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A NEW WAY OF PREDICTING CEMENT STRENGTH — FUZZY LOGIC

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ABSTRACT

This paper is to analyse the fuzzy logic method of predicting cement strength and to calculate some samples with fuzzy models. In order to compare, samples of them are calculated with regression method. All of results are shown in both root mean square error and scattered map. © *1997 Elsevier Science Ltd*

Introduction

A number of attempts have been made to predict cement strength from the examination of the corresponding cement and thus to control the cement process. The reported methods are generally based on physics and mathematics. Usually, the 1-day (3-day) tested values of cement in chemistry and physics are used to predict the 28-day compressive strength (ccs) of cement. In the past, this problem was treated in a simple regression formula. On the base of our research (1-5), we think the prediction of cement strength belongs to the fuzzy logic problem domain. It should be studied with fuzzy theory (6).

The fuzzy of predicting cement strength lies in:

(1) Fuzzy Property in the Field of Tested Values. In order to get the tested values normally, the proper authority should make out specific rules to test instruments, equipment and operation. However, because of mechanical wear and transfiguring, the precision of instruments and equipment will diminish after being used for some time. At the same time, the operators' characters, habits and their understanding of the standard will make diversity in testing results. Therefore, the tested values in practice are not the same as ones shown by authority. That is to say, the tested values in chemistry and physics can only represent the property of cement to a certain extent. That is the fuzzy property in the field of tested values. But people used to take it as definite.

(2) Fuzzy Property Caused by Difference in Tested Sample. As shown in deep research, each tested value in chemistry and physics comes from a different respective sample. The sample used to be tested in chemistry isn't the one used in physics. The sample used to test 1-day ccs also isn't the one used to test 3- and 28-day ccs. Therefore, the tested values in chemistry and physics can only partly represent the property of the sample, which was used to test the 28-day ccs. It is the fuzzy properties caused by differences in the tested sample,

that make it impossible to get an analytic representation between the 28-day ccs and the tested values. It explains that well, that the values of 28-day ccs of two the samples are of great difference, but the tested values are almost identical.

(3) Fuzzy Property in Correlating Between the Tested Values and the 28-Day ccs. The traditional regression theory for predicting cement strength is based on classical sets theory. Only the terms correlated to the 28-day ccs are considered in regression predictive models. In fact, all of the tested values in chemistry and physics express the property of cement from different aspects. And they are correlative to the 28-day ccs to a certain extent. The factors abandoned do relate to the 28-day ccs, but its correlative extent isn't so large as the ones selected in regression formula. The factors are absolutely divided into two types—"relative" and "irrelative" in regression formula, and only the relative factors are considered. Thus, some useful information may be lost. Such simple handling doesn't completely conform to practice.

The diversity in correlation between the tested values and the value of the 28-day ccs is an objective reality, which is called the fuzzy property in correlating. As mentioned above, the essence of the fuzzy property is to accept the middle state in extent of membership. In fuzzy mathematics, the membership "1" represents the tested value, which is related to the 28-day ccs absolutely, the membership "0" represents the tested value, which does not relate with the 28-day ccs absolutely. Factors not only in relative to 28-day ccs, but also in a certain extent relative to 28-day ccs can be considered in fuzzy models. It is easy to know, that this logic is more rational, and it is just the characteristic of fuzzy logic.

Usually, the 1-day (3-day) tested values of cement (clinker) in chemistry and physics are used to predict the 28-day ccs. It is a multivariable, nonlinar, large time-delay problem. It must be researched in fuzzy theory. In the past, such a complicated problem was treated in a simple way. We can easily know, there are some shortcomings in reasoning and methods, which is the reason that regression prediction can't be applied in practice widely.

On the basis of our research (1-5), we think this problem belongs to the fuzzy problem. Fuzzy mathematics should be used to study it. Of course, there are various models for prediction. The practical model should be the most efficient one, which is selected from many models.

Fuzzy Models of Predicting Cement Strength: Fuzzy Pattern Recognition

In order to predict cement strength, we can make use of the fuzzy pattern recognition. If we can affirm what pattern the sample individual belongs to, then the strength value of the individual is just that pattern. There are two models widely used in practice: the distance model and the similarity model.

