We have, therefore, tried to use at first the DPL to fit the acoustic attenuation spectra of the investigated glasses (Fig. 3).

To fit the acoustic spectrum using the DPL model (Eq. (10)) was applied and the calculated lines gave an excellent agreement with measured spectrum in intermediate and high temperature range represented by spotted line in Fig. 3 illustrating the acoustic spectrum.

We can see, that the complete spectrum another sample illustrated in Fig. 4, cannot be fitted similarly as in the case of supposing only two relaxation processes. The additional third relaxation process should be taken into account with maximum at the temperature around 270 K.

The values of $T_{\text{max}}$ can be easily and directly found from the theoretical fits. In this temperature region, the relaxation processes can be described by Arrhenius temperature dependencies of the relaxation time (Eq. (3)) and the values of $\xi$ can be determined using this function in first approximation. The preexponential factor $\xi_0$ can be estimated from some typical frequencies characterized the shortest possible time processes of the relaxation [10] or determined from acoustic spectra obtained at various frequencies [12].

4. CONCLUSION

The experimental and theoretical investigation of the self-conductive glasses in system Cu-CuCl$_2$-Cu$_2$O-P$_2$O$_5$ proved that acoustical spectroscopy can be very useful technique for study of transport processes in fast ion conductive glasses. An important finding from the present study is that the superposition attenuation peaks described by theoretical models can fit all acoustic attenuation spectra. It was found that the investigated relaxation process could be described by a relaxation theory. Using the theoretical models we can describe the relaxation processes and find some ion parameters.

The acoustic spectra of all investigated ion conducting glasses prepared in the system Cu-CuCl$_2$-Cu$_2$O-P$_2$O$_5$ consist of more than two thermally activated relaxation processes for temperatures over 220 K. The superposition of three loss peaks with different activation energies can better fit the investigated spectrum of the glasses.

Further analyses of acoustic spectra obtained by investigation of glass samples with different compositions in wider temperature and frequency range should be done for better understanding of ion transport mechanisms for various types of the investigated ion conducting glasses.

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ADVANCED METHOD OF THE ELASTOMAGNETIC SENSORS CALIBRATION

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Summary

Elastomagnetic method (EM method) is a highly sensitive non-contact evaluation method for measuring tensile and compressive stress in steel. The latest development of measuring devices and EM sensors has shown that the elastomagnetic phenomenon has a strong influence on the accuracy during the EM sensor calibration. To eliminate the influence of this effect a two-dimensional regression method is presented.

1. INTRODUCTION

The elastomagnetic (EM) method of stress measurement is a highly precise non-contact method based on the analysis of the magnetic field inside the EM sensor. Stress evaluating devices using the elastomagnetic phenomenon, i.e. the modification of the magnetic hysteresis loop of the ferrous material by static or dynamic mechanical stress, are similar to those, using the effect of change of electrical resistance according to applied stress i.e. resistive strain gauges. The magnetic characteristics of amplitude permeability and incremental permeability in properly chosen working point are, however, about 100 times more sensitive than those electrical resistance effects [1, 2]. The relative change of steel's magnetic incremental permeability is up to $10^3 \text{ MPa}^{-1}$, while the relative change of a strain gauge electric resistance is about $10^4 \text{ MPa}^{-1}$.

2. THEORETICAL BACKGROUND

The magnetic characteristic of ferromagnetic material is the relation between external (magnetising) magnetic field strength $H$ and inner (induced) magnetic field flux density $B$, so called hysteresis loop. Experimentally we can measure the magnetic flux $\phi = AB$ through the cross-section $A$. In practice in any case the measured magnetic flux is combination of a flux, depending on measured material and a flux depending on sensor arrangement and magnetic surrounding. For precise measurement the magnetic field must be closed inside the sensor, practically it means magnetic shielding of the sensor.

Amplitude permeability is defined as ratio $B/H$ and incremental permeability is defined as ratio $\Delta B/\Delta H$. In both cases the permeability depends also on "working point" in which it is measured. Only for very high field strength, where no hysteresis occurs (technical saturation), these characteristics are not affected by the magnetic history of material. Both amplitude and incremental permeability are stress and temperature dependent and they can be used for stress estimation.

