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RESEARCH ARTICLE

Experimental Investigation on Color Change and Weight Loss of Steel Fibre Reinforced Concrete when Exposed to Elevated Temperature

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Abstract

Objectives: This study mainly focuses on different steel fibres content behaviour, when exposed to various temperature. **Methods**: In this experimental investigation, the prism specimen of size 500 x 100 x 100 mm with steel fibre content of 0% and 1.5% were exposed to temperature of 100 °C, 300ºC, 500 °C and 700 °C. The Temperature-Time graph was obtained as an outcome of the experiment. Color change and weight loss of specimens at different temperatures was assessed. **Findings**: The RSM weight loss prediction model has been proposed for specimen before and after exposure of temperature. Color changes at 100 °C, 300 °C, 500 °C and 700 °C was observed to be no color change, red, grey and whitish grey respectively. Mass loss of 0% steel fibre concrete prism at 100 °C, 300 °C, 500 °C and 700 °C was found to be 2.17%, 4.33%, 4.24% and 6.55% respectively. Mass loss of 0% steel fibre concrete prism at 100 °C, 300 °C, 500 °C and 700 °C was found to be 0.61%, 4.51%, 5.66%, and 6.27% respectively. **Novelty**: Very few studies have been conducted on the combination of color change and weight loss of the specimen. Weight loss prediction model is the novelty of this study. The RSM prediction model clearly indicates that the response values are 97.21% and 96.12%, where the model is fit for weight of specimen before and after exposure to temperature respectively.

Keywords: SFRC; Color change; weight loss; RSM; Temperature

1 Introduction

Concrete is a complex material which consists of cement, fine aggregate and coarse aggregate. Portland cement is the most widely used cement in the concrete. Raw materials most commonly used to produce cement are lime, silica, alumina and iron oxide. Concrete production are of two major types, ready mix concrete and central mix concrete. The main difference is that the ready mix concrete plant mixes all the other ingredients excluding water, whereas central mix concrete plant adds all the ingredients including water. However, degree of consolidation and water to cement ratio has the major important role in the concrete production process[1]. The rubber powder modified polypropylene fiber concrete (RPFC) of 20 mix proportions were casted and surface color were observed for the specimens when exposed to temperatures of 100 °C, 200 °C, 400 °C and 600 °C. It is observed that the strength was higher at 400 °C[2]. Steel fibre volume fraction of 0.75% when exposed to elevated temperature of 200 °C, 400 °C, 600 °C and 800 °C showed that the compressive strength of reinforced geopolymer composites specimen at ambient was found to be higher and better, when compared to that of the control concrete[3]. The reinforcement, after exposure was observed that the per lite coated specimen shows good protection than the normal reinforcement, to retain the strength[4]. The siliceous aggregate shows less strength than calcareous aggregate when exposed to elevated temperature upto 800 °C[5]. At 700 °C, steel fibre clearly indicates the stiffness reduction based on the type, aspect ratio and volume fraction[6]. There are some literature in the above mentioned studies and hence after the exposure to the temperature, the concrete specimens color change and the weight losses have been noted.

2 Materials and Methods

The prism specimens of size 500 x 100 x 100 mm with 0% and 1.5% Hooked-end steel fibre content were casted and after curing were subjected to the elevated temperature. The steel fibre percentage has been limited to 1.5% because beyond which ballling effect will happen when steel fibre is added. The temperature has also been limited to 700 °C, because beyond there will be spalling effect in concrete. The steel fibre of aspect ratio 60 was used. The specimens were placed inside the furnace. The furnace used in this study consists of the outer chamber, which is fabricated from the mild steel sheet sections and the reinforcement for mechanical rigidity. The outer coating is finished using the heat resistance paint. The inner face of the chamber is made of high temperature ceramic fibre blanket with supporting insulations. The refractory supports are provided to hold the heating elements. The heating elements are connected by the terminal connector bolts. The terminal bolts are further interconnected to achieve the desired power rating and the output wires are connected to the control panel. The furnace specifications are mentioned in Table 1.

