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Communication

# A new technique for the measurement of the impact resistance of wall coatings

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**Abstract**

A new technique for the quantitative assessment of the impact resistance of thick plaster or cement coatings on walls is presented. The technique uses a new device that measures the energy absorbed by the coating during the impact of a steel ball striking its surface. The energy absorbed is proportional to the height of rebound of the steel ball. Not only is it possible to measure the damage caused to the coating, but the technique also allows a quantitative evaluation of the extent of damage per unit of energy absorbed. These measurements can help in predicting the operational lifetime of wall coatings. Some results are presented for various types of wall coatings. © 2001 Elsevier Science Ltd. All rights reserved.

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## 1. Introduction

It is sometimes difficult to obtain a quantitative measurement of the resistance to impact of a material. The fundamental aspects of simple testing methods such as the Charpy toughness test still generate interest [1,2]. These techniques are effective in measuring ductile-to-brittle transitions in metal alloys, for example. Such techniques are also used to measure the toughness of plasters and cementitious materials [3]. However, they usually require the fabrication of samples of specific size and geometry, which may be impractical for ceramic samples.

It is particularly difficult to assess the practical impact resistance of a coating of plaster or cement on a substrate such as a wall. In such conditions, it is not only the properties of the material that are tested, but the properties of the coating–wall combination. Since the coating is bonded to the wall, there can be a significant amount of interaction between the two, and it can become very difficult to distinguish the actual properties of the coating from a measurement of the properties of the coating–wall combination. There is a strong need for a simple device able to quantitatively assess the impact resistance of coating materials in situ. In this paper, we describe a simple device able to obtain a quantitative measurement of the impact resistance of a coating on a wall. Various types of cement and plaster materials are tested.

## 2. Experimental

We built a simple device as shown in Fig. 1. A 13 mm (1/2″) thick coating is applied uniformly on a standard gray 40.5 cm (16″) block cap of concrete; actual dimensions: 40.5 cm L × 20.25 cm W × 5 cm D (16″ L × 8″ W × 2″ D). A steel ball is suspended vertically so that at rest the ball touches the surface of the coating, which is also supported in a vertical position. The ball is released from an initial height $h_1$, and the height of the rebound after impact $h_2$ is measured. Before the release, the potential energy of the ball is $mgh_1$, and after the impact, $mgh_2$. The difference $mg(h_1 - h_2)$ is the energy lost to the system during the impact.

The energy balance of the ball gives:

$$E_{p1} - E_{p2} = E_{loss}$$

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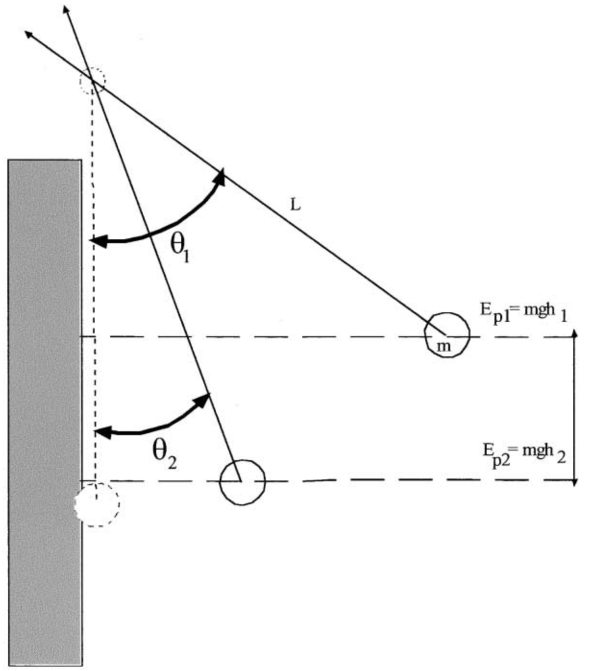


Fig. 1. Schematic of the experimental setup.

Where $E_{p1}$ is the energy of the ball before impact, $E_{p2}$ is the energy after impact, and $E_{loss}$ is the energy lost by the ball during impact. $E_{loss}$ is in fact the sum of the energy lost to the apparatus (due to vibrations, friction, and undesirable effects) and the energy required to deform the material plastically. In a perfectly elastic collision, the ball would rebound to its original position. We shall assume that the amount of energy lost to the apparatus is the same for all materials tested. As stated before, the energy measured approximates the energy spent to permanently deform the coating. Therefore, a measurement of this energy is directly proportional to the extent of deformation.

