Sonic Technique Tests Refractory Quality

Impulse excitation technique allows the producer to assess the quality of refractory products by evaluating the homogeneity of the lot

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Test	Number of Measurements	Coefficient of Correlation	Equation for Linear Regression Line
Breaking strength under flexure at room temperature	175	−0.819	y=51.12−0.031x
Cold crushing strength	175	−0.903	y=81.50−0.050x

The impulse excitation technique has been used successfully for many years to determine the hardness of grinding wheels and honing stones. Investigations were carried out at the Minerals & Refractories Laboratories to determine if this method could be used to access the quality of refractories.

This nondestructive method uses an instrument originally developed to determine the modulus of elasticity of grinding wheels. Because it measures the frequency of fundamental vibrations, the instrument also should provide excellent results in testing refractory products.

Measurement principle

The instrument utilizes the impulse excitation principle, rather than continuous excitation. The method consists of the excitation of a test object by means of a light mechanical impulse. The resulting relaxation will take the form of a damped vibration, which depends on the nature of the material, as well as the geometry and mass of the test piece.

The vibration, picked up by the detector and initially amplified, is analyzed by an electronic circuit in order to select the fundamental mode from what is generally a rather complex vibration spectrum. The instrument, which measures the frequency of this fundamental vibration, consists of probes to detect the vibrations and electronic measurement circuits.

Of the two types of probes—direct contact and microphone—the direct contact probe is used most often. Shaped like a small pencil with a metallic point, it consists of a piezoelectric crystal and a two-stage preamplifier. The microphone probe is used for very small samples and in automated test set-ups.

Measurement circuits

After eliminating the first periods, which are disturbed by the harmonic interferences, the instrument will sample eight periods of the signal. Results are displayed as a numerical reading. A quartz watch with a reference crystal of 2 MHz measures the duration of these eight periods.

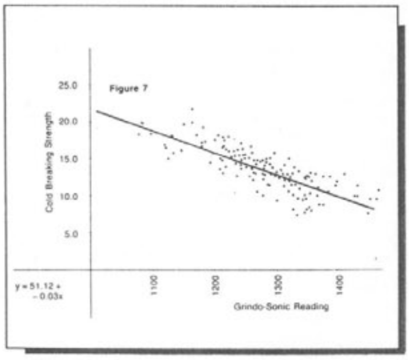
In the first stage, MRL established correlations for cold mechanical strength for shaped isolation products (see Fig. 7, 8). In the second stage, MRL oriented its study more specifically to the existing relationship between the modulus of elasticity and the cold crushing strength for these same brick.

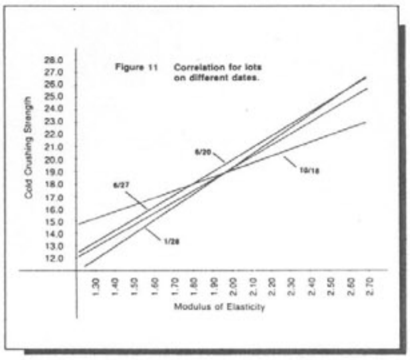
It is well worth considering the modulus of elasticity rather than the instrument reading because of the relationship between these two units, part of which is a shape factor. When reasoning about the modulus of elasticity, it is possible to compare several lines obtained from samples of different size and shape.

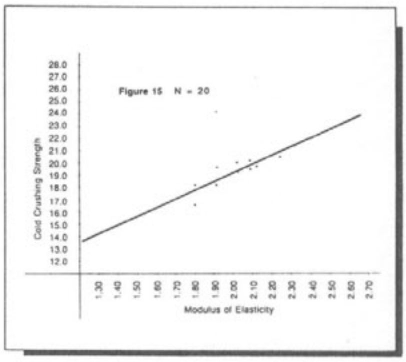
The linear relationship derived is good with a correlation coefficient of 0.803, as shown in Fig. 9 which illustrates a population of 219 values. These measurements represent 12 lots received at four different dates.