1. Distance Model. A pattern discribed with n factors is a point in n-dimensions space. A system consisted of m patterns is a point space, which is contained with m n-dimensions points.

According to the principle of the least distance, after the least distance between patterns and the individual has been determined, the individual belongs to the pattern in relation to the least distance. Distance can be written as:

$$d_{ij}=\left[\sum_{k=1}^{n}(\alpha_{ik}-\beta_{jk})^{p}\right]^{1/p},i=1,\cdots,m;k=1,\cdots,n \tag{1}$$

The d_{ij} in Eq.1 stands for the distance between sample individual $B_j = (\beta_{j1},\cdots\beta_{jn})$ and patterns $A_i = (\alpha_{i1}, \cdots\alpha_{in})$, p stands for the index, α_{ik} and β_{jk} stand for the k-th tested value of both A_i and B_j respectively. From the weight of factors being considered, we get weighted distance shown as Eq.2:

$$d_{ij}=\left[\sum_{k=1}^{n}\omega_k(\alpha_{ik}-\beta_{jk})^{p}\right]^{1/p} \tag{2}$$

Here $$\sum_{k=1}^{n}\omega_k=1$$

We should predict the cement strength value instead of observing the pattern in practice. It is more difficult than recognizing the pattern. A key to the problem is how to get the strength value from recognized pattern. As shown in Eq.7, in a two-patterns system, individual membership in relation to one pattern is equal to the relative distance to another numerically. Therefore, with an individual to be measured being put into a two-patterns system, we can get memberships in relation to two patterns respectively. The two patterns are the nearest from the individual to be measured. From Eq.7, we can get the distance model of predicting cement strength shown as Eq.3.

$$Y_j=\mu_1 y_1+\mu_2 y_2 \tag{3}$$

In Eq.3 Y_j stands for the predicted strength value of individual B_j, μ_1 and μ_2 stand for the memberships of individual B_j in relation to the nearest and the next nearest pattern, y_1 and y_2 stand for the strength value of the nearest and the next nearest pattern. As mentioned above, there are

$$\begin{aligned}\mu_1&=d_{j2}/d\\ \mu_2&=d_{j1}/d\\ d&=d_{j1}+d_{j2}\end{aligned} \tag{4}$$

In Eq.4 d_{j1} and d_{j2} stand for the nearest and the next nearest distance from individual to patterns.

2. Similarity Model. We know that the membership can be represented by similarity. From fuzzy mathematics, the similarity can be shown as following:

$$\sigma(A_i,B_j)=\frac{\sum_{k=1}^{n}\min(\alpha_{ik}.\beta_{jk})}{\sum_{k=1}^{n}\max(\alpha_{ik}.\beta_{jk})},i=1,\cdots,m;k=1,\cdots,n \tag{5}$$

According to the principle of the maximum membership, the pattern of a sample individual to be measured can be described as that pattern in relation to the maximum membership.

TABLE 1

General Conditions and Root Mean Square Error (MPa) of Predicting

order of samples	source of samples	capacity of samples	root mean square error in Mpa	
			with fuzzy model	with regression model
1	Jinshan plant	80	1.78(Fig.1)	3.00(Fig.2)
2	Wusong plant(92)	80	1.57	
3	Wusong plant(94)	80	1.42(Fig.3)	
4	Putong plant	110	1.58	
5	Hongshan plant	76	1.50	
6	E-cheng plant	90	1.73(Fig.4)	2.10(Fig.5)

Thus, the similarity model of predicting cement strength can be shown as Eq.6.

$$Y_j = \mu_{ji} y_i \tag{6}$$

In Eq.6, μ_{ji} stands for the maximum membership of sample individual B_j in relation to patterns. The y_i stands for the strength value of that pattern. Obviously, $i \in \{1,\ldots,m\}$.

Practical Examples

We made use of the fuzzy models in this paper to predict cement strength of six samples. In order to compare, we also predicted two samples among them with the regression model. The general conditions of samples are shown in Table 1. All of predicted results are shown as Table 1 and Figure 1 ~ Figure 5. The characteristics of six samples are shown in Table 2.