As the ball drops and hits the coating, the maximum potential energy $E_{p1}$ is converted to a maximum of

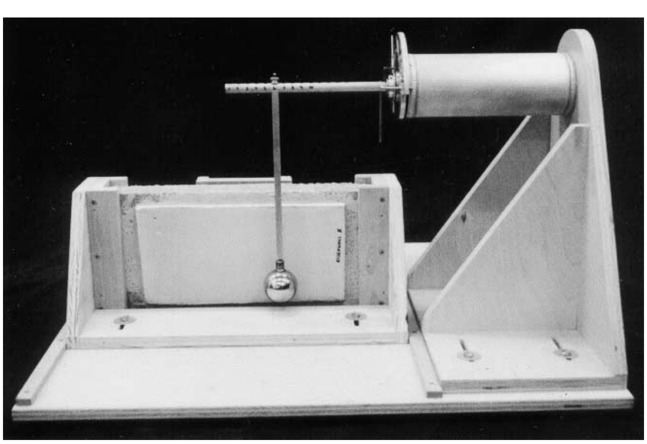

Fig. 2. Photograph of the experimental apparatus.

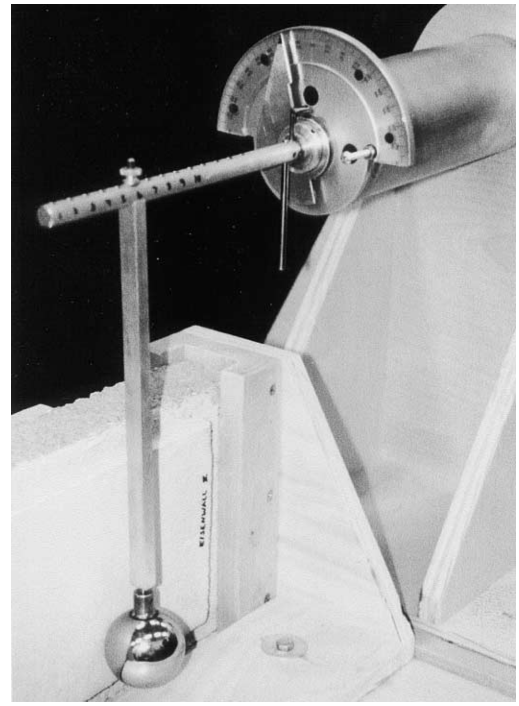

Fig. 3. Photograph of experimental apparatus.

kinetic energy at the point of impact. This kinetic energy is primarily used to break chemical bonds in the coating. From a macroscopic standpoint, this results in a plastically deformed "crushed" area, of perhaps lower porosity.

A coating that does not sustain damage will have a higher rebound and a lower energy rating. A coating with low impact resistance will be damaged more easily and have a lower rebound, hence a higher energy rating. It should be noted that this technique is probably more accurate for brittle coatings.

Photographs of the device are shown in Figs. 2 and 3. The device incorporates a 3.8-cm (1.5″) steel ball suspended from a lightweight aluminum bar. All parts are precision machined to minimize friction and unwanted vibrations, and the main shaft pivots on two oversize "frictionless" bearings. The pivoting shaft has 10 mounting holes to allow multiple data points to be collected from a single sample. The pendulum is raised to a 90° position with the horizontal, where it encoun-

Table 1
Results for various materials tested

| Material tested | Energy absorbed (mJ) | Depth of indentation (mm) | Energy/depth of indentation (mJ/mm) |
|---|---|---|---|
| 1 | 709 | 0.221 | 3274 |
| 2 | 742 | 0.401 | 1875 |
| 3 | 731 | 0.373 | 1983 |
| 4 | 775 | 0.909 | 857 |
| 5 | 776 | 1.102 | 706 |
| 6 | 781 | 0.808 | 1007 |

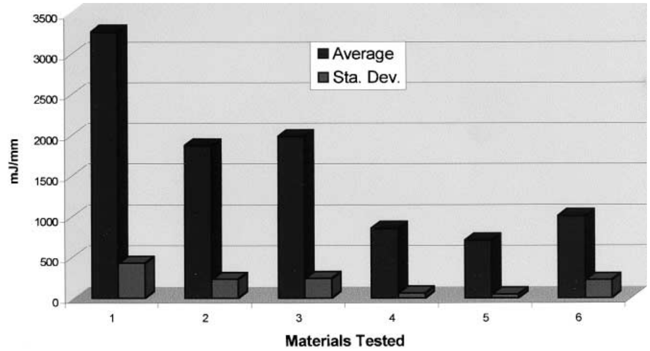


Fig. 4. Energy required for given depth of indentation.

