JOURNAL OF MATERIALS SCIENCE 31 (1996) 1261–1263

Ultrasonic evaluation of gypsum plaster

S.K. DALUI, M. ROYCHOWDHURY, K.K. PHANI
Central Glass and Ceramic Research Institute, Calcutta 700 032, India

Ultrasonics have been used for the characterization of set plaster in the water ratio range 0.3 to 1. The variation of ultrasonic velocity with porosity has been studied. The elastic modulus and strength of plaster have also been evaluated. The study indicates both elastic modulus and strength properties correlate well with the ultrasonic velocity. Thus the ultrasonic velocity can be used as a predictor of strength and elastic moduli of these materials.

1. Introduction

It is a well known fact that the strength of set gypsum plaster is very much dependent on the quantity of water which is used in preparing the original plaster mix. This quantity of water is determined by the use to which the plaster is to be put. Thus, for uses in the pottery industry the mix must be easily pourable; on the other hand, for plastering building walls it must be of a sufficiently stiff consistency to stay on the wall during the setting period. The water plaster ratio is thus chosen in accordance with rheological requirements and it is of importance to know its influence on the mechanical strength of the final product. An attempt has therefore been made in this work to characterize gypsum plaster using ultrasonic velocity to evaluate the elastic constants and find the correlation between physical properties and ultrasonic velocity.

2. Experimental procedure

The gypsum plasters used in this study were obtained by calcining rock gypsum obtained from two different sources (from Rajasthan in India and Bhutan). The calcining process was carried out both in a kettle under atmospheric pressure and in an autoclave at a high pressure for each type of rock gypsum. The four types of plaster thus obtained were designated Rajasthan autoclave (RA), Rajasthan kettle calcined (RK), Bhutan autoclaved (BA) and Bhutan kettle calcined (BK). Plaster cubes of size 25 mm were prepared from these plasters for the water ratio, w (number of cubic centimetres of water per 100 g plaster) varying from 0.3:1. However, for kettle calcined plasters, only a water ratio above 0.4 gave pourable consistency for the preparation of cubes. The cubes were allowed to dry in a laboratory atmosphere for 48 h followed by oven drying at 40 °C to constant weight.

The ultrasonic velocity (longitudinal) was measured using the ultrasonic tester USIP 12 (Krautkramer) interfaced with a 100 MHz oscilloscope (Philips model 3350) in through transmission mode. The centre frequency of the transducers (10 mm diameter) was 5 MHz. The transit time was measured with an accuracy of $\pm$ 1 ns.

The compressive strength of the cubes was determined using a Instron-1185 machine at a crosshead speed of 1 mm min^{-1}. Compressive strength was calculated using the breaking load recorded by the machine and the cross-sectional area of the cubes.

The density of the plaster cubes was calculated from their physical dimensions and weight, and the porosity of the individual samples was determined from the relation

$$P = \frac{\rho - \rho_0}{\rho} \quad (1)$$

where P is the porosity, ρ and ρ_0 are the densities of porous and pore-free material, respectively. The value of ρ_0 was taken as 2.31 g cm^{-3} for the set plaster [1]. The calculated porosity values agreed within $\pm$ 5% with the values calculated from the water ratio by Equation 1

$$P = \frac{w - 0.15}{w + 0.36} \quad (2)$$

The elastic moduli of the samples were calculated from measured ultrasonic velocities using the equation

$$E = V_L^2 \rho \quad (3)$$

where E is the elastic modulus and V_L is the ultrasonic longitudinal velocity.

3. Results

Fig. 1 presents the plot of longitudinal ultrasonic velocity against calculated pore volume fraction, P. As can be seen from the figure, irrespective of the source of rock gypsum and the method of calcination, the data points seem to fall on a single curve. Thus, the measured values were fitted into a relation of the form

$$V_L = V_0(1 - P)^n \quad (4)$$

where V_0 is the velocity in non-porous material and n is a constant.

It has been shown [2] that the relation of the type given by Equation 4 describes the relation of physical properties with porosity well, and it is also consistent with the theories of physical acoustics. Equation 4 was

0022–2461

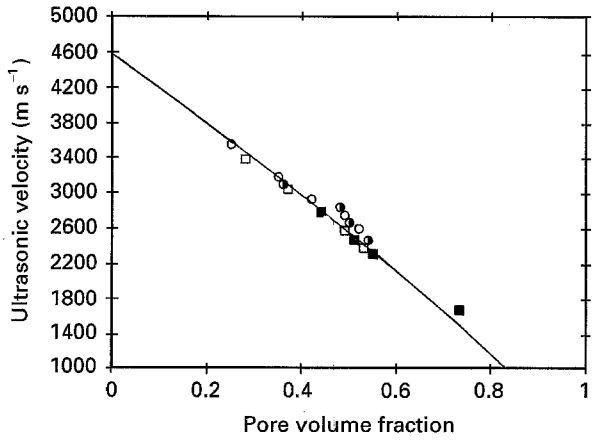

Figure 1 Variation of ultrasonic velocity with pore volume fraction: (■) BK, (○) RA, (□) BA, (◑) RK.