The electrical furnace operates on the resistive heating principle. In the interior part of the furnace, the coils are wound spirally and are held by the refractory supports. Due to the resistive heating property, the power transmitted to the elements is converted to the heat energy. Thus, this energy heats the samples placed inside the inner chamber of the furnace. The samples were placed with caution at the centre of the working area. The temperature and time are then controlled and set in the control panel.

Table 1. Furnace specifications

Furnace specifications	
Type of Furnace	Box type
Working chamber dimensions	300 mm x 300 mm x 605 mm
Continuous operating temperature	1200°C
Accuracy	+/- 1°C
Sensor Type	Chromel / Alumel (“K” Type)
Power Rating	15kWs
Operating Phase	3 ph. 440V A.C. with Neutral
Current Rating	32 amps

3 Results and Discussion

3.1 Time to temperature

Time to temperature graph of the specimen exposed to various high temperature is shown in Figure 1. Concrete specimens were maintained at the temperatures of 100 °C, 300 °C, 500 °C and 700 °C for time of 1 hour. From the previous researchers work, heating curve of lightweight concrete[7] when exposed to heating treatment was shown in Figure 2. Thus, the comparison of heat curve is clearly seen between the normal concrete and lightweight concrete.

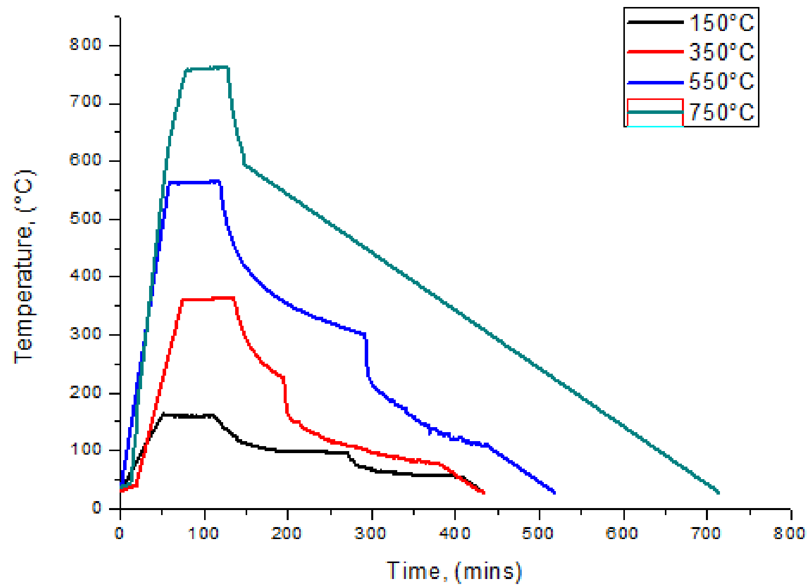

Fig 1. Concrete specimens exposed to various elevated temperature with respect to time

