Prediction of post-heating damage in self-compacting concrete

R. H. Haddad[1], **A. N. Ababneh**[1], **R. Odeh**[1], **and H. Amawi**[1]

[1] *Department of Civil Engineering Jordan University of Science and Technology,*
P.O. Box 3030, 22110 Irbid, Jordan. E-mail: rhaddad@just.edu.jo

---

Abstract

Empirical models have been developed based upon on a comprehensive study aimed at establishing a data base to understand more the thermal behaviour of self-compacting concrete and determine the most appropriate invasive methods to detect resulting damage. Two groups of models have been generated using the statistical software “Statistica”; the first relate induced heat damage in terms of residual compressive strength and elasticity modulus to various damage indices of invasive techniques used; whereas the second models were empirical parametric models for residual compressive strength and elasticity modulus as function of controlling factors. The fit of various models of data used ranged from very good to excellent.

Keywords: Concrete, damage, cracks, statistical modelling, waves.

---

1. Introduction

The use of self compacting concrete (SCC) has been on rise since 20 years ago. SCC has been used extensively in the latest decade in construction of highway pavements, bridges, and multi-storey building [1]. Regardless of the many works published about SCC, there still a lack in the knowledge regarding behaviour of SCC under elevated temperature [2-3]. Understanding such behaviour and determining proper testing techniques to evaluate the extent of resulting damage are very essential to build future repair strategies for fire-damaged structures. For this, an experimental study was undertaken to investigate the potential use of various well-known invasive techniques in detecting heat damage and evaluating its extent in self-compacted concrete (SSC). Standard cylindrical (150x300 mm) and prismatic SSC specimens were cast at three w/c ratios from 0.4 to 0.5 and two types of aggregates (limestone and basalt), cured for 28 days and then stored for about 2 months under different environments to modify internal humidity to four distinct levels ranging from 30 to 95%. Reference crushing compressive response was obtained from measurements on standard cylinders, whereas invasive reference measurements using ultrasonic pulse velocity (UPV), resonance frequency (RF), and rebound hummer (RN) testing techniques were carried out on prismatic specimens. Specimens were then subjected to elevated temperatures from 300-600^o, before restored for another 2 months at the different environments to regain the humidity each specimen had prior to heating. Finally, heat-damaged cylinders were crushed while prisms were tested non-destructively in pairs.

2. Models development, discussion and conclusions

2.1 Invasive Evaluation

Correlation between damage indices defined in terms of (ultrasonic pulse velocity, resonance frequency, and rebound number) and residuals for compressive strength and elastic modulus has been established with a multiple coefficients of determination (R^2) ranging from (80-90%) and (57-69%), respectively. The statistical analysis indicated that UPV test had the highest sensitivity towards induced cracking followed by RF and RN tests. Models for residual compressive strength and elastic modulus that incorporated all damage indexes as independent variables showed better fit of data obtained experimentally.

2.2 Modelling Residuals

Empirical models have been developed to predict residuals for compressive strength (RCS) and elastic modulus (REM) in terms of controlling parameters namely: aggregate type, w/c ratio, relative humidity inside specimens, and exposure temperature; eqns. 1 and 2. The multiple coefficients of determination were in excess of 90% for both equations. The residuals distribution showed no specific trend to indicate that the adopted models are improper.

$$\left.\begin{aligned} RCS &= K\frac{1-(0.00345\sqrt{T}-0.4)^3}{1+(0.0045T-0.4)^2} \\ K &= (123LA+136BA)\left(\frac{w}{c}\right)^{0.15}(1-\frac{RH}{100})^{0.01} \end{aligned}\right\} \qquad (1)$$

$$\left.\begin{aligned} REM &= K\frac{1-(0.0061\sqrt{T}-0.72)^2}{1+(0.0061T-0.72)^2} \\ K &= (286LA+302BA)\left(\frac{w}{c}\right)^{0.13}\left(100-RH\right)^{0.01} \end{aligned}\right\} \qquad (2)$$

Where, K, w/c, RH, and T are coefficient of basic properties, water to cement ratio, percentage relative humidity, and, exposure temperature in degree Celsius, respectively. LA and BA refer to limestone and basalt aggregate that take values of either 0 or 1 (dummy variables).

2.3 Model Trend Behaviour

To exam the model trend behaviour, eqns. 1 and 2 were used to generate residuals for compressive strength and elastic modulus considering various typical values for the models-controlling basic property parameters, w/c ratio, aggregate type, and relative humidity for variable exposure temperatures. For studying the effect of a specific parameter, the other controlling parameters were kept constant.

Figures 3 demonstrates the effect of elevated temperature on concrete limestone mixtures made with w/c ratios, ranged from (0.3-0.60), at a constant relative humidity of 80%. The trend behaviour of the curves with temperature is in an excellent agreement with that obtained experimentally. Similar to their experimental trend behaviour, the residuals for compressive strength and elastic modulus experienced slightly higher values at higher w/c ratio.

