Correlating Process Parameters Using NDT

Florida Tile is gaining valuable knowledge about its manufacturing process through the use of statistical tools and the assistance of new computer software

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For the past three years, Florida Tile has been involved in a transformation—in the way it does business and in the way it views and evaluates its manufacturing processes. With the assistance of an outside consultant, significant progress has been made in understanding process variation.

At Lawrenceburg, Ky., Florida Tile has begun using a nondestructive testing method that provides a valuable insight into the interaction of processing variables.

Inherent in all testing methods is a variation in the instrumentation and the procedures used. This variation or standard deviation occurs because of problems in repeatability and reproducibility of the instrument measurement. Repeatability is defined as the ability to achieve testing accuracy from different operators, and reproducibility is the ability to obtain identical results test after test with the same operator. The problems became obvious as attempts were made to identify variations in raw material quality.

Florida Tile's quality control staff spent many hours this past year using new methods and computer software, only to discover that the variation in the testing procedures was as much as or greater than the variation they were attempting to identify. They backtracked and refocused on the procedures themselves in order to improve the repeatability and reproducibility of the methods and instruments.

At the suggestion of one of the firm's suppliers, the quality control staff found an instrument which would help solve some of their problems: the Grindo-Sonic. Not only is this nondestructive testing instrument easy to use, it also provides quick data output. Best of all, it is repeatable and reproducible. After a few minutes of practice, readings can be obtained with a standard deviation approaching zero.

The instrument makes use of the pulse excitation principles which analyze the transient vibration of the test piece following a mechanical impact. The energy from the impact is dissipated in the form of a damped vibration, which depends on the geometry of the piece, as well as the density and the elastic properties of the material.

A piezoelectric probe captures the vibration and converts it into an amplified analog signal. The instrument then selects the fundamental component of the vibration through time analysis and measures the natural period of the vibration against a precision quartz crystal oscillator. The results are displayed on the front panel of the instrument and, for the purpose of this article, are referred to as the Grindo readings.

Test procedures

Fig. 1 shows the testing configuration used. By tapping the corner of the tile with a small mallet and sensing the vibration with the probe, readings were obtained quickly. Changes in probe placement, operator and tapping strength caused extremely low variation in readout.

In this study, the impact was generated manually; however, the impact and probe placement could be automated. Two modes of vibration are possible: torsional and flexural. In this investigation, the torsional mode proved most useful.

The first step was to verify the instrument's ability to produce meaningful data that could be related to established test methods and to the physical characteristics of the tile.

A random sample of glazed, fired tile was collected from the production lines. Because processing variables were of immediate interest, kiln variation was minimized by collecting the samples from one kiln setting. Grindo readings were made on each of the 586 randomly selected tile (see Fig. 2).

Next, 115 tile were selected at random from the distribution, and physical measurements were made. The press and cavity number of each piece was recorded, along with measurements of weight, size and thickness.