We made use of root mean square error to evaluate the predicting method. The root mean square error can be shown as following:

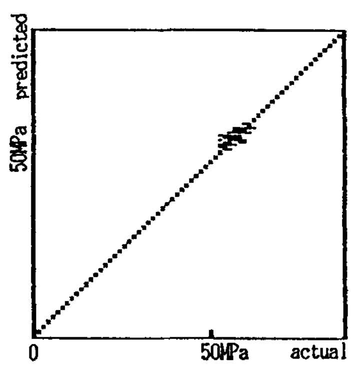

FIG. 1.
Result of fuzzy predicting for sample 1. E = 1. 78MPa.

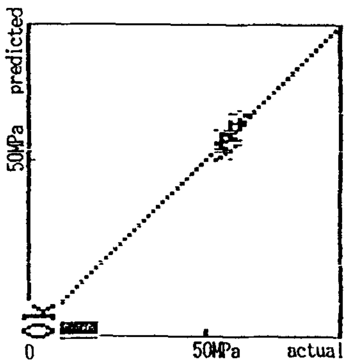

FIG. 2.
Result of regress predicting for sample 1.
E = 3. 00MPa.

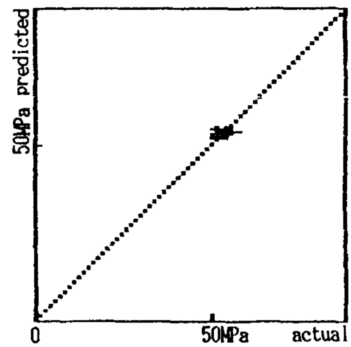

FIG. 3.
Result of fuzzy predicting for sample 3.
E = 1. 42MPa.

$$E=\left(\sum_{j=1}^{L}(y_j-\hat{y}_j)^2/(L-1)\right)^{1/2}, j=1,\cdots,L \tag{7}$$

In Eq.7, E stands for the root mean square error of predicting, Y_j and $\hat{Y}_j$ stand for the actual 28-day ccs and the predicted 28-day ccs respectively, L stands for the predicting capacity.

Summary

We think the prediction of cement strength belongs to the fuzzy system problem, and fuzzy mathematics should be used to study it. This paper is to propose some fuzzy models to predict cement strength. The practical model should be the most efficient one, which is selected from many models .

This paper is to open up the new way for predicting cement strength, at the same time, to pioneer the new applying range for fuzzy theory.

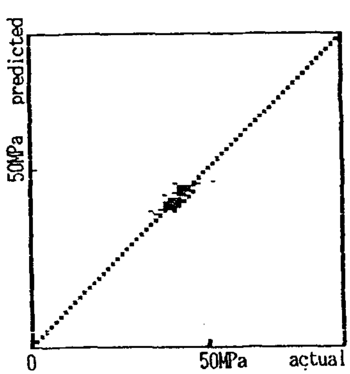

FIG. 4.
Result of fuzzy predicting for sample 6.
E = 1. 73MPa.

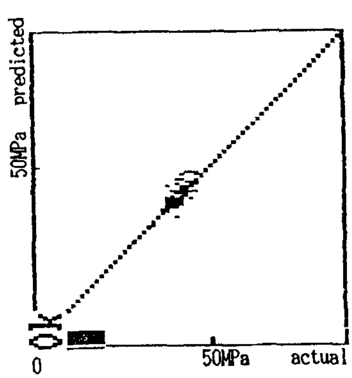

FIG. 5.
Result of regress predicting for sample 6.
E = 2. 10MPa.

TABLE 2

Characteristics of Six Cement Samples

order of samples	SO_3 (%)	slag (%)	fineness (%)	flexural strength(MPa)		compressive strength(MPa)		
				1day	1day (with thermal)	1day	1day (with thermal)	28day
1	2.22	13.16	3.44			19.6	36.9	57.1
2	2.04	40.00	6.28	2.4		7.9		53.6
3	2.09	44.28	5.31	2.4		8.1		53.7
4	2.08	43.96	5.43	2.0	5.3	8.0	28.5	51.9
5	2.50	45.37	6.79		2.8		12.7	38.9
6	2.25	46.77	6.07		3.3		17.1	42.5

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