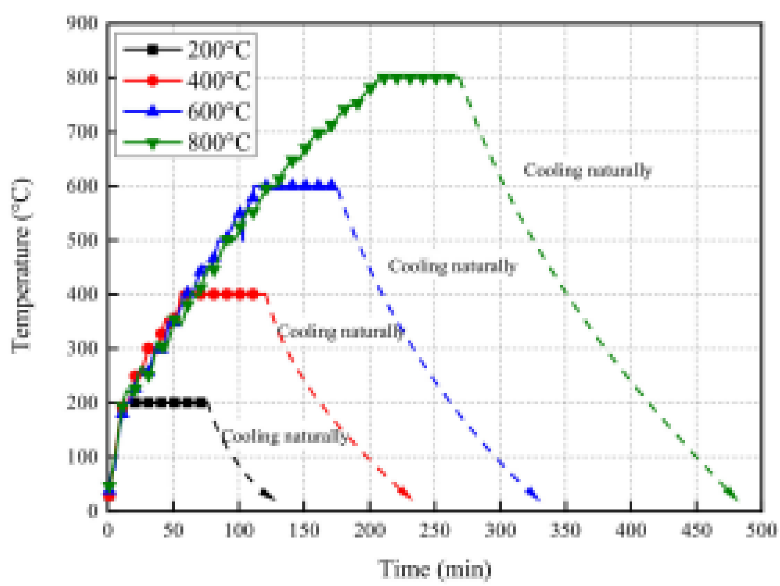

Fig 2. Heating curve of light weight concrete exposed to heating treatment [7]

3.2 Colour change

When exposed to the temperature, the specimen with steel fibre content started fading in color after exposure to 100 °C[8,9]. The cooling process of concrete was done after heating, whereby the visual colour change was observed. It is clearly observed, that at 100 °C, no major change in colour was observed. At 300 °C, the colour of concrete was observed to be red. At 500 °C, the concrete turned its colour to grey. The concrete when subjected to 700 °C, the colour changed to whitish-grey, which occurs due to the calcination process, where calcium carbonate turns into lime. The color change of normal concrete when exposed to various elevated temperature is clearly illustrated in Figure 3. The color change of SFRC at various elevated temperature is clearly illustrated in Figure 4.

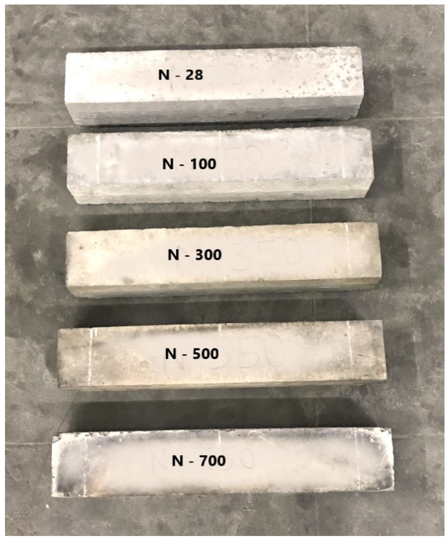

Fig 3. Colour change of normal concrete at various elevated temperature

Fig 4. Colour change of SFRC at various elevated temperature

3.3 Weight Loss

Weight loss in concrete ensues in three stage process. The main stage shows that the loss in weight gradually increases with time, as the heat confiscates the moisture from the concrete. The weight loss to time curve remains concave for some time. In the second stage, evaporation of moistness was fast, thus the weight loss was rapidly increasing with respect to time. When the increase rate reached the maximum level, the curve becomes convex. In the third stage, the evaporation rate decreases, where the weight loss increased with a decrease in time and thus reached the ultimate level. When the concrete was cooled, the absorption of moisture from the air occurs, thus the weight loss to time curve bends slightly. In this study, the SFRC was exposed to several high temperature for a time period of 1 hour. It is observed that the weight loss is more at 700 °C, due to the moisture evaporation. When the SF content is 1.5%, mass loss at 100 °C and 300 °C is lesser than the concrete with 0% steel fibre. When the temperature exceeds 500 °C and 700 °C, the mass loss is little higher than the 0% steel fibre concrete. Figure 5 shows the mass loss of concrete with different SF volume fraction at different high temperature. It is clearly observed from the illustration that the weight loss is more after the concrete is subjected to the temperature of 700 °C.