FIG. 1

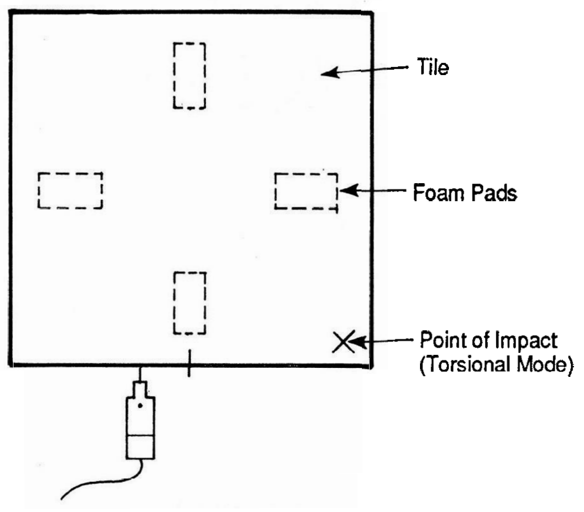


FIG. 2

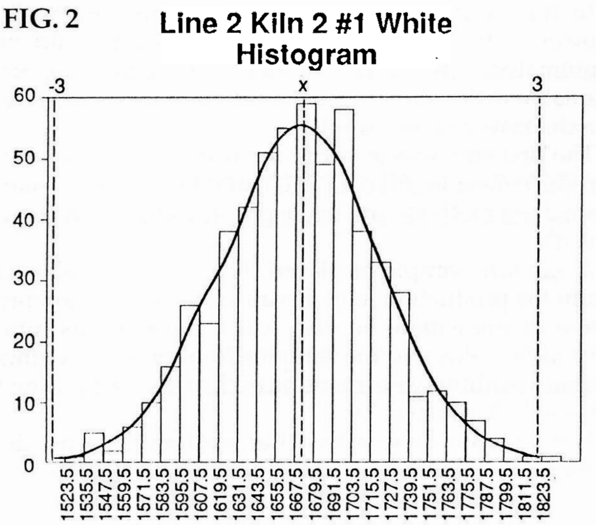


FIG. 3

DEPENDENT VAR. 1 GRINDO
SY.X=38.62344 RSQ=.788832 DEG FREEDOM=144

VARIABLES IN EQUATION

VAR.	B	T	RSQ	
0	2.01620E+04			
6	-2.31223E+01	-14.78	.72	WEIGHT
7	-3.66912E+03	-2.92	.21	SIZE
8	5.11609E+03	4.11	.71	THICKNESS

