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AN ATTEMPT TO USE THE COHERENCE FUNCTION FOR TESTING THE STRUCTURE OF SATURATED COMPOSITE CASTINGS

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This article proposes to use the coherence function in structural examination of saturated composite castings, widely used in the maritime industry and the construction of machines and vehicles. These castings are characterized by a complex structure due to the presence of a tough reinforcement phase in a matrix, mostly an alloy made of light metals. Such combination generates a number of defects, particularly in composite materials made by casting. Elimination of the defects, preceded by immediate detection, preferably through non-destructive tests, may contribute to reducing operating costs.

Key words: casting, aluminium alloy / carbon, composite materials, defects of composites, elastic waves of acoustic emission

INTRODUCTION

New technologies developed over the past decade in the foundry engineering have broadened a range of metal casting products, which include pistons of internal combustion engines, submarine pump sealings, and oil rig components [1–3]). New materials – cast composites – and new joining technologies offer benefits such as lower mass, greater accuracy of dimensions and higher quality of castings, which meet new higher technological and cost-effective requirements. The use of metal composites as a material for castings generates new features of the castings, unknown due to a specific structure of these composites or having minor significance in traditional metal castings. These features pertain to the structure of metal matrix, and result from the crystallization in the presence of reinforcement that may induce nucleus formation. Quality features are related to the homogeneity of the reinforcement phase, that is its distribution, quantity, size and shape, and to composite-specific types of porosity, resulting from composite casting density, e.g. occluded gas bubbles.

Continuous examination of composite casting structures is crucial if defective items are to be eliminated before assembly, an effective way to maintain or cut operational costs. Non-destructive tests are most useful and preferable: computer tomography, X-ray diffraction or acoustic emission, referred to in this work. Acoustic emission has been combined with the coherence function in an attempt to determine the structure of a composite material, examining samples randomly chosen from a batch of composite metal castings with saturated reinforcement.

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EXPERIMENTAL RESEARCH

The tested material – composite castings – are made by saturation with liquid aluminium alloy (AlSi11) under a pressure of 30 MPa. The saturated preforms were in a form of felt, consisting of short carbon fibers, and satisfied all requirements of the relevant technology [1]. Cylindrical samples (*f* – 44 mm, *h* – 6 mm) has been taken as they are easy to cast, machine and test. The structure of materials made was not homogeneous (excluding the presence of reinforcement phase). Material defects has been identified (Figure 1), using a computer tomograph.

It was assumed that any defect existing in the examined structure will generate a disturbed signal (e.g. as an excited elastic wave). To compare two signals: one from a model, the other from a defective sample, the relation

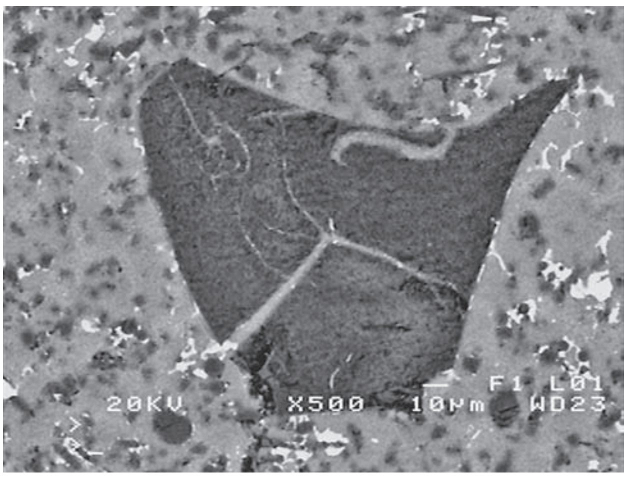

Figure 1 A defect of composite material AlSi11/C. A visible inclusion (for-eign matter in the casting structure) – SEM

between them can be determined by using the coherence function.

The value of coherence function may vary within certain limits. For linear systems with constant parameters $\gamma^2_{xy}(f) = 1$, which means that signals $x(t)$ and $y(t)$ are completely coherent. If for a certain frequency $\gamma^2_{xy}(f) = 0$, signals $x(t)$ and $y(t)$ are incoherent. If signals $x(t)$ and $y(t)$ are statistically independent, then $\gamma^2_{xy}(f) = 0$ for all frequencies. When the value of coherence function is contained within the limits, it means that measurement results comprise disturbances, that is an output signal is affected by an input and other signals, or the system combining the signals $x(t)$ and $y(t)$ is nonlinear.