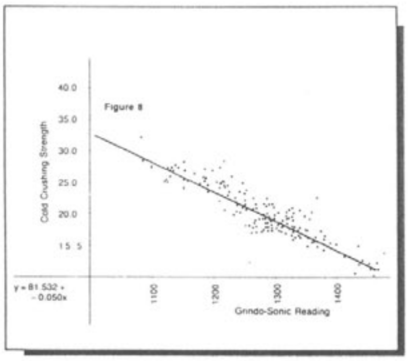
The relationship obtained for each lot is illustrated in Fig. 10. The spread of lines is due to the variation in product quality and the number of samples in each lot. The correlation established for each test shows that product quality varies as a function of time (Fig. 11). The line corresponding to the test on Oct. 18 is significantly separated from the others. This may be caused either by an important variation in product quality, or a coincidence in sampling.

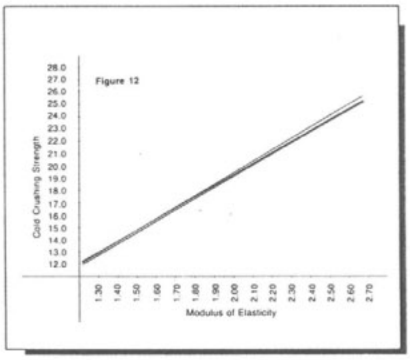
Lines are obtained by taking at random one point out of two, one point out of five, or one point out of 10, as represented in Fig. 12. The results obtained were very similar. Therefore, a line of correlation can be obtained from relatively few points as long as they origi-

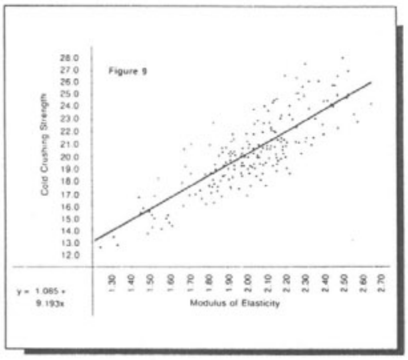


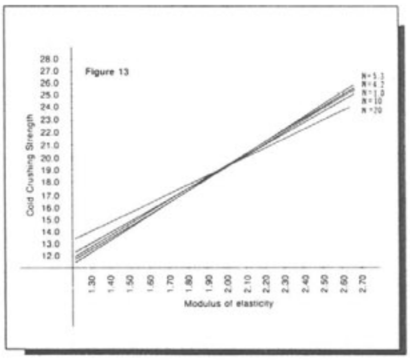


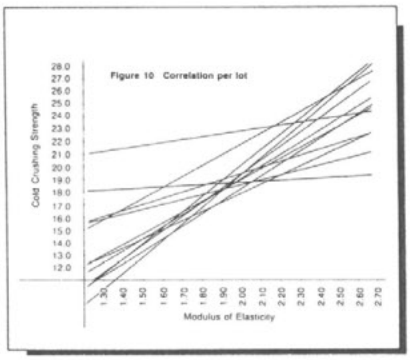


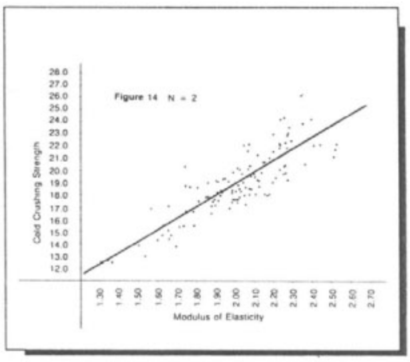












nate from several test lots.

In the next testing stage, groups were formed at a random of 2, 3, 4, 5, 10 and 20 points and the mean calculated (Fig. 13). Results indicate the higher number of points taken, the closer the cloud of points approaches the "theoretical" line (Fig. 9).

This is clearly shown by comparing Fig. 14, 15 (n=2 and n=20, respectively). By knowing the "theoretical" curve, measurements will be taken at the reception of the lot production and the mean calculated. Therefore, the cold crushing strength can be determined with increasing precision as n increases.

The relationship between the resonant frequency and the reading is:

$$R = 2T \times 10^6 = \frac{2 \times 10^6}{f}$$

where R = the reading of the instrument

T = the period of the vibration in microseconds

f = the frequency of the vibration in Hz.

Refractory products testing

Easy to use, the instrument has three principal characteristics— simplicity, speed and accuracy. Just hold the probe against the object to be tested, tap it with a hammer, and read the result on the instrument. The measurement takes only one second. A standard frequency reference, incorporated in the stop watch circuit, suppresses all calibration and stability problems.

