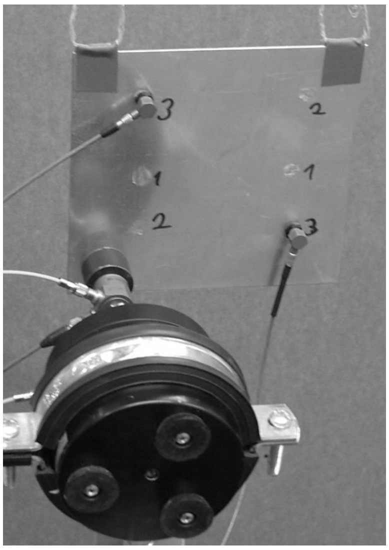

Fig 1: Experimental set-up for the examination of bake-hardening sheets using conventional measuring technique

Experimental Research. The structures dealt with in this article are on the one hand sheet metals, which are locally modified using the bake hardening effect [11], as well as tailored sandwich composites with circular stiffeners [12]. The composite consists of two steel liners with a core of polyolefin film. To increase the strength cylindrical wholes are cut into the core and cylindrical steel plates are put in instead.

The measurements were done with conventional shear accelerometers and a so-called Laser-Doppler-Vibrometer (LDV). A LDV works with a laser which is brought into focus on the test-bodies surface and then the beam is scattered back. If the detected surface is moving, a frequency shift occurs because of the Doppler-effect between the send-out and the reflected beam. The frequency shift is proportional to the surface velocity. Moreover, a LDV can be equipped with a scanning unit to measure various points on a surface without moving the whole apparatus. The specific advantage of this method is, that the specimen is measured contactless, which means without any influence. The scanning unit is combined with a digital camera is an image measuring device which delivers fast impressions of the operational vibrations.

During the extensive measurements it became apparent, that the biggest advantage of the laser vibrometry is the impact-free sensing. Especially fine plate structures are influenced by conventional acceleration pickup. Furthermore, with a sampling rate of 2.5 MHz a much higher temporal resolution can be reached and for instance an examination in the ultrasonic range is possible. Also, observation of the wave propagation after an impact excitation could be used to determine vibration characteristics. Besides, an optional number of measurement points can achieve a high local resolution. Furthermore, it is very easy and quick to define the measurement points through the video screen.

The examination of the bake hardening plates was done via conventional measurement technology. Four plates of 120x120 mm² were stimulated by an electro-dynamic vibration exciter with a chirp-signal. At several positions, the oscillations are measured with piezo-electric accelerometers. In addition, the excitation impedance was detected by an appropriate detector head (Fig. 1).

In Fig. 3, it can be seen that the level of acceleration for the hardened plate is lower for several frequencies than the one of the not-hardened plates. Therefore, a better material damping can be assumed. Beyond that a slight frequency shift of the maxima in the middle frequency range of 3500 Hz...6500 Hz is taking place.