In case of composites, existence of any inhomogeneity causes the elastic wave signal to change, thus the coherence function will change. That is why this function can be used in detecting discontinuities (defects) or changes in material characteristics. The coherence function, like cross-correlation function, is a measure of the similarity of source signals, separately for each frequency. The function reflects a relative content of information in the output signal about the input signal.

Considering a simple model with recorded input and output signals (Figure 2), where $x(t)$ and $y(t)$ are, respectively, signals recorded at the input and output, and $G_{xx}(i, f)$ and $G_{yy}(i, f)$ are respective spectral densities of power of these signals.

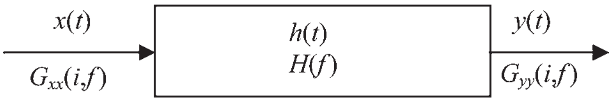

Figure 2 A model of a simple system with input / output signals [1, 4]

For such signal, the complex function is described by this relation:

$$H(i\omega) = \frac{Y(i\omega)}{X(i\omega)} \quad (1)$$

where $Y(i\omega)$ and $X(i\omega)$ are complex transforms of input and output signals, or by one of two methods:

$$H_1(f) = \frac{G_{xy}(f)}{G_{xx}(f)} \quad (2)$$

$$H_2(f) = \frac{G_{yy}(f)}{G_{yx}(f)} \quad (3)$$

where $G_{xy}(f)$ and $G_{yx}(f)$ correlated power spectral densities.

The two functions are equal to each other only for an undistrubed linear system [4–6]. In any other case their ratio, referred to as the ordinary coherence function, is lower than unity:

$$\gamma^2_{xy}(f) = \frac{H_1(f)}{H_2(f)} = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}G_{yy}} < 1$$

In the classical frequency-domain analysis relatively simple rules are applied for the separation, based on the value of the coherence function, of disturbances at the system input or output, knowing what type of disturbance occurs. No simple rules, however, are available for interpretation of low values of ordinary coherence, if a system is nonlinear [5–8]. Images (Figures 3–4) present, subsequently, excitation signal of elastic wave propagating in a flawless sample, in a sample with an inclusion, and the resultant ordinary coherence function of the two samples.