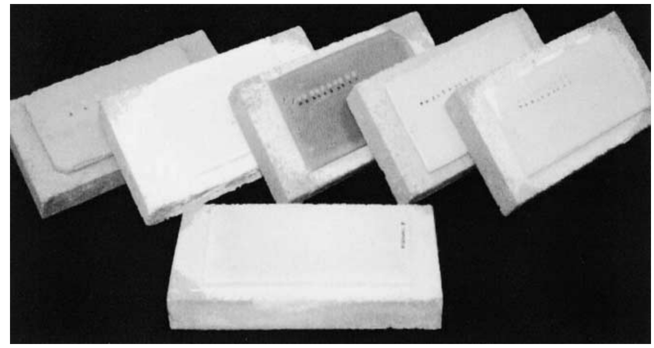

Fig. 5. Photograph of the various samples tested.

ters a rigid stop to ensure consistent energy upon release. Before the pendulum is released, a small "catch" is set which will engage the indicator arm upon rebound. The indicator arm gives an angular measurement of rebound, which is converted to energy by the following relation:

$$E_{abs} = mgL\sin\theta$$

In which $E_{abs}$ is the energy absorbed by the sample, $m$ is the mass of the steel sphere, $g$ is the acceleration due to earth's gravitational field (9.8 m/s$^2$), $L$ is the length of the metal rod, and $\theta$ is the angle the pendulum makes with the horizontal, i.e., a high absorbed energy would correspond to an angle close to 90°. A closeup photograph of the mechanics of the experimental apparatus can be seen in Fig. 3.

There are several advantages to the angular method of measurement over methods which simply drop a hard sphere of known mass onto a sample and record the vertical rebound. Most importantly, the pendulum is ideally suited to nonelastic materials that absorb a majority of the impact energy in that its low angle rebound varies as a sine function and not linearly as with the vertical rebound test. For example, a given low rebound in energy will correspond to a much greater movement of the steel sphere in the angular test, resulting in both greater accuracy and greater consistency of measurement.

Six different cementitious wall coatings were tested, exact descriptions of which can be found in Appendix A. Uniform samples were fabricated under equal conditions and allowed to cure for 72 h. The values in Table 1 are an average of 10 measurements.

## 3. Results and discussion

The results of the tests are shown in Table 1. Fig. 4 is a graphical representation of the impact energy per unit deformation, also shown in Table 1.

Sample 1 outperformed both Samples 2 and 3 (which both performed comparatively) which outperformed Samples 4, 5, and 6 (the three of which performed comparatively). Table 1 shows the average energy absorbed on impact. Sample 1 absorbed 4% less energy than Sample 2, which absorbed 5% less energy than Sample 6. The depth of indentation was measured for all samples and is shown in Table 2. However, the better representation of practical impact resistance is given by the energy required to deform and cause damage to the material, in other words the amount of energy required per unit deformation (in this case depth of penetration of the ball). This empirical quantity is also shown in Fig. 4, for all materials tested. Sample 1 is 75% more impact resistant than Sample 2, which is

Table 2
Porosity of the materials tested

| Material tested | Percent porosity |
|---|---|
| 1 | 10.6 |
| 2 | 12.0 |
| 3 | 13.7 |
| 4 | 24.6 |
| 5 | 23.9 |
| 6 | 25.0 |

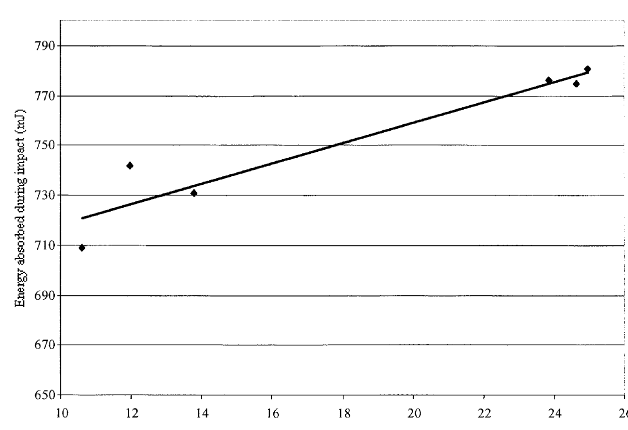


Fig. 6. Relationship between porosity and energy absorbed by the coating material.