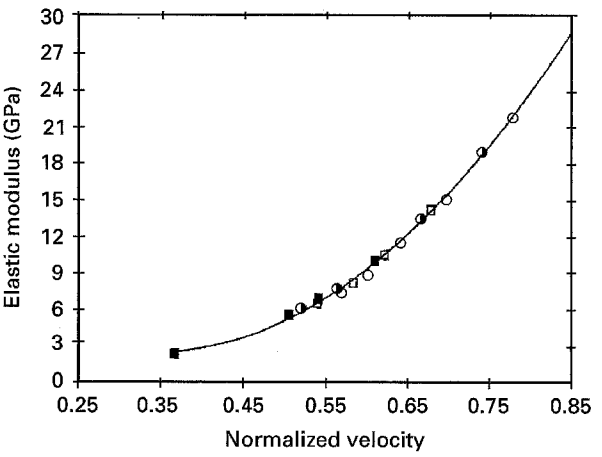

Figure 3 Elastic modulus of plaster against normalized ultrasonic velocity: (■) BK, (○) RA, (□) BA, (◑) RK.

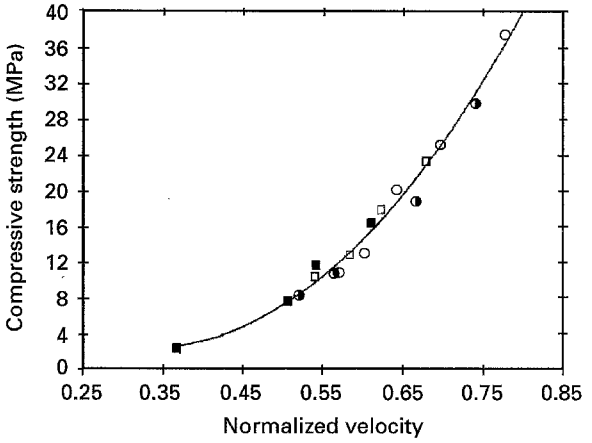

Figure 2 Compressive strength of plaster against normalized ultrasonic velocity: (■) BK, (○) RA, (□) BA, (◑) RK.

fitted to the data by non-linear regression analysis (3) yielding the relation

$$V(\mathrm{m\,s^{-1}}) = 4571.4(1 - P)^{0.84} \quad (5)$$

A correlation coefficient of 0.94 was obtained, confirming good agreement between data and the fitted equation.

It is well established that ultrasonic velocity depends not only on the value of porosity but also on pore shape and orientation [2, 4]. However, the above relation indicates that in the case of plaster it is at least independent of the methods of calcination of rock gypsum or the source from which it has been procured. Thus, it will be reasonable to assume that the value of V_0 for pore-free gypsum will be the same for all types of plaster.

If the dependence of strength and elastic moduli on shape, size and structure of the pore is similar to that of velocity, a good correlation can be expected between the velocity and strength or modulus. For ceramics like uranium dioxide, sintered iron compacts and silicon carbide, linear correlation between elastic modulus and longitudinal velocity has been reported in the literature [4–6], though such a relation is totally inconsistent with the theory of physical acoustics (Equation 3). Figs 2 and 3 present plots of compressive strengths and elastic moduli against normalized velocity, respectively. The velocity values were normalized with respect to the velocity of pore-free materials, i.e $V_0 = 4571.4\ \mathrm{m\,s^{-1}}$. The data points were fitted to a polynomial of second degree yielding the relations:

compressive strength

$$\sigma(\mathrm{MPa}) = 22.92 - 119.74\left(\frac{V_L}{V_0}\right) + 176.39\left(\frac{V_L}{V_0}\right)^2 \quad (6)$$

elastic modulus

$$E(\mathrm{GPa}) = 14.27 - 69.06\left(\frac{V_L}{V_0}\right) + 101.44\left(\frac{V_L}{V_0}\right)^2 \quad (7)$$

with correlation coefficients of 0.980 and 0.999 for compressive strength and elastic modulus, respectively, showing excellent agreement between the data and fitted equations. Because the usual water ratio used in production is well within the range (0.3–1) for which data have been analysed, these relations may be used for measuring compressive strength and elastic modulus of set plaster as a routine check in a production plant, by simply measuring longitudinal ultrasonic velocity.

4. Discussion

Plaster used in this study was obtained by two different methods of calcination, which induce differences in crystal size and habit; these features in turn should influence the physical properties of the plaster. However, the velocity data indicate that neither the crystal habit nor the usual type of impurities are as important as the porosity. This is possibly due to the fact that the crystal habit mainly determines the water demand of the plaster, i.e the quantity of water which gives a workable mix, and this itself affects the physical properties indirectly by the porosity due to excess water. If this is true, Equations 6 and 7 should be equally applicable to all types of plaster, irrespective of the source of raw material or methods of manufacture. To verify the same, another 35 plaster cubes of five different batches of plaster were tested. These were