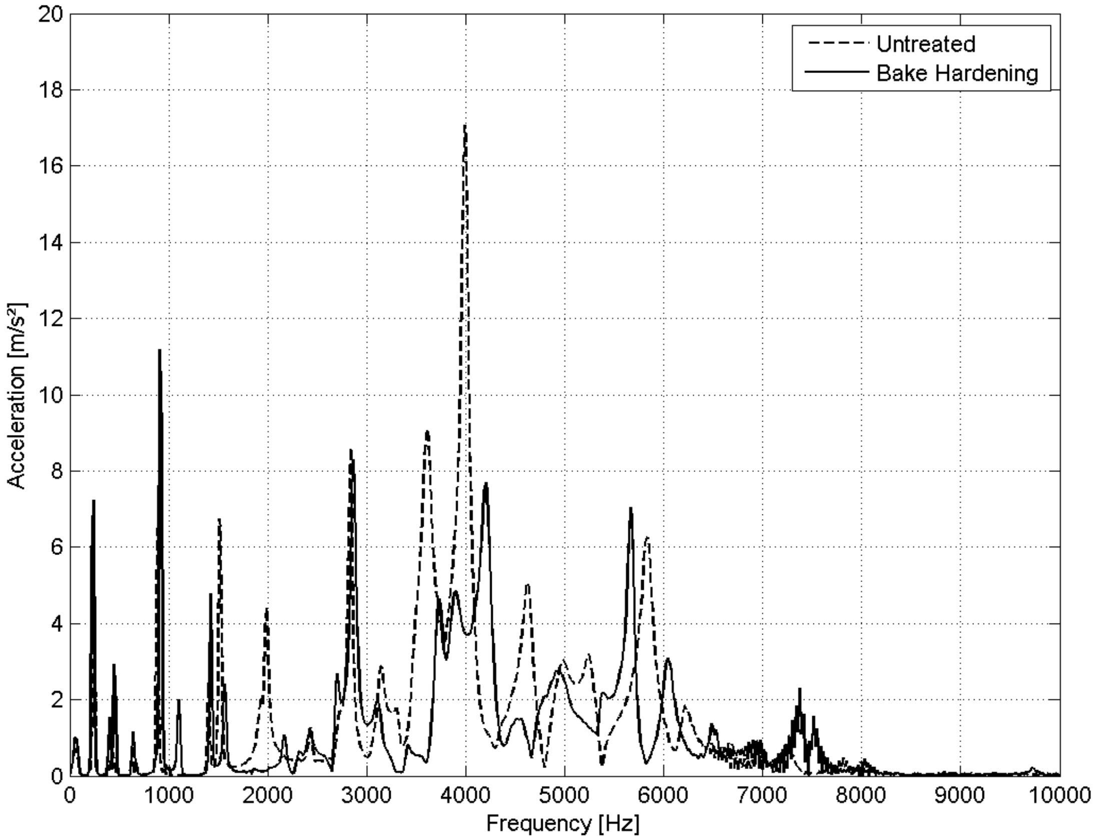

Fig. 2: Comparison between the acceleration spectra of an untreated DP800 sheet metal and a bake-hardened one

The composite plates were also animated by an electro-dynamic shaker, however, an impulsive signal was used and the following decay process was observed. To meet the requirements of an ideal Dirac-impulse and the mechanical limits of the shaker, a Ricker-wavelet was used for excitation. These measurements were carried out with the scanning LDV. At quasi-statically excitation the spread of the excitation can be noticed. Furthermore, this information can be used in software for experimental modal analysis (EMA).

In Fig. 4, the measurement grid for the transient and modal analysis is shown. There are 287 measurement points, which are circular oriented around the excitation point, which is in the middle of the plate. The measurement points are scanned synchronic to the excitation signal, so that after a short time the decay process or the mode of vibration can be shown.

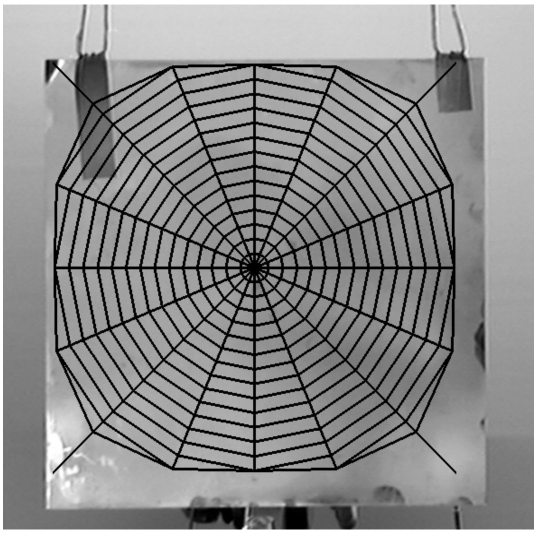

Fig. 3: The virtual grid where the velocities are measured by the LDV

Snapshots from the decay process of two sandwich structures with and without local reinforcement are shown in Fig. 4. It is evident that on the right hand side the deflection patterns are distributed symmetrically due to the nodal points around the local reinforcement element. The oscillation of the common composite structure on the left hand side moves around the whole plate.

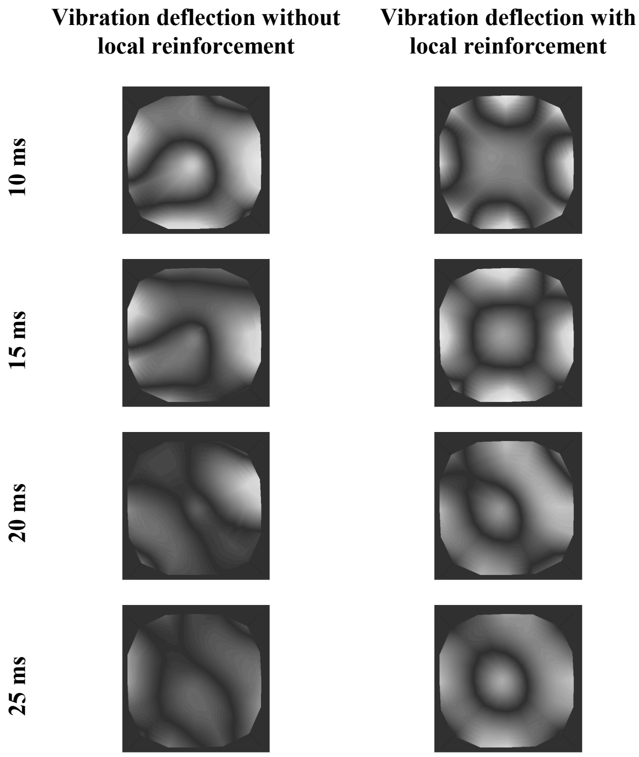

Fig. 4: Vibration deflections at different times of the decay process

Numerical Analysis. Analyzing numerically the dynamic behavior of the sandwich panels, FE-Models were created. Due to the need to model the stiffeness within the structure, a solid-model was used. The stiffening was introduced by changing material behavior locally. A contact between the stiffening and the surrounding sandwich area was neglected. A linear elastic material was defined for each of the sandwich components. Performing a modal-analysis, no external loads and no fixation were introduced to the model. Both the eigenfrequencies and the mode-shapes were analyzed with this model.

