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INVESTIGATION INTO THE PROPAGATION OF ACOUSTIC WAVES IN METAL COMPOSITE MATERIALS WITH CARBON REINFORCEMENT

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This paper presents the results of research into the parameters of the ultrasonic wave propagation in the infiltrated composite AlSi11 – pressed carbon fibres. The research data allowed determining changes in the speed and damping coefficient dependent on the composite material density.

Key words: *metal composite, carbon reinforcement, propagation of acoustic waves*

Ispitivanje širenja akustičkih valova u kompozitnim metalnim materijalima ojačanim ugljikom. Ovaj rad prikazuje rezultate istraživanja parametara širenja ultrazvučnih valova u infiltriranom kompozitu AlSi11 ojačanom ugljičnim vlaknima. Podaci dobiveni istraživanjem omogućuju da se odrede koeficijenti brzine i prigušivanja u ovisnosti o gustoći kompozitnog materijala.

Ključne riječi: *metalni kompozit, ugljik kao ojačivač, širenje akustičnih valova*

INTRODUCTION

Materials having bee used for a long time are increasingly being replaced by those with better properties for use in a particular industry.

Composites, continually examined and improved, are now undergoing a dynamic development [1, 2].

If we assume the matrix material to be a criterion for a classification, composites may be divided into metallic, polymeric and ceramic ones. The same three groups of materials are used as composite reinforcement. The most common cast metal composite materials have a ceramic reinforcement in the form of particles, short fibres, long fibres and fibrous spatial structures.

These materials are widely used in mass production of machinery. The assurance of adequate reliability, safety of work and extension of non-failure time of machine operation require higher and higher quality standards. In meeting these requirements non-destructive ultrasonic tests are helpful as they allow to determine the correct position of ceramic reinforcement inserts or the content of reinforcing particles of cast composites [3, 4].

It is crucial to ensure that composite materials are of proper quality. Used in vital machine components, composite materials are manufactured in relatively difficult technological processes. Apart from meeting the basic technological requirement - proper connection at the phase boundary of metal matrix/ceramic reinforcement - one should aim at obtaining a uniform cohesive material. Various discontinuities (defects) that may occur in cast composites may significantly affect their strength [5]. These defects may be as follows:
- discontinuities in the form of cavities resulting from the evolution of gas dissolved in metal,
- discontinuities connected with shrinkage or incorrect construction of the mould,
- segregation of reinforcement particles,
- ceramic impurities created in the technological process,
- incorrect position of the ceramic preform in the casting space.

Ultrasound waves, like any type of waves, are a space-time phenomenon. The shape and dimensions of the ultrasound field depend upon the source dimensions and wave frequency.

The energy of the flat ultrasound wave coming through a medium decreases, thus its acoustic pressure, dependent on medium properties, decreases too. This drop is caused by:
- divergence of wave beam;
- processes of energy absorption;
- scattering processes (reflections, refraction and diffraction of waves at boundaries of grains, inclusions, pores etc.);
- losses at boundary surfaces of the examined medium.

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Ultrasonic examination of materials is mostly performed with defectoscopes. It goes without saying that this method has some advantages, such as low costs, a wide range of applications, and possible automation of examination; however, one should note certain disadvantages [6]. The most difficult to cope in the ultrasonic control of materials is data interpretation. This is due to the fact that the defectoscope displays only a symbolic image of ultrasound waves transition through a material. It is particularly troublesome to interpret the results in the case of metal composite materials because of their varied structure.

In composite materials reflected and scattered multidirectional waves occur. This causes changes in the intensity and direction of the wave beam as well as its attenuation.

At the boundary of two solid materials (e.g. metal and ceramic), where both longitudinal and transverse waves are generated, one kind of waves is transformed into the other. In composites, where this phenomenon is common, the kind, shape and size of reinforcement play an important part.

The investigation attempted at defining the effect of discontinuities (porosity) of the cast metal composite with a ceramic reinforcement on the propagation of ultrasound waves.

RESEARCH

The examination focused on the composite material with the aluminium alloy AlSi11 matrix and carbon reinforcement, which had a form of spatially disordered structure made of fibres of 5 mm diameter. Ceramic cylindrical profiles (Figure 1.) were infiltrated under pressure with the liquid aluminium alloy. The samples were made in isothermic conditions, that is the temperature of the liquid metal and a special mould for pressurised casting was approximately equal and amounted to 690 - 700 °C. Samples were made at varied pressures of liquid metal (5 - 40 MPa). The steady temperature and pressure were maintained for a period of 300 seconds. Then, at that pressure, the sample was cooled. A fracture of the examined composite displaying reinforcement fibres is shown in Figure 2.