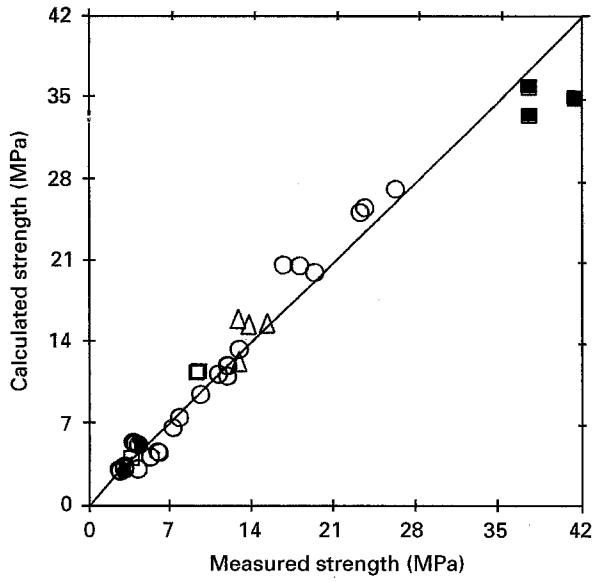

Figure 4 Comparison of calculated strength with the measured value: (■) P1, (○) P2, (□) P3, (△) P4, (◑) P5.

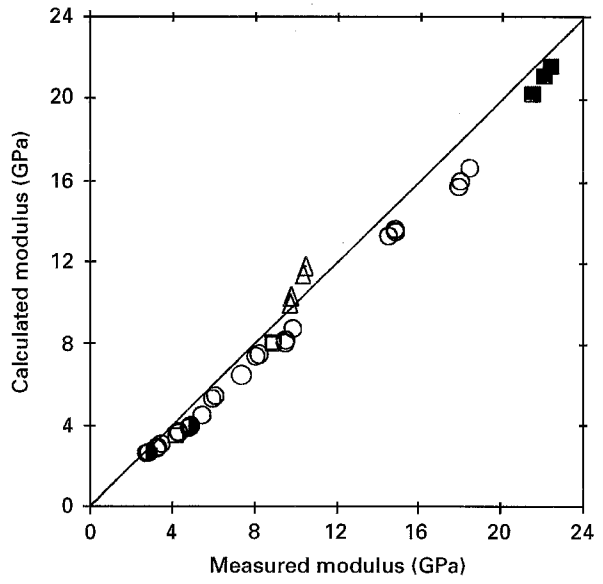

Figure 5 Comparison of calculated modulus with the measured value: (■) P1, (○) P2, (□) P3, (△) P4, (◑) P5.

untested specimens left over from the routine laboratory tests. The source of raw material or method of manufacture were also unknown. These five batches were designated P1, P2, P3, P4, and P5. Of these, P1 had the minimum impurity content of about 4%, whereas P5 had the maximum impurity content of about 14%. The compressive strength and elastic moduli of each cube was calculated from the measured ultrasonic velocity using Equations 6 and 7 and a V_0 value of 4571.4 $m\,s^{-1}$. These calculated values, along with the measured values, are shown in Figs 4 and 5 for compressive strengths and elastic moduli, respectively. The data points tend to fall on a line having slope of 45° indicating good agreement between the measured and predicted values. (Regression analysis of data yielded straight lines having slopes of 43.3° and 43.5° for strength and moduli data, respectively, with small intercepts on the σ_c axis.)

5. Conclusion

Ultrasonic velocity, compressive strength and elastic moduli data of four batches of gypsum plaster in the water ratio range 0.3–1 have been generated. The measured velocity values are fitted to an equation $V_L = V_0(1 - P)^n$ irrespective of the method of manufacture. Further, analysis of data shows that there is good correlation between compressive strength and normalized ultrasonic velocity (normalized with respect to the velocity value of pore-free gypsum) over a water ratio range 0.3–1 (porosity range 23%–73%). Similar relations also exist between elastic moduli and normalized ultrasonic velocity. Predicted values based on these correlations showed good agreement with the measured values of five different batches of plaster, indicating that it can serve as calibration graphs for using ultrasonic velocity to monitor physical properties of gypsum plaster.

Acknowledgements

The authors thank M/s Kalinga Fibroplast Pvt Ltd for providing the plaster used in this study, and Dr B. K. Sarker, Director of the Institute, for his permission to publish this paper.

References

1. K. K. SCHILLER, in "Mechanical Properties of Non-Metallic Brittle Materials", edited by W. H. Walton (Butterworths Scientific, London, 1958) pp. 35–49.
2. A. K. MAITRA and K. K. PHANI, *J. Mater. Sci.* **29** (1994) 4415.
3. D. LEWIS III, *Am. Ceram. Soc. Bull.* **57** (1978) 434.
4. J. P. PANAKKAL, *Bri. J. Non-destruct. Test.* **34** (1992) 529.
5. J. P. PANAKKAL, H. WILLIAM and W. ARNOLD, *J. Mater. Sci.* **25** (1990) 1397.
6. J. P. PANAKKAL, *IEEE Trans. Ultrason. Ferroelect. Freq. Control* **38** (1991) 161.

Received 27 January
and accepted 8 September 1995