Comparison between numerical and experimental results. With the EMA-software and the measured information, eigenmodes can be diagnosed. In Fig. 5, the eigenmodes at 1500...1900 for an ordinary and a reinforced sandwich plate is shown. It can be seen that beyond the frequency shift the characteristic of the vibration shape is varied.

The numerical results in the first row of Fig. 5 show a good correlation with the actual measured vibration shape. It is expected that the differences in the eigenfrequencies can be reduced with a more detailed simulation.

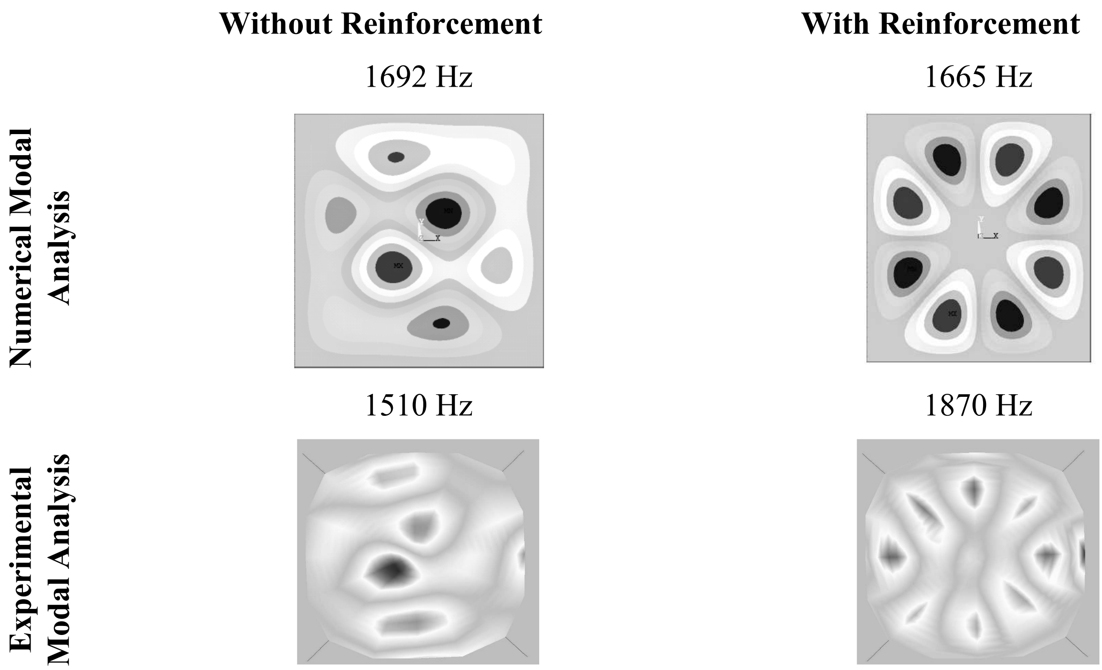

Fig. 5: Comparison between experimental and numerical modal analysis of not-reinforced and reinforced plates

Benefit of acoustic localisation. The acoustic localisation of local property changes is a quality tool that is to be used in the manufacturing process of products made from these innovative materials. Instead of sorting out defective parts, as it is done in conventional acoustic accept-reject checks, the information from the localization will be used in the following process steps.

An example is the production of sandwich composites with local reinforcements. In the manufacturing process can slide the local reinforcement elements. If the sheet is then deep-drawn, the reinforcement elements must be appropriately aligned with the tool. In the acoustic localization, the sheet before deep-drawing is excited to vibrate. The vibrations do not harm the material in any way. After evaluating the vibrations of the plate with the procedures to be developed accurate information may be provided to the industrial handling, how the sheet has to be inserted into the deep drawing press.

In addition to this the information can also be used to influence the production process of high-strength structures and joints. As the localisation is quantifiable the manufacturing may be controlled by its results.

Summary

To develop structures with local variations of material properties, appropriate methods are necessary to verify the quality of these modifications. In this article, acoustic measurements both in time- and frequency-domain are suitable to detect different material behavior. These results can be achieved with experimental or numerical tests. Future research will refine these methods to develop tools for quality control of such structures and components. Ideally, these methods reveal the information, whether the tailored material properties are at the desired position.

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