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# Diagnostics of State of Materials Closed in the Cover*

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## Introduction

Various factors such as temperature, moisture, pressure, etc. influence and lead to different state of heterogeneous material closed in the cover (e.g. loose substance in the container). Therefore, it is of great importance of construct a diagnostics method for determining the state of material. This paper presents the results of investigation a new and non-traditional way for diagnostics of the state by using the propagation of ultrasound oscillations.

## Diagnostics methodology

Initially, we have set up and analysed a physical model (Fig. 1.) which enabled us to evaluate possible different states of same material.

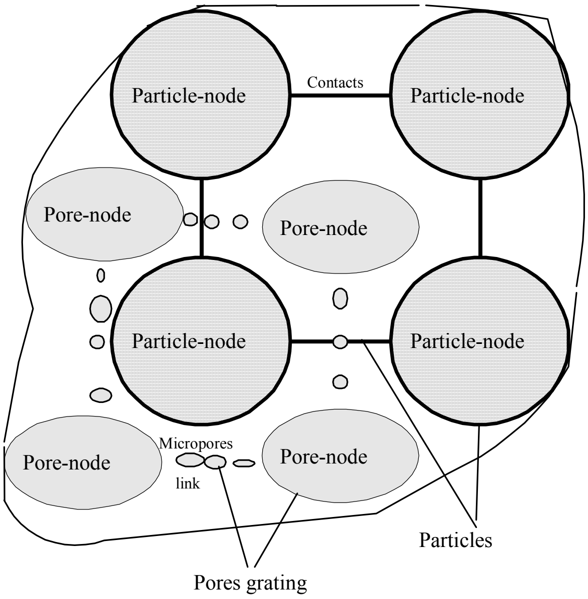

Fig. 1. **The simplified plane view of the loose medium fragment**

The intersection of pores with particle gratings is considered to be medium. In some gratings the nodes are particles and the links are contacts among them, in the order gratings the nodes are pores and the links are micropores connecting the pores. It indicates that the structure of stuck together and not any longer friable material, its inner links and the interaction of inner forces fluctuate according to the state of the particles and the pore gratings. Physical model shows, that reasons of substance state depends from particle and pore gratings, and caused by external factors, such as temperature, static and dynamic load, moisture and etc. In simplified way this is represented in Fig.2.

Let us assume that water in the pores is freezing (state Y). Then the state of pore gratings changes and a particle grating is being restrained that results in a loss of fluency. On the other hand, it may be caused by altering the state of a particle grating, as it happens when the contacts among particles are cementing (state X). For this purpose we have analyzed the phenomena of ultrasound oscillations spreading in non-homogeneous medium. Different states of same material are known to correspond to different wave velocities. This information allows us to determine the material state and violation of its fluency.

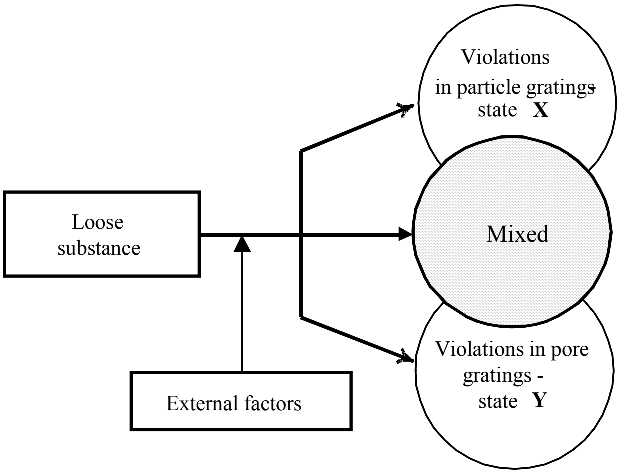

Fig. 2. **The scheme of structural changes in the loose substance**

Let's suppose that we succeeded in the diagnostics of the adequate state of substance. It remains to determine the approximate values of its physical-mechanical parameters, such as density $\rho$, shear modulus $G$ and Poisson's ratio $\mu$. Considering that the solid substance is elastic one we can suppose that between the sound velocity within the elastic substance and its physical-mechanical properties there is some link, which can be defined by the linear dependence. So we make an assumption that in the case of the same material sticking together the different models will have different dependencies between the physical-mechanical properties and ultrasound oscillations propagation velocity. According to this we will be able to determine approximately the values of the necessary parameters. Functional dependencies in the different models are defined by the experiments [1]:

$$\rho = f_n(v_L) \qquad (1)$$

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$$\mu = f_n(v_L) \tag{2}$$

where $\rho$ - material density; $v_L$ - ultrasound longitudinal wave velocity within the substance; $n$ - index of the model.

Further let's suppose that we defined parameters $\mu$ and $\rho$ according to the ultrasound longitudinal oscillations propagation velocity within the substance. Thus we can approximately calculate the elasticity parameters of the substance using the following expressions:

$$E = k v_L^2 \rho \tag{3}$$

$$G = \frac{E}{2(1+\mu)} \tag{4}$$

where $E$ - elasticity (Young's) modulus; $k$ - coefficient subjective to the geometry of the object being investigated.

In that case the object is three–dimensional, so

$$k = \frac{(1+\mu)(1-2\mu)}{1-\mu}$$

Thus, after performing the preliminary experimental research we can determine expressions (1) and (2) for every modelled state of the material, which marked with corresponding indexes.