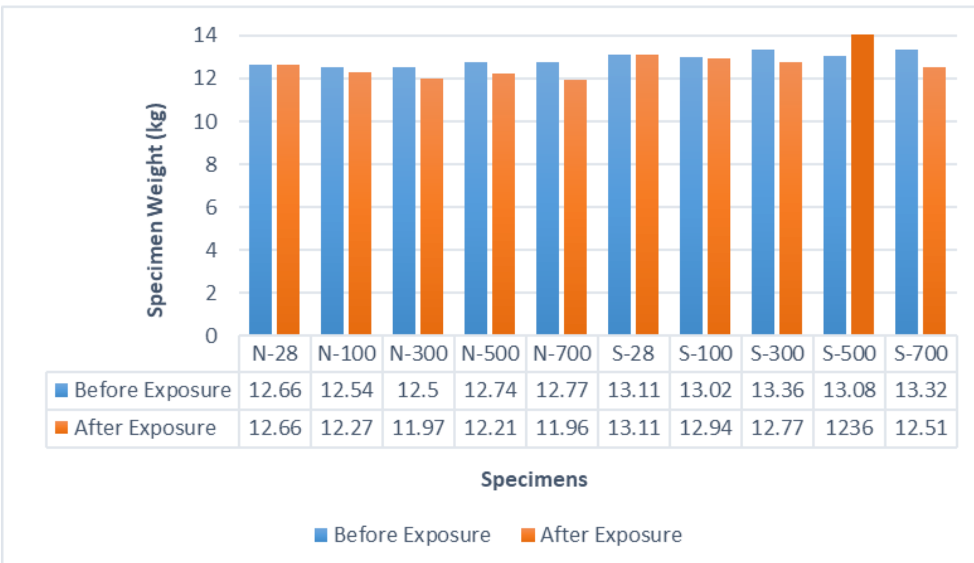

Fig 5. Weight loss of concrete with various steel fibre content at different temperatures

3.4 RSM Model

Weight before and after temperature exposure quadratic model has been developed:

$$V = 12.65 - (0.54A) - (6.87\,X10^{-4}\,B) + (9.92\,X\,10^{-5}\,AB) + (0.60\,A^2) + (1.13X10^{-6}\,B^2) \quad (1)$$

$$V = 12.72 - (0.50A) - (2.79\,X10^{-3}\,B) + (9.92\,X\,10^{-5}\,AB) + (0.58\,A^2) + (2.37X10^{-6}\,B^2) \quad (2)$$

Where A is the steel fibre volume fraction (%) and B is the temperature (°C).

For Equation (1), the adjusted R-squared of 0.9721 suggests that the RSM model explains 97.21% of the variability for weight (before temperature exposure) in the response values. The remaining 2.79% represents unexplained variance due to other factors not included in the model. For Equation (2), the adjusted R-squared of 0.9612 suggests that the RSM model explains 96.12% of the variability for weight (after temperature exposure) in the response values. The remaining 3.88% represents unexplained variance due to other factors not included in the model. Thus, these models show a good fit. Figures 6 and 7 shows the 3-D surface chart of weight of specimen before and after temperature exposure respectively, which is mainly influenced by the RSM model developed. Figures 8 and 9 shows the contour plot of weight of specimen before and after temperature exposure respectively.

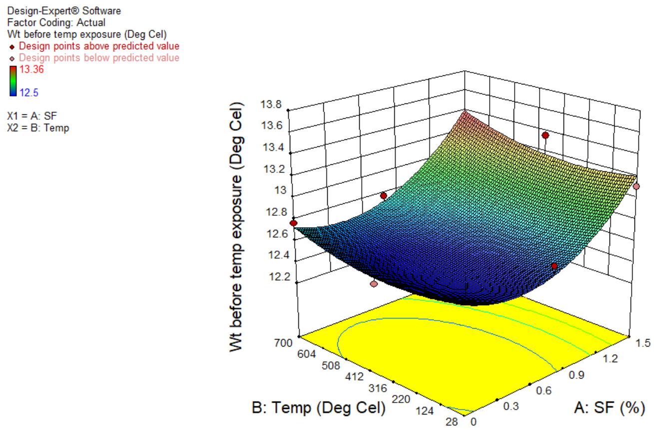

Fig 6. 3-D surface chart for Weight (Before Exposure)