VARIABLES NOT IN EQUATION

VAR.	3	4	5	9	10	11
T	.80	.53	-2.06	-1.47	.71	-1.05
RSQ	.23	.03	.02	.05	.06	.09

ROWS NOT INCLUDED 141

FIG. 4

Grindo-Sonic Correlation with Weight

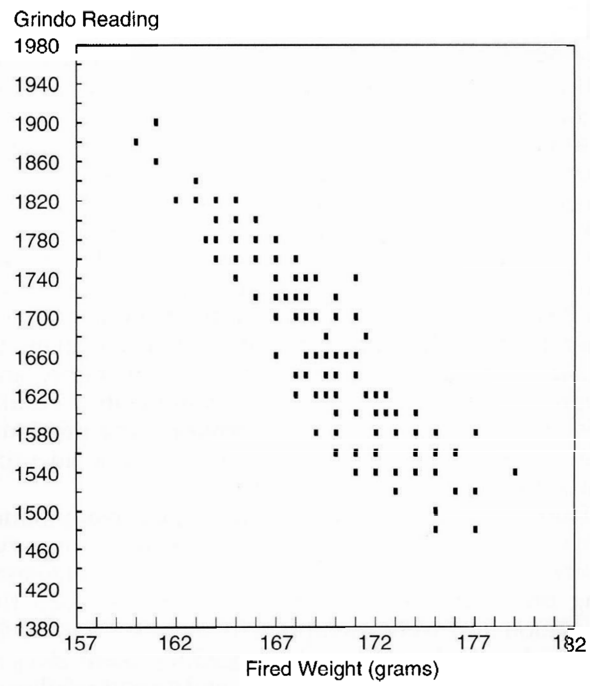


FIG. 5

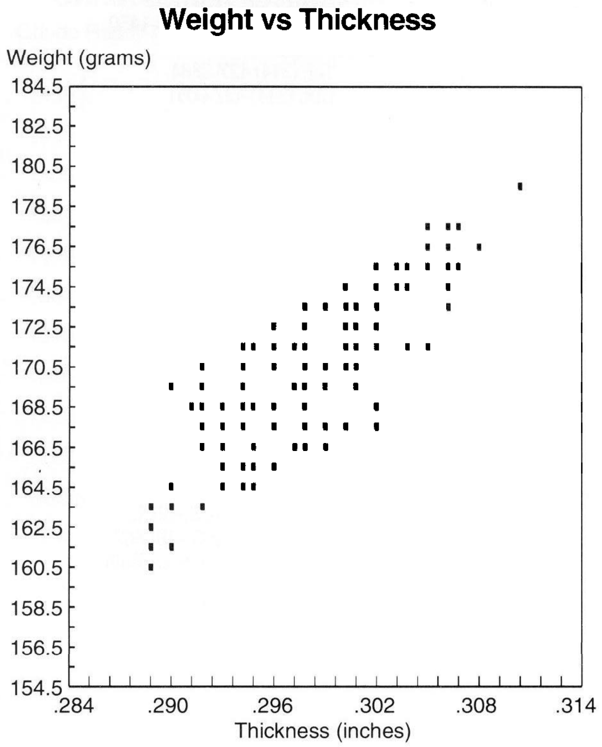


FIG. 7

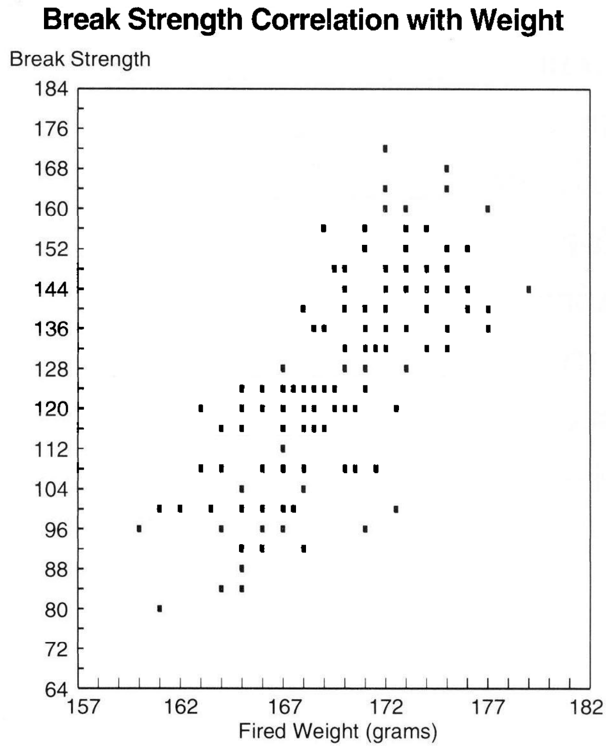


FIG. 6

DEPENDENT VAR. 2 BREAK STRENGTH
SY.X=12.76242 RSQ=.637533 DEG FREEDOM=145

VARIABLES IN EQUATION

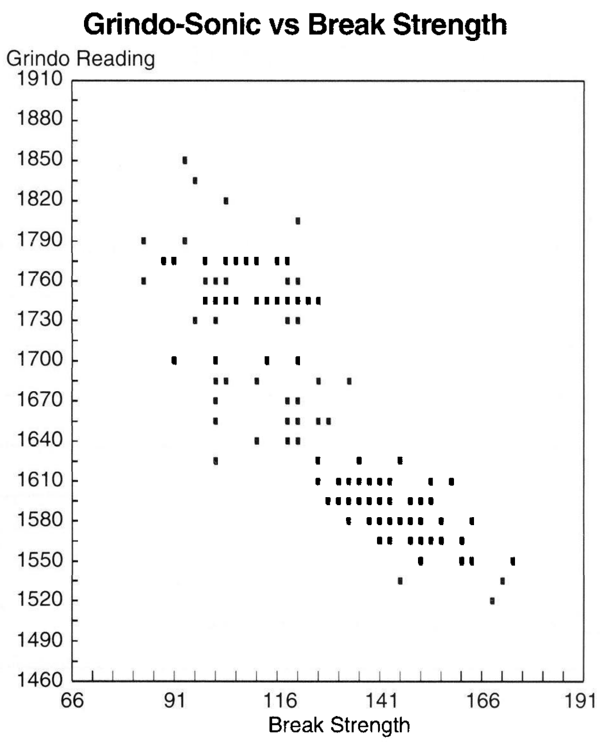
VAR.	B	T	RSQ	
0	-7.31957E+03			
6	4.03416E+00	14.39	.04	WEIGHT
7	1.54082E+03	4.09	.04	SIZE

VARIABLES NOT IN EQUATION

VAR.	3	4	5	8	9	10	11
T	-1.50	-1.22	1.80	-.69	.40	-1.51	-.29
RSQ	.18	.03	.01	.71	.03	.05	.06

ROWS NOT INCLUDED 141

FIG. 8



The tile were then broken on an apparatus similar to the specifications outlined in ASTM C- 648. All data were loaded into a multiple correlation computer program.

Computer program

The program used has the capability to correlate up to 40 variables and interactions. A correlation analysis determines which variables significantly affect the measured properties and which ones are not critical. Fig. 3 shows the final printout of the analysis, after deleting all variables not fitting in the equation.

The Grindo reading was chosen as the dependent variable. A **T** value of >2 indicates the variable is significant in predicting the dependent variable.