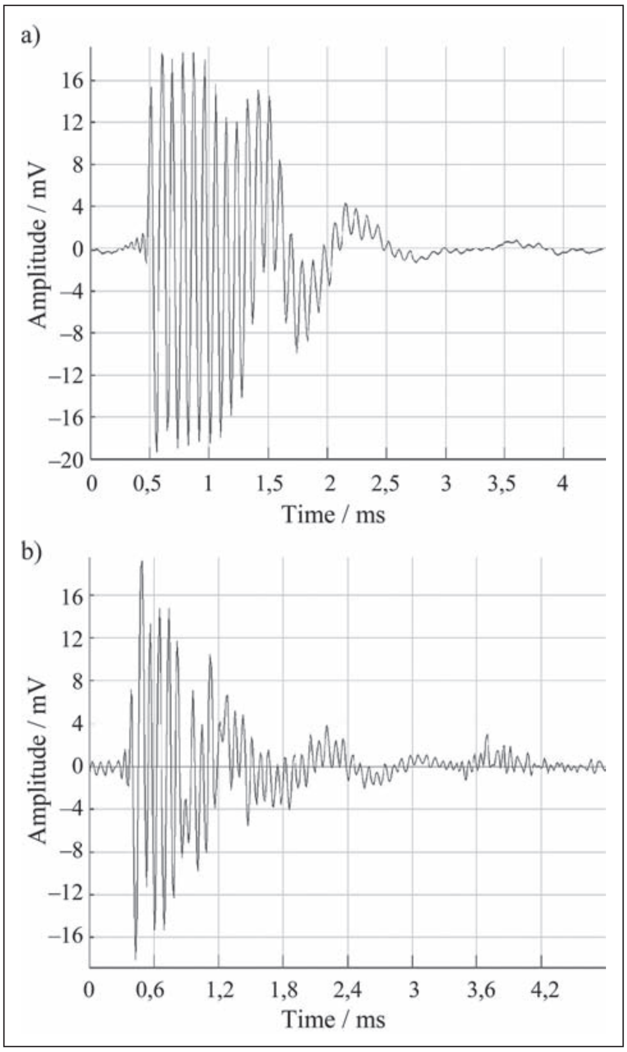

Figure 3 Visualized wave signal of composite materials a) flawless b) defective

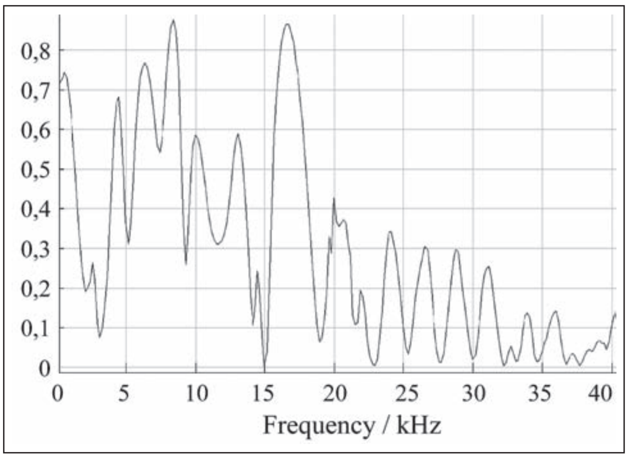

Figure 4 The coherence function determined for flawless and defective composite material samples

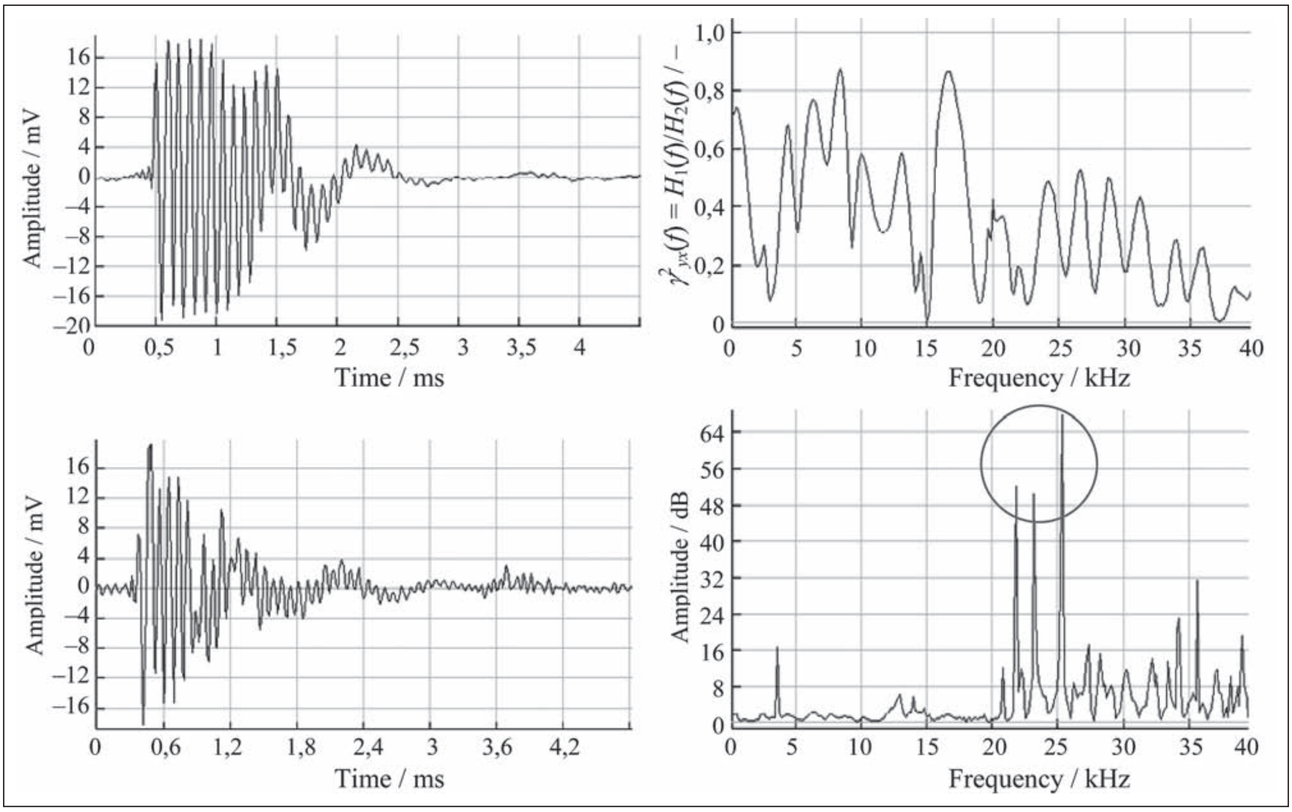

Figure 5 Source signals of the elastic wave for flawless (top left) and defective (bottom left) composite material, and the coherence function with circled peaks of the gain coeffi-cient γ^2_{xy} $(f) = H_1(f)/H_2(f)$ / –

Figure 5 includes images of signal analysis with the coherence function and change in the gain coefficient (system transmittance module). The transmittance module in this case presents a frequency-dependent relation of input / output signal amplitude ratio. Most sensitive areas are found at frequencies of approx. 22 kHz, 23 kHz and 25 kHz.