Figure 1. **A sample of the examined composite material; left: reinforcement in the form of a carbon profile**
Slika 1. **Uzorak ispitivanog kompozitnog materijala: lijevo - ojačanje u obliku ugljičnog profila**

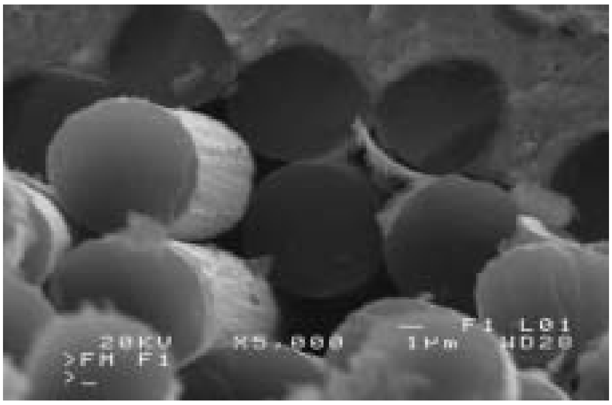

Figure 2. **Carbon fibres in a metal matrix (fracture magnified)**
Slika 2. **Ugljična vlakna u metalnoj matrici (prijelom uvećan)**

The samples are characterised by a varying density. The effect of infiltration pressure on density is presented in Figure 3.

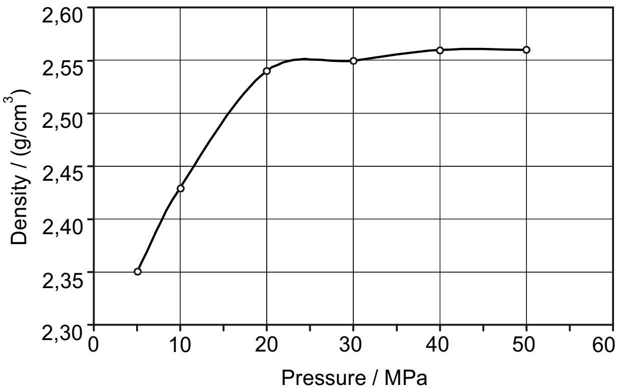

Figure 3. **Effect of pressure on sample density**
Slika 3. **Djelovanje tlaka na gustoću uzorka**

Measurements of ultrasonic wave velocity in the material and attenuation coefficient were carried out. In order to obtain maximum repeatability of results and to allow comparison the following conditions were assumed:

- samples should be of the same size and shape so that interference due to wave reflection from side walls is minimized,
- measurements should be performed with the same probe and with the same amplification,
- samples should have equal surface roughness,
- the squeeze pressure should be such that the value of the first impulse in each measurement is comparable,

- each measurement should be made between the same impulses,
- the settings of defectoscope controls should be identical for each measurement.

The examination was carried out with the use of a UNIPAN 510 type defectoscope at the constant frequency of 5 MHz. The ultrasound wave image was displayed on the screen from which one could read out the height and distance between selected peaks. The samples were cylindrical in shape, measuring 45 mm in diameter and 37 mm in height.

Before measurements, front surfaces of the samples were polished with sandpaper, similarly to metallographic specimens. Their roughness was measured with a type 301 MITUTOYO device. The roughness values obtained did not exceed 1,3 μm.

Surface roughness is essential for the thickness of a coupling layer between the head and material. The thicker this layer becomes, the weaker becomes the ultrasound wave, and thus repeatability and accuracy of results are reduced.

Examination of ultrasound wave velocity

The velocity of longitudinal ultrasound wave propagation was determined by the comparative method with a contact technique [6]. A measurement standard WI was used in the examination; its l_w = 25 mm (l_w - standard height, mm) and c_v = 5920 m/s (c_v - velocity of ultrasound wave propagation in steel).

This measurement consists in comparing the time of wave transition through the standard t_w and sample t_p.

If l_w and l_p respectively, denote the dimensions of the standard and the examined sample, then the velocity of wave propagation in the sample c_p may be found from the equation describing the principle of the echo method:

$$c_p = c_w \frac{l_p t_w}{l_w t_p} \tag{1}$$

where its c_w is a known wave velocity in the standard WI.