In this analysis, the fired weight of the tile has the strongest correlation (-14.78), followed by thickness (4.11) and size (-2.92). The SY.X value represents the variability in the dependent variable not explained by the given model. The RSQ value is the amount of variation in the dependent variable which has been explained by the variables in the model.

Using the graphics capability of the multiple correlation program, Fig. 4 shows the correlation of the weight with the Grindo reading. Fig. 5 shows the ability to correlate two of the independent variables by making one of them the new dependent variable.

Using the same data, the break strength then was made the dependent variable, and a similar correlation analysis was run (see Fig. 6). This printout shows that only 63.8% of the variation has been explained, suggesting a weaker correlation of the break strength with the process variables than with the Grindo readings.

Varying process parameters

Having shown the usefulness of the method in correlating measured properties of production tile, an experiment was intentionally designed to vary selected process parameters. The body preparation and press areas were chosen, since known variability exists and selection of a limited section of the process would help minimize the overall complexity of the analysis.

Another powerful software program was used to design an efficient and statistically accurate experiment. Fig. 9 shows the final printout of the experiment from the experimental design optimizer.

Four variables, CBF quantity (gallon of water), mix time, press and cavity number were chosen. The program calculated an optimal design of eight experiments out of a possible 36 which could be run. The experiments were then run in sequence, with the appropriate variations in process parameters. Additional measurements of green ware weight and thickness were made as 10 tile from each experiment were collected. The tile were then fired, without glazing, in one kiln setting.

In the final printout (Fig. 10) of the multiple correlation analysis, with the Grindo-Sonic as the dependent variable, the weight and thickness of the tile show the strongest correlation with the CBF quantity being somewhat weaker.

The remaining variable of interest is the CBF (batch

FIG. 9

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VAR. NO	VAR. NAME	N LEVELS	LEVELS		
1	CBF	2	15	16	
2	Mx Time	3	2.5	3.5	4.5
3	Press	2	41	42	
4	Cavity	3	1	3	5

Squared Variables

VAR. NO	SQUARED EFFECTS
2	YES
4	YES

The total time taken: 0.12 min
The Number of Experiments in the Design: 8
The Average error of prediction: 1.031
The Maxium error of prediction: 1.275
at 15 3.5 42 5
The Minimum error of prediction: 0.791
at 16 4.5 41 3
The total number of admissible expts.: 36

The EDO* Generated Design is .

	CBF	Mx Time	Press	Cavity
1	15	2.5	41	1
2	15	4.5	41	5
3	16	2.5	42	5
4	16	4.5	42	1
5	16	3.5	41	3
6	16	4.5	41	3
7	15	3.5	42	1
8	15	2.5	42	3

*EDO — EXPERIMENTAL DESIGN OPTIMIZER VERSION 5.0

FIG. 10

DEPENDENT VAR. 1 GRINDO READING
SY.X=18.14920 RSQ=.879669 DEG FREEDOM=73

VARIABLES IN EQUATION

VAR.	B	T	RSQ	
0	2.41151E+03			
2	2.72589E+01	6.08	.17	CBF
3	-1.07889E+01	-2.25	.28	PRESS
5	-1.37402E+01	-2.92	.00	CAVITY B
7	-1.83029E+01	-20.16	.62	WEIGHT
8	7.99042E+03	9.76	.54	THICKNESS