The transmittance module considered is also presented in a diagram depicting amplitude-time-frequency relations (Figure 6). Characteristic frequencies above a 20 kHz band are visible.

Power spectral density is one basic signal parameter determined in the time domain. This parameter has been

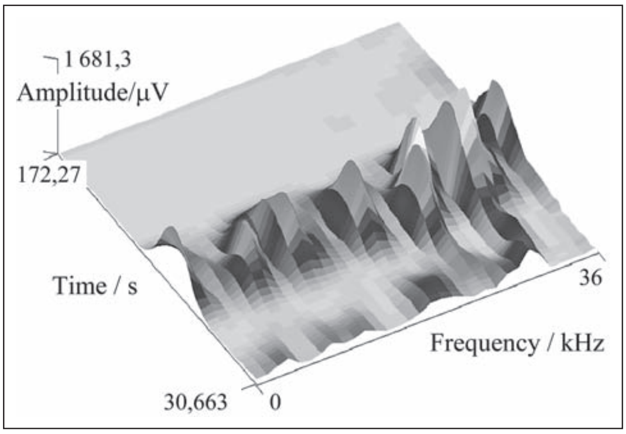

Figure 6 Amplitude-time-frequency charac-teristics of the transmittance module of the coherence (function) between a signal from a flawless composite and a signal from a composite sam-ple with an inclusion (visible char-acteristic frequencies above 20 kHz)

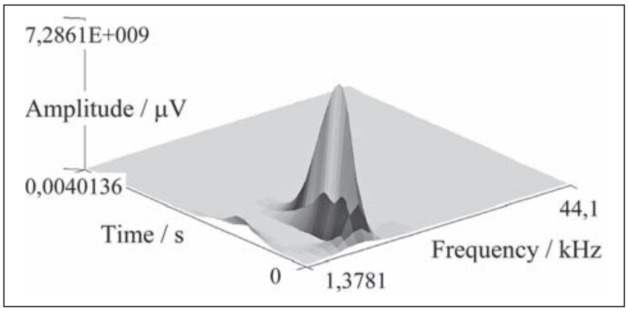

Figure 7 Amplitude-time-frequency charac-teristics of spectral density of elastic wave signal for a flawless sample

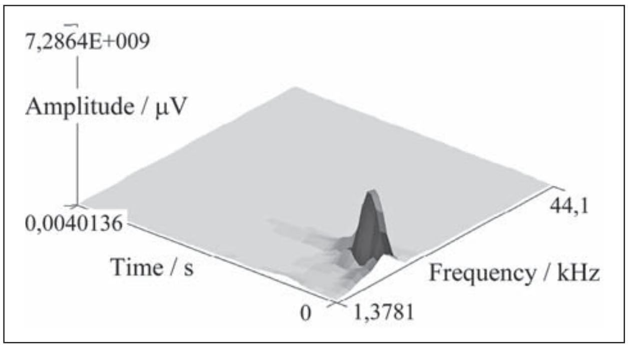

Figure 8 Amplitude-time-frequency charac-teristics of spectral density of elastic wave signal for a sample with an inclusion

used for the determination of differences in a linear combination of harmonic functions of a signal excited in a flawless sample and the one with a foreign matter in the casting structure. The research results reveal that the defective composite sample (Figure 8), compared to the flawless sample (Figure 7), generates a visibly lower spectral density amplitude of the elastic wave (Figure 7). In the sample with an inclusion a multiple reduction of the wave signal amplitude and a shift towards higher frequencies (by approx. 2 kHz relative to the base signal) can be observed.

SUMMARY

An analysis of the measurement results indicates that changes in the module transmittance are particularly useful in detecting inhomogeneities (such as inclusions in our case) in a composite material. Most sensitive areas are found in the frequency ranges of about 22 kHz, 23 kHz and 25 kHz. It can be concluded that in selected narrow bands of high frequency the coherence function is sensitive to an inhomogeneity occurring in a composite material. Besides, there exists a visible disturbance, or reduction, of spectral density amplitude of an elastic wave signal passing through a composite material containing a foreign matter in its structure. It seems that in such case an elastic wave is scattered and reflected, which reduces the energy value of the wave passing through a tested material. Therefore, the coherence function as a combined parameter of two compared signals of elastic waves passing through a composite material, as well as the value of an amplitude of power spectral density of that signal, may be excellent tools conveying information on the features of a tested casting (material).

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Note: Kłosiński Janusz is resposible for English language, Szczecin, Poland