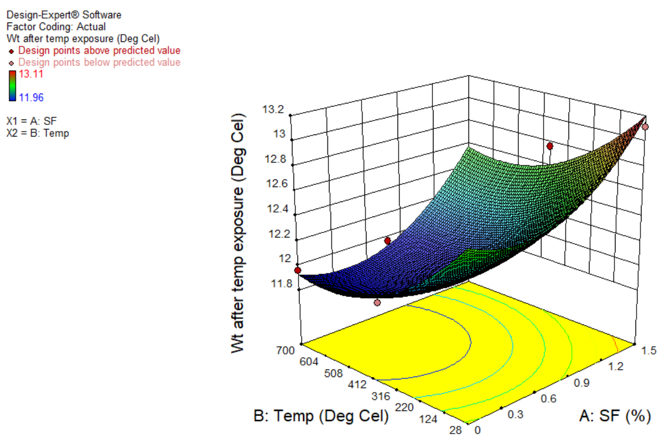

Fig 7. 3-D **surface chart for Weight (After Exposure)**

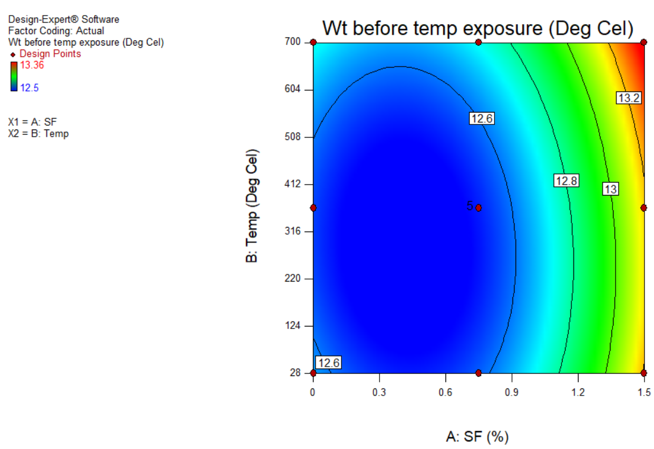

Fig 8. Contour plot for Weight (Before Exposure)

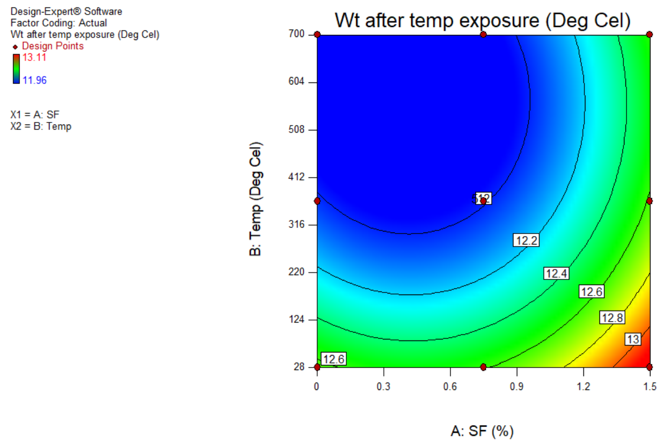

Fig 9. Contour plot for Weight (After Exposure)

4 Conclusions

1. Colour change at 100 °C, 300 °C, 500 °C and 700 °C was noted to be no colour change, red, grey and whitish-grey respectively.
2. Mass loss of 0% steel fibre concrete prism at 100 °C, 300 °C, 500 °C and 700 °C was found to be 2.17%, 4.33%, 4.24% and 6.55% respectively. Mass loss of 1.5% steel fibre concrete prism at 100 °C, 300 °C, 500 °C and 700 °C was found to be 0.61%, 4.51%, 5.66%, and 6.27% respectively.
3. The RSM model has been created for the weight of the specimen before temperature exposure and after temperature exposure. The limitation of the prediction model is the steel fibre variable content between 0% to 1.5%, temperature can be between 28 °C and 700 °C and the concrete mix design is M 30.

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