3. MEASURING METHOD

The EM sensor takes the form of the hollow cylinder in the middle of which the measured specimen (bar, wire, strip, cable) passes through. The sensing part of the system is the measured specimen itself. The setup consists of primary (magnetising) and secondary (sensing) windings, mounted in a protective steel shield and sealed with an insulating material. The temperature of the material is measured in the middle of the sensing coil by a highly precise temperature sensor tightly connected to the specimen with very low transitional thermal resistance.

As we mentioned before, magnetic permeability is temperature dependent; therefore during the long time measurement the temperature error caused by sensor heating by current flowing through the magnetizing winding may be significant. This drawback was overlooked by using pulse method of measuring incremental permeability. The incremental permeability is measured during duration of short and high current pulse so that the temperature change is very low and no heating of sensor occurs. Magnetic field inside the sensor is generated by a huge current pulse (peak power value up to 10kW), which magnetizes the specimen to deep saturation (magnetic intensity up to 10T), simultaneously erasing the magnetic history of the material and hereby creating clearly definable measurable input.

By this reason in following we aim our interest on incremental permeability.

4. CALIBRATION PROCESS

The first step of calibration is to measure the incremental permeability $\mu_{\text{inc}}$ as a function of mechanical stress $\sigma$ and temperature at various working points $T_{\text{w}}$. The mechanical stress is measured by precise annular dynamometer. The moment of strain and temperature accuracy error is very exactly synchronized in both measurement systems and the acquired data are stored in the control computer with timestamp. From this set of data we choose the working point and fix it for the rest of the calibration process at which the relationship between the stress and permeability is the most linear. At this point the incremental permeability we could represent as
\[ \mu(\sigma, T) = \mu_0(\sigma_0, T_0) + \frac{\partial \mu_0}{\partial \sigma_0} (\sigma - \sigma_0) \]

\[ \frac{\partial \mu_0}{\partial T} (T - T_0) \]

For reference values of temperature and stress we should use zero values, hence

\[ \mu(0, T) = \mu_0(0, T_0) = \mu_0(0) + \alpha T \]

where \( \mu_0(0) \) and \( \alpha \) are the values of the property at zero stress. This value of \( \mu_0(0) \) should be measured (material with zero stress at zero temperature) or calculated from the measured values of material with stress at different temperatures. Our goal is to eliminate the temperature influence due to the thermomechanical effect [3,4]. Typical behavior of the thermomechanical effect is shown in Fig.1. As the measured data shows, the temperature change due to applied stress is significant, because the sensitivity of stress measurement is approximately \( -5 \text{MPa}^{-1} \). According to this effect it is suitable to divide the regression process into two separate parts. At first the correction of stress values and the consequent correction of temperature values.

\[ \mu(\sigma, T) = \mu_0(\sigma_0, T_0) + \alpha T \]

By this method we gain a new set of data points of functional dependence of permeability. The next step is to calculate the corrections to the permeability due to temperature influence.

\[ \mu(\sigma_0, T) = \mu_0(\sigma_0, T_0) = \mu_0(\sigma_0) + \alpha (T - T_0) \]

By this process we achieve data points that are lined-up both in values of mechanical stress and temperature. We are also able to gain functional dependence between the coefficient \( \alpha \) and the mechanical stress \( \sigma \). Using this functional dependence we are able to predict (interpolate) the function \( \mu(\sigma, T) \) for arbitrary values of mechanical stress. The calibration curves are functions to these graphed values, i.e., the calibration curves are functional dependence of mechanical stress \( \sigma \) as a function of incremental permeability \( \mu \).

5. CONCLUSION

The effort to obtain more precise stress measurement devices leads to necessity to use more sophisticated methods to gain precise and valuable calibration curves. We use a two-dimensional regression method divided to subparts for easy and flexible modification of fitting functions of individual functional dependencies. This regression process is used to eliminate the significant influence of thermomechanical effect on quality and accuracy of calibration curves. The main result of this process is the exact and accurate form of functional dependence of the coefficient \( \alpha \) as a function of stress \( \sigma \), which allows us to calculate the whole set of calibration curves.

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