After performing preliminary research, determination of coefficients in expressions (1) and (2) we can create conditions for diagnostics of state any loose material according to adequate material states. For this purpose we make a gridline for object state identification on the base of defined critical parameters and ultrasound longitudinal wave velocity. Gridline for any loose material is presented in Fig. 3.

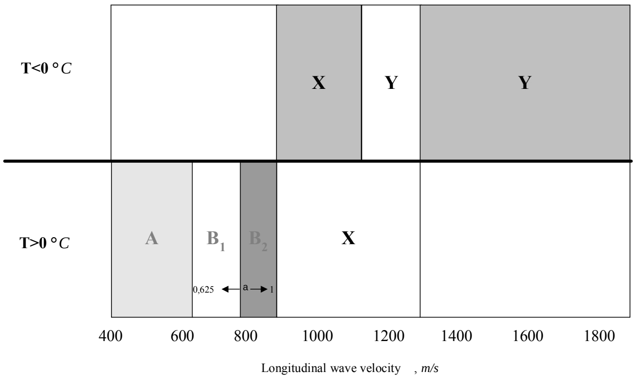

Fig. 3. **Gridline for diagnostics states**

Overall area of the diagram can be conditionally divided into parts (object states). Let's consider that:

- Material friability is ideal in the area **A**;
- Material friability may be passable and inadequate, material may be stuck together – **B**;
- Material is stuck together (rigid), a particle grating being inhibited, contacts being cemented – **X**;
- Material is stuck together (rigid), a pore grating being inhibited, water frozen in pores and micropores - **Y**.

Diagnostics solution rule is the following:

***State A***

$$\bar{v}_L < v_A \text{, then } \bar{v}_L \in A \text{ and } \bar{v}_L > v_A \text{, then } \bar{v}_L \in B \tag{5}$$

where $v_A$ - critical velocity of ultrasound longitudinal wave propagation, that differ states of object **A** and object **B**.

Parameter $v_A$ can be determined according to a priori results of physical experiments. At ideal material friability there may be cases when registration of ultrasound impulse transition signal through the material being investigated is unsuccessful and it is impossible to determine the longitudinal wave velocity. This can be considered as the additional indication of the object attachment to the state **A**, which can be expressed:

$$\bar{v}_L = 0 \text{, then } \bar{v}_L \in A \tag{6}$$

***State B***

$$v_A < \bar{v}_L < v_B \text{, then } \bar{v}_L \in B_1 \text{ and}$$

$$v_B < \bar{v}_L < v_X \text{, then } \bar{v}_L \in B_2 \tag{7}$$

$$B_1 \cup B_2 = B \tag{8}$$

where $B_1$ - conditional state **B**, at which friability is satisfactory; $B_2$ - conditional state **B**, at which friability is unsatisfactory, i.e. there are local hardening.

At first we define the critical parameter $v_X$. In the case of its exceeding, object is attached to **X** state according to the (7) condition. Hence, the solution rule is the following:

$$\bar{v}_L > v_X \text{, then } \bar{v}_L \in X \tag{9}$$

With known parameter $v_B$ and using condition (7), we can attach the object to state $B_1$ and $B_2$, and suppose that at state $B_1$ material friability is satisfactory, at state $B_2$ – unsatisfactory, because of some stickings, though material isn't absolutely solid. In that case it is purposeful to model the dynamics of loose restoring process in the substance and analyze it by vibrating methods. Besides, for the qualitative estimation of indefinite state $B_2$ according to the results of performed experimental research we can use an additional diagnostical indication – conditional dispersion $\alpha$ of ultrasound longitudinal wave velocity with the respect to the container space. Dispersion is expressed:

$$a = \frac{v_{LV}}{v_{LA}} < 1 \tag{10}$$

where $v_{LV}$, $v_{LA}$ - ultrasound longitudinal wave velocity in the upper and lower sections of the material.

It is obvious, that the closer parameter $\alpha$ approaches to 1, the greater volume of the container is occupied by the stuck together material and the more powerful measures are needed for the friability restoring.

The temperature higher than 0°*C* can be considered as an additional parameter for state **X**.

***State Y***

It is obvious, that temperature lower than 0°C is necessary condition for the existence of that state. So solution rule can be expressed:

$$\text{when } T < 0^\circ C \text{ and } \bar{v}_L > v_Y \text{, then } \bar{v}_L \in Y \tag{11}$$

Parameter $v_Y$ can be determined according to the a priori results of the physical experiment.

***Mixed state***

It's obvious that this state is possible only at temperature below 0°C. So the solution rule can be expressed:

when $T < 0^\circ C$ and $\bar{v}_L > v_{XY}$, then $\bar{v}_L \in Y$ (12)

when $T < 0^\circ C$ and $\bar{v}_L < v_{XY}$, then $\bar{v}_L \in X$ (13)

According to the diagnostics gridline (Fig. 3) and solution rules we can determine state of substance. Further we have to compute physical-mechanical parameters of this state according to expressions (1), (2), (3) and (4).

## Conclusion

Investigated diagnostics procedures allows us to obtain one-meaning information about the state of materials closed in the cover.

### References

1. **Halmshaw, R**. 1993. Non-destructive testing. London Melbourne Auckland: A division of Hodder&Stoughton.

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**Medžiagų būvio uždaruose apvalkaluose diagnostika**

Reziumė

Pasiūlytas ir ištirtas ultragarsinis impulsinis nehomogeninių medžiagų būvio uždaruose apvalkaluose tyrimo metodas. Pateikiama šio metodo taikymo metodika biriųjų medžiagų būvio uždaroje talpykloje diagnostikai.