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Prediction of Flexural Strength By Using RSM

Niyazi Ugur Kockal[1]

[1]*Akdeniz University, Department of Civil Engineering, 07058, Antalya, Turkey*
Email:<ukockal@yahoo.com>.

ABSTRACT

In this study, a statistical method was applied to analyze the experimental data of the compressive strengths, flexural strengths and elastic moduli of cementitious materials. For this purpose, response surface methodology (RSM) was adopted in optimising experimental data obtained in previous study. Regression equation was yielded by the application of RSM relating response variables to input parameters. With the help of this method, the experimental results could be predicted accurately within an acceptable range of experimental errors. Also, a new empirical relationship between flexural strength, modulus of elasticity and compressive strength is proposed.

INTRODUCTION

The static modulus of elasticity, flexural strength and compressive strength are important properties of materials [Anbuvelan and Subramanian 2014]. These are the basic parameters for computing deflection in reinforced concrete structures. Various countries have been established their design codes based on this empirical relationship between static modulus of elasticity, modulus of rupture and compressive strength of plain concrete at 28 days of curing. The compressive strength of concrete is commonly considered in structural design, but for some purposes, the tensile strength is of interest for example in the design of highway and airfield slabs, shear strength and resistance to cracking [Khan and Lynsdale 2002].

The aim of this study is to identify the input variables and provide the requisite solutions by researching methods to represent, design and process models with promoting the use of these by researchers. Therefore, present study illustrates parameter optimization of compressive strength, flexural strength and modulus of elasticity of cementitious materials by statistical design.

OPTIMIZATION STUDY

In Design Expert software, historical data design is also used for importing data that already exists [Design-Expert software User's guide 2014]. RSM has shown to be a powerful tool in optimizing experimental conditions to maximize or minimize various responses. Modulus of elaticity, flexural strength and compressive strength were the three parameters investigated. According to range of each variable, the independent variables are coded to the (-1, 1) interval. The low and high levels are coded -1 and +1, respectively. The three factors and lower, middle and upper design points for RSM in coded and uncoded values. In RSM, natural variables are transformed into coded variables that have been defined as dimensionless with a mean zero and the same spread or standard deviation. Multiple regression equations were generated relating response variable to coded levels of the independent variables.

Statistical method was applied to analyze the experimental data of the compressive strengths, flexural strengths and elastic moduli of materials. The experimental data was obtained from a previous study [Kockal 2015]. In pronounced study, performance of cement mortars prepared by replacing 30% and 60% of crushed calcareous fine aggregate with waste fine aggregates namely, crushed brick aggregate, crushed marble aggregate and crushed ceramic aggregate was investigated. Fine aggregate increases the initial modulus of elasticity and reduces the strength and ductility of mortar in comparison to cement paste [Shraddhakar et al. 1990]. Fine aggregate acts as a stress raiser, thus increasing the local compressive and lateral tensile stresses within the material [Attiogbe and Darwin 1985]. The increase in local stresses reduces both the strength and the strain capacity of the composite materials compared to paste. Lim and Zollinger (2003) found that the relationship between the compressive strength and elastic modulus of materials could be expressed in a single equation regardless of aggregate type and mixture proportions. This finding contradicts test results obtained by Amjad (1999) which indicated that the red sand produced mortar with higher strength than that of white sand and the modulus of elasticity for the white sand mortar was higher than that of the red sand mortar. It is obvious that fine aggregate type and its proportion lead to differences in cementitious material behavior due to these mentioned reasons. In the present study, an attempt has been made to obtain a generalized model for mortars with different originated fine aggregates.

X represented compressive strength, Y represented modulus of elasticity and Z represented flexural strength. The test of multivariate analysis of variance with 95% confidence level (α =0.05) was applied.

The application of response surface methodology yielded the following regression equation which is an empirical relationship between the flexural strength (σ_t) and compressive strength (σ) and modulus of elasticity (E).

$$\sigma_t=a+b*\sigma+c*E+d*E^2 \tag{1}$$

The value of the determination coefficient (R^2 = 0.89) verifies the suitable fit of the model, thus indicating a discrepancy of 0.11 % for total variation, which is a normally accepted range of experimental error. Table 1 shows actual and predicted values by response surface fit for flexural strength. The large R^2 values were evidences for the good relationships which proved that there was no remarkable variations between the experimental and estimated values [Kockal 2011]. The value of the adjusted determination coefficient (adjusted R^2 = 0.66) is also high enough which indicates a significance for the model. Figure 1 illustrates 3D view of the predicted values obtained by the software. The F value of the quadratic model and individual model terms helps in finding their significance. The F-test with a very low probability value showed a very high significance for the regression model.

Table 1. Actual and Predicted Values by Response Surface Fit for Flexural Strength

X	Y	Z	Z Predicted	Residual	Residual %
43.8	2.845e+04	8.6	8.43	0.1681363	1.9550734
43.0	2.82e+04	8.5	8.32	0.1750163	2.0590148
42.8	2.813e+04	7.9	8.30	-0.401113	-5.077376
42.1	2.794e+04	8.1	8.17	-0.069027	-0.852186
40.2	2.756e+04	7.8	7.68	0.1176352	1.5081434
39.0	2.431e+04	7.7	7.63	0.0655586	0.8514102
37.4	2.389e+04	6.8	6.86	-0.056207	-0.826568

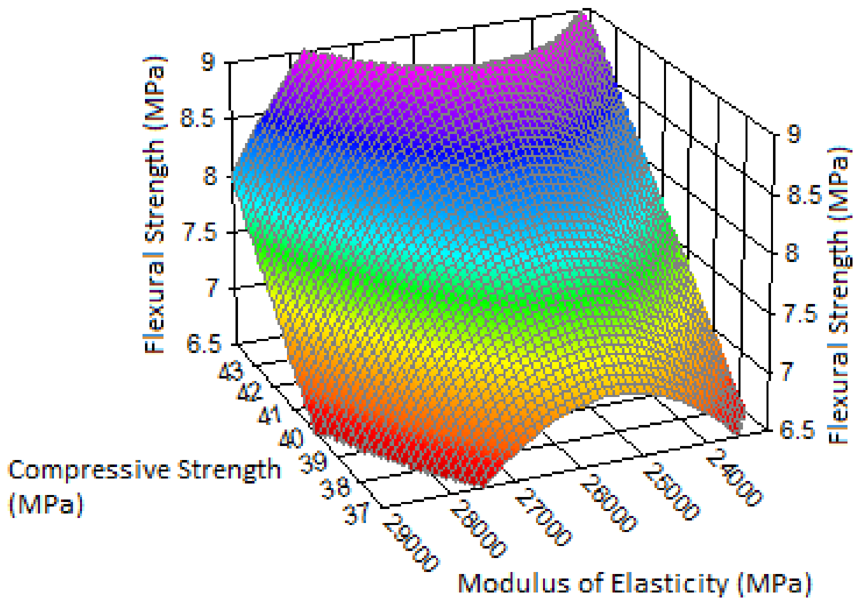

Figure 1. 3D View of Predicted Values

CONCLUSION

The results demonstrated that the model developed was quite accurate as the percentages of error in prediction were in a good agreement. All the estimated values were close to actual values and showed small variations with the experimental results.

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