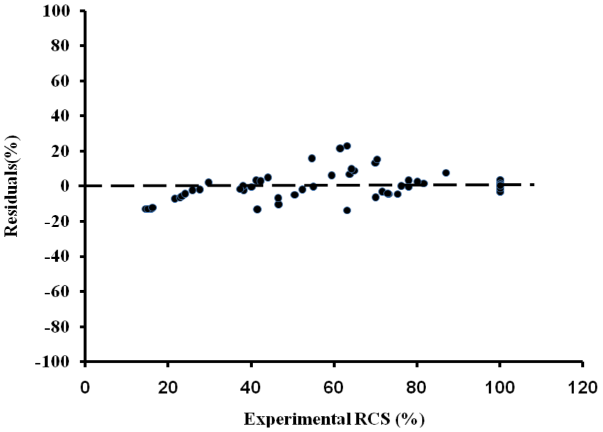

Figure 1: Residuals versus experimental residual compressive strength.

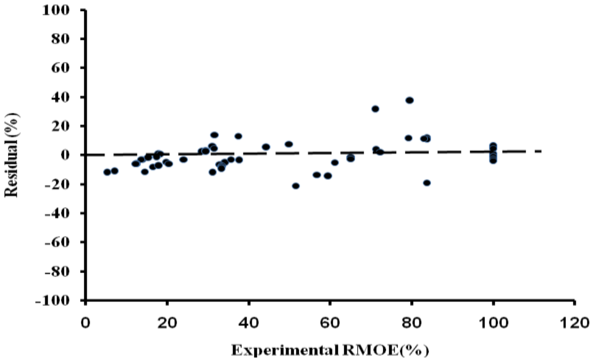

Figure 2: Residuals versus experimental residual elastic modulus.

Figures 4 demonstrate the effect of elevated temperature on RCS of concrete mixtures made at a constant w/c ratio of 0.50 using two types of aggregate, limestone and basalt, at constant relative humidity of 80%. The trend behaviour of the curves with temperature is in an excellent agreement with that obtained experimentally. Similar to their experimental trend behaviour, the residuals for compressive strength and elastic modulus showed higher values for the mixture with basalt as compared to that with limestone.

Similar to their experimental trend behaviour, the predicted residuals for compressive strength showed fairly lower values for the mixture with higher relative humidity content. On contrary, the predicted relative humidity had insignificant influence on residual elastic modulus as stipulated experimentally.

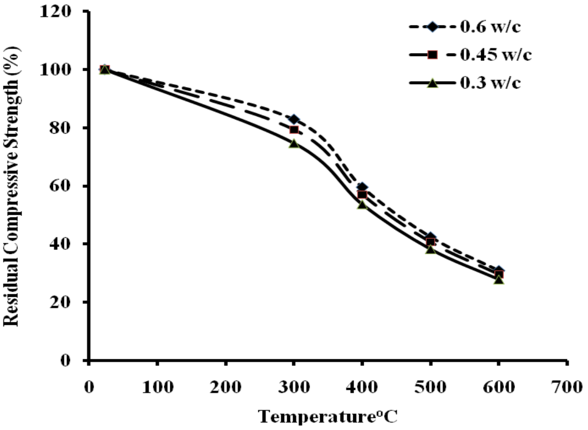

Figure 3: Effect of elevated temperature on RCS prepared of limestone aggregate at different w/c ratios (RH=80%).

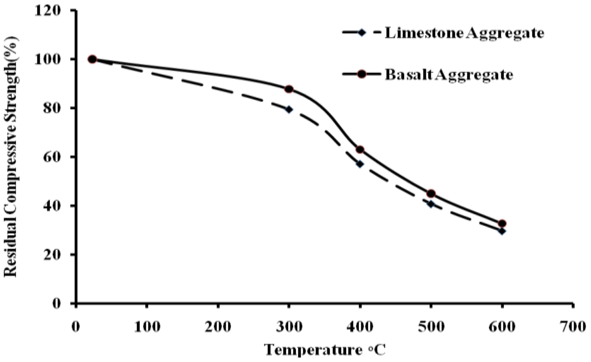

Figure 4: Effect of elevated temperature on RCS for concrete prepared at 0.45 w/c ratio using two types of aggregate, limestone and basalt. (RH=80%).

References

[1] Ouchi, M. Nakamura, S. Osterberg, T. Hallberg S. and Lwin, M. *Applications of self-compacting concrete in Japan, Europe and the United States. High Performance Computing, 5th International Symposium, ISHPC,* 2003.

[2] Persson, B. Self -compacted concrete at fire temperatures, *Cement and Concrete Research*, Vol. 33, pp. 1933-1938, 2003.

[3] Persson, B. Fire resistance of self-compacting concrete, SCC, *Materials and Structures,* Vol. 37, pp. 575-584, 2004.