A variation of less than 0.5% in several consecutive measurements of the same part is typical when measuring refractories. When measuring a cracked part, the instrument will dis-

TABLE 1 LOT NUMBER	NUMBER OF SAMPLES	% OF DEFECTIVE BRICK	MEAN m	STANDARD DEVIATION σ	STANDARD DEVIATION COEFFICIENT $\frac{\sigma}{m}$ %
1	89		612	158	25.8
2	200		695	140	20.1
3	132	7.6* + 12.1** = 19.7	691	155	22.5
4	203		782	91	11.7
5	161	3.7* + 16.8** = 20.5	704	114	16.2
6	133		745	75	10.1
7	54	0	510	46	8.9
8	49	0	393	32	8.2
9	50	0	500	63	12.5
10	1639	0.12	669	70	10.5
11	1500	1.05	598	83	13.0
12	130	0	871	79	9.0
13	148	1.3	1245	58	4.6
14	149	0.7	1232	39.4	3.2
15	150	0	1251	87.1	7.0
16	80	0	771	70	9.1
17	100		553	20	3.7
18	705		497	27	5.5
19	524		452	57	12.7

* cracked brick   ** inhomogeneous brick

play numbers at random. In the case of inhomogeneous parts, the values will be within a certain range, though they will vary more than 0.5%.

Viewing this phenomenon with an oscilloscope indicates a homogeneous part will show a regular envelope (Fig. 1), and a heterogeneous part will show an irregular envelope (Fig. 2).

Studying Table 1 results reveals the percentage of defects varies from 0% to 20.5% for the 19 lots tested. The proportion of cracked brick is between 0% and 7.6%.

Measurement speed permits the testing of large brick quantities. It also allows one to:

- Accurately determine % defective brick in a lot;
- Draw an accurate histogram;
- Determine variations by calculating the mean, the standard deviation and the standard deviation coefficient.

Results indicate the mean deviation coefficient may vary from 3.2% to 25.8%. A well made lot has the lowest possible standard deviation coefficient with an upper limit of 10%. This limit may be less, depending on the nature of the product and its application.

The histogram shape may vary considerably, indicating the distribution is:

- Very normal when the production is homogeneous;
- Bimodal when the lot consists of a mixture of two homogeneous production runs;
- Dissimetric;
- No shape at all as the lot is very inhomogeneous.

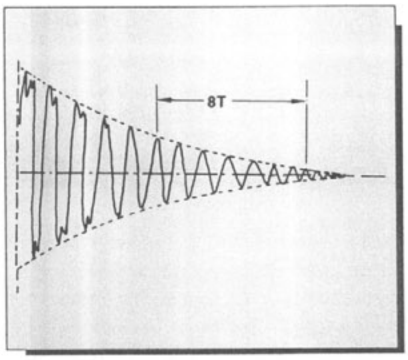


Figure 1. Vibration phenomena of a free Oscillating homogeneous object.

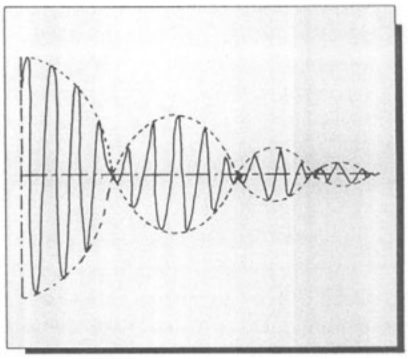


Figure 2. Vibration phenomena of a free Oscillating inhomogeneous object.

Manufacturing process stability

Comparing results obtained from two lots of the same product purchased at different dates, permits evolution monitoring of the manufacturing process. Comparison can be made by histograms, the standard deviation or the standard deviation coefficient.

Investigating correlations allows us to replace certain destructive tests with a simple resonant frequency test and to predict in-service behavior. Unfortunately, property correlations often are difficult to obtain because destructive tests are time-consuming, expensive, and a large number of results is necessary for accuracy.

This survey only studied the cold crushing strength correlation. However, its principles can be extended to other properties, such as bending strength at elevated temperature and thermal shock resistance.

Applying the resonant frequency measurement technique on refractory products and materials gives accurate, nondestructive results on product quality— immediately upon reception of the lot. More specifically, the measurement indicates production and delivery homogeneity which can be an important factor in choosing a supplier. The technique also allows a manufacturer to monitor production accurately and to determine possible degradation quickly. □

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