Because the locations of the echo (peak) for the sample x_p and for the standard x_w on the defectoscope display are proportional to the times of wave transition t_w, and t_p the relations above may be written in this form:

$$c_p = c_w \frac{l_p x_w}{l_w x_p} \tag{2}$$

When the measuring range is adjusted so that the distance x_p satisfies the condition:

$$x_p = c_w \frac{l_p}{l_w} \tag{3}$$

then, according to the equation, the location of the peak base of standard WI directly defines the looked-for velocity c_p. The value of ultrasound wave propagation velocity in

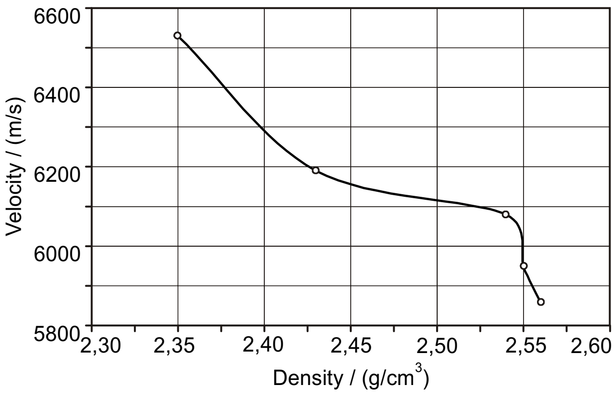

Figure 4. **Wave propagation velocity as a function of composite density**
Slika 4. **Brzina širenja vala kao funkcija gustoće kompozita**

the examined composites as the function of density is shown in Figure 4. The regression equation has been determined:

$$c_p = -2794{,}92 \times \rho + 13060{,}97 \tag{4}$$

with the correlation coefficient equal to: $R = -0{,}95941$.

Measurement of attenuation coefficient

The measurement of attenuation coefficient was performed by the echo method in the far field with direct (contact) coupling [6].

Due to sample dimensions and interference resulting from a diversified structure – the attenuation was measured between the second and third echos (in the case of further echoes in certain samples there was interference).

The attenuation coefficient was calculated from this equation:

$$\alpha = \frac{1}{2q} \cdot 201q \cdot \left(\frac{H_n}{H_{n+1}} \cdot \frac{k_{n+1}}{k_n} \cdot R \right) \tag{5}$$

where:

a - attenuation coefficient / (dB/cm),
q - thickness of the material / (cm),
H_n/H_{n+1} - ratio of two subsequent heights based on the difference of echo heights,
k_n - coefficient of correction (divergence) for the n-th echo (assumed 1,7),

R - coefficient of reflection at the head-sample boundary (assumed 0,75).

The determined values of ultrasound wave attenuation coefficient dependent on composite density are shown in Figure 5.

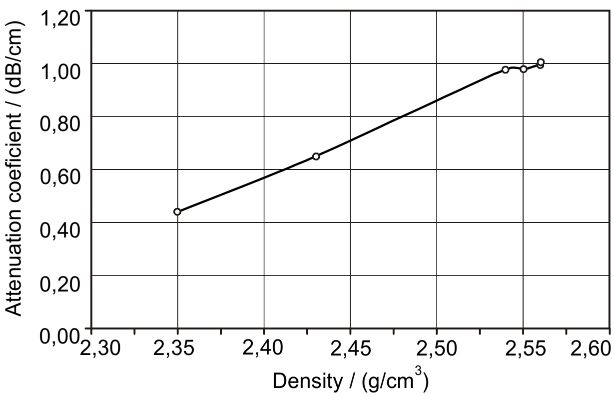

Figure 5. **Attenuation coefficient dependent on composite material density**

Slika 5. **Umanjenje koeficijenta u ovisnosti o gustoći kompozitnog materijala**

The regression equations were also defined:

$$\alpha = 2{,}73305 \times \rho + 5{,}98537 \qquad (6)$$

with the correlation coefficient equal to: $R = 0{,}998736$.

CONCLUSIONS

1. Increasing of composite density causes reduction of velocity of ultrasound according formula (4).
2. Increasing of composite density causes increasing of attenuation coefficient according to formula (6).
3. The measurement of ultrasound wave velocity may be applied in estimating the quality of metal composite materials.

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