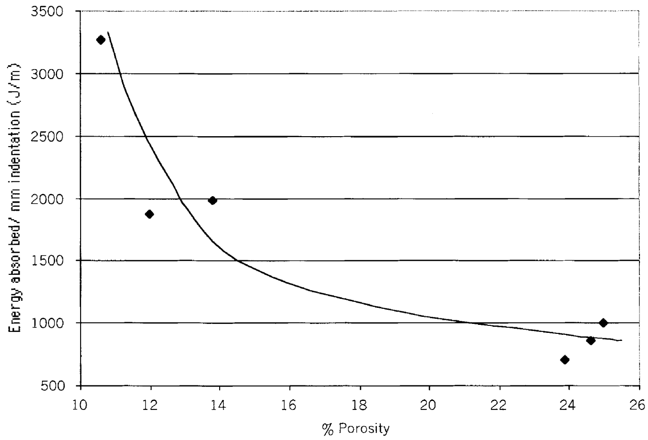


Fig. 7. Energy absorbed/indentation per percent porosity for the materials tested.

86% more impact resistant than sample 6. Sample 1 is over three and a half times more impact resistant than sample 5 (Fig. 5).

### 3.1. Role of porosity

These differences between coating materials can be explained in terms of their varying porosity. It is well known that porosity has a detrimental effect on the mechanical properties of a material. The traditional relationships for Young's modulus $E$ and strength $\sigma$ are:

$$E = E_0(1-1.9P + 0.9P^2) \text{ and}$$

$$\sigma_{fs} = \sigma_o \exp(-nP)$$

where $P$ is the percent porosity, $n$ is an experimental constant, and $E_0$ is the modulus of the nonporous material. Since the extent of the damage caused by an impact is a function of both strength and modulus, it would be expected that the porosity had a significant influence on the measurement of impact resistance. The porosity of the materials was determined by Archimedes' method (ASTM C-20), and is shown in Table 2. It can be seen that there is a general trend toward lower impact strength as we increase porosity.

One would anticipate that the amount of porosity would strongly affect the energy absorbed during impact. Fig. 6 does show that the materials with higher porosity absorbed more energy during impact. But more importantly, the measure of the energy required for a given amount of deformation (as measured by the ratio of the energy absorbed to the depth of penetration of the steel ball) might be a better measure of the performance of the coating material. Using this measurement, it is possible to obtain a quantitative indication of the amount of energy necessary per unit plastic deformation. Fig. 7 shows that the more porous materials require much less energy to create permanent damage.

## 4. Conclusions

A simple device was developed to test the impact resistance of coating materials applied on walls. The experimental setup involves measuring the energy absorbed during impact of a steel ball on the surface of the coated wall. The measurement can be complemented by a measurement of the depth of indentation formed. In first approximation, it is confirmed that the porosity of the coating plays an important role in the impact resistance of the coating. This simple and inexpensive technique allows quantitative analysis of the performance of coating materials.

## Acknowledgments

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## Appendix A. Wall coatings tested

1. RAPID SET Cement All, a mixture of fast-setting cement and sand (CTS Cement Manufacturing, Cypress, CA).
2. RAPID SET Eisenwall Cement, mixture of fast-setting cement and additives, mixed with high quality washed plaster sand (CTS Cement Manufacturing, Cypress, CA).
3. RAPID SET Mortar Mix, a mixture of fast-setting cement and graded plaster sand (CTS Cement Manufacturing, Cypress, CA).
4. QUIKRETE Mason Mix, a blend of masonry type cement and graded sand (Quikrete Construction Products, Corona, CA).
5. SUPERIOR Exterior Stucco Mix, a blend of Portland cement and sand (Paragon Building Products).
6. STRUCTO-LITE Pre-mixed Perlited Gypsum Plaster, a mixture of gypsum plaster of Paris and expanded perlite (United States Gypsum).

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