VARIABLES NOT IN EQUATION

VAR.	4	6	9	10	11
T	-.37	-.59	-.37	-.37	-.37
RSQ	.58	.30	.79	.58	.63

ROWS NOT INCLUDED 8

FIG. 11

Grindo-Sonic Correlation with Weight

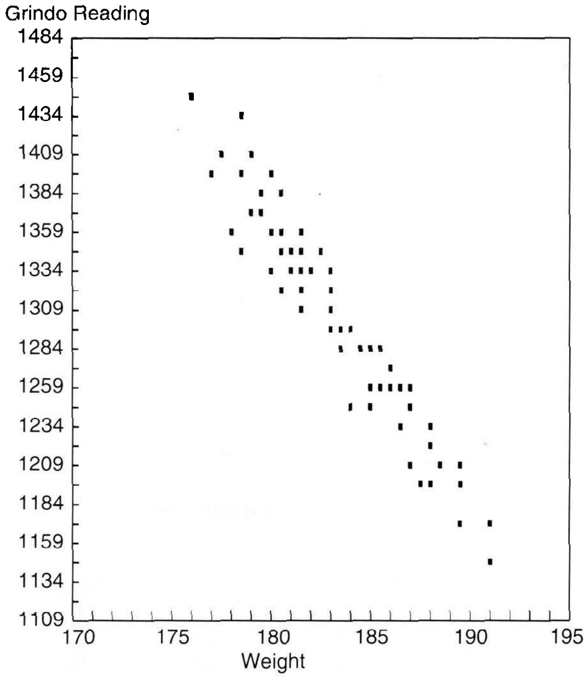
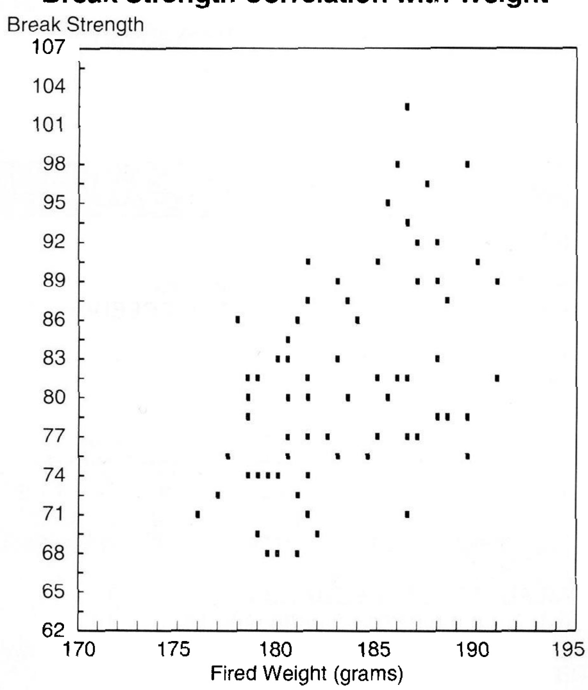


FIG. 12

Break Strength Correlation with Weight



moisture) quantity, which was chosen at only two levels in the experiment. To graph this correlation, the prediction feature of the software was used to generate data points between the two end points. Fig. 13 shows the expected correlation of Grindo readings with the CBF quantity.

With the break strength as the dependent variable, the analysis was run again. The graph (Fig. 12) and the printout (Fig. 14) indicated a weak correlation with only 47.8% of the variability being explained.

The Grindo-Sonic testing instrument has been shown to be an accurate, easy-to-use tool, generating data that complement the statistical problem-solving methods used today. The method demonstrated is a starting point in gaining knowledge of processing variable interactions.

Continuing and future work will focus on refining the statistical models used, as well as confirming the ability of the results to contribute to the constant improvement of quality. □

For more information on the Grindo-Sonic, complete the fax/mail form on the back.

FIG. 13

Grindo-Sonic Correlation with CBF Quantity

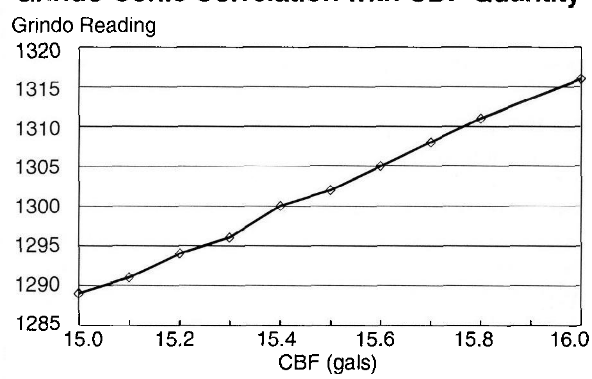


FIG. 14

DEPENDENT VAR. 2 BREAK STRENGTH
SY.X=6.80327 RSQ=.477490 DEG FREEDOM=76

VARIABLES IN EQUATION

VAR.	B	T	RSQ	
0	-1.19243E+02			
5	4.51128E+00	4.78	.12	CAVITY A
8	1.04458E+00	4.77	.12	WEIGHT

VARIABLES NOT IN EQUATION

VAR.	3	4	6	7	9	10	11
T	1.75	1.10	-.54	-1.24	-1.45	-.54	.54
RSQ	.08	.29	.00	.00	.75	.50	.98

ROWS NOT INCLUDED 57