International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

Mechanical Properties of Concrete Containing Roof Tile Aggregate Subjected to Elevated Temperature

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Abstract— Influence of elevated temperature on the properties of concrete containing Crushed Tile Aggregate (CTA) replacing Natural Coarse Aggregate (NCA) as a fire resistant aggregate. Three water cement ratios were selected for three mixes and for each mix control mixes were prepared. NCA was replaced with 0%, 50% and 100% of CTA and was tested for compressive strength and tensile strength at ambient temperature and after subjecting to 200°C and 400 °C after 28 days of curing. For optimizing the experimental procedure a statistical method was adopted called Box-Behnken Design. And the analysis of the same was carried out using ANOVA. Accordingly the model prepared for the same was checked correlation between the experimental and predicted values. The replacement of NCA with CTA can be justified not only in terms of production cost but also in terms of effective waste disposal.

Keywords— Aggregates, Box-Behnken, Elevated, Fire resistant aggregate, Recycling, Replacement, Temperature,.

I. INTRODUCTION

Sustainable reuse of waste materials reduces the environmental impact by recycling materials generated during building construction, demolition and renovation. The construction field is in real need for the alternatives for the concrete due to depleting nature of natural resources. Fire has become one of the greatest threats to buildings and thus concrete are usually exposed to elevated temperatures during fire. High temperature is one of the most important physical deterioration processes that influence the durability of concrete structures and may result in undesirable structural failures. Therefore, preventative measures such as choosing the right materials should be taken to minimize the harmful effects of high temperature on concrete. The high temperature behaviour of concrete is greatly affected by material properties, such as the properties of the aggregate, the cement paste and the aggregate- cement paste bond, as well as the thermal compatibility between the aggregate and cement paste. Aggregates represent a considerable proportion of volume in the concrete and the thermal conductivity of concrete must be considerably influenced by the thermal conductivity of aggregates. Conductivity evolves differently with temperature depending on the type of aggregates and because of bleeding and a wall effect; there is an accumulation of water at the paste–aggregate interface. The clay roof tiles are subjected to firing in tunnel furnace during several hours at temperatures ranging from 850°C to 1200°C. And hence tile pieces can be used for concrete as replacement of normal aggregates.

II. LITERATURE REVIEW

The behaviour of normal strength conventional concrete under fire, which started to be investigated in the 1920s and has been the object of several studies since then, is now reasonably well understood. At temperatures of 70 to 80°C ettringite dissociates and at about 100°C the water physically bound in both the aggregates and the cement matrix starts to evaporate, increasing capillary porosity and microcracking starts. At these relatively low temperatures, concrete may only experience a minor loss of strength. At temperatures ranging from 250 to 300°C the loss of bound water in the cement matrix becomes more prominent and a significant loss of strength is often observed. Up to 600°C, most aggregates undergo thermal expansion and the consequent internal stresses give rise to extensive cracking and the concrete gets already severely affected. From 600 to 80°C, carbonates suffer decarbonation and in the case of calcareous aggregates, a considerable contraction may occur (due to the release of carbon dioxide) causing severe microcracking of the cement matrix. Finally, from 800 to 1200°C, calcareous constituents suffer complete disintegration and concrete become a calcinated material [2]. Weight loss increment by increased exposure to fire is also prominent and the residual strength levels revealed that the type of aggregate is the most important factor at a temperature greater than 800°C [1]. Chen et al. Decrease in the splitting tensile strength due to the more destructive microcrack and brittle microstructure formation that resulted from the tensile stress. Mathew and Paul presented a mix design procedure for Laterized Self Compacting Concrete (LSCC) and its performance under elevated temperature and LSCC was considered as a substitute fire protection material for conventional concrete. Ergun et al. assessed effects of elevated temperatures and cement dosages on the mechanical properties of concrete. The relative residual compressive and flexural strength–temperature relationships of concrete were found not to depend on the cement dosages. Cakır and Hızal prepared Self consolidating lightweight concrete (SCLWC) mixtures by using two different lightweight coarse aggregates and by replacing normal weight crushed coarse limestone aggregate and he found that concrete porosity adversely affects the resistance of self consolidating lightweight concretes to elevated temperatures. Xing et.al found that with a lower w/c ratio, the porosity of the paste–aggregate interface zone decreases, and bond strength between paste and aggregate was improved. By the use of waste tiles as aggregates from the tile industries and demolition of buildings have positive effect in both post fire behaviour as well as on environment and obtaining lower cost [5].

III. MATERIALS AND METHODOLOGY

A. Aggregates

1) Crushed tile aggregate: The broken pieces of roof tiles cannot be used for the roofing purpose. Hence these tiles become a waste product, Even though the strength of a crushed roof tile aggregate concrete would be much less when compared to normal concrete, this type of concrete can be successfully used for the encasement of steel and concrete when the same are subjected to high temperature by a presumption that, as the tiles are manufactured under high temperature these would perform better at elevated temperature. Tiles were crushed using hammer and sieved accordingly in order to produce aggregates of required size and have got a specific gravity of 2.44. The gradation of aggregate is shown in Table 1.

2) Natural coarse aggregate: The natural coarse aggregate was bought from the nearby quarry which got a specific gravity of 2.72. The gradation of aggregate is shown in Table I.

3) Fine aggregate: Manufacturing sand is used as fine aggregate as a substitute of Natural River sand which has got a specific gravity of 2.66. The gradation of aggregate is shown in Table I.

TABLE I
GRADATION OF AGGREGATES

Sieve size (microns)	Cumulative % passing		
	CTA	NCA	Fine aggregate
25,000	100	100	100
20,000	96.3	95.8	100
12,500	55.5	46.1	100
10,000	21.3	12.8	100
4,750	0	0	100
2,360	0	0	75.6
1,180	0	0	55.8
600	0	0	40.4
300	0	0	14.8
150	0	0	9.5

B. Cement

The cement used in the experiment was RAMCO OPC 53 grade. The physical properties of cement are as shown in Table II.

TABLE II
PHYSICAL PROPERTIES OF CEMENT

Sl. No.	Properties	Value
1	Specific Gravity	3.14
2	Standard Consistency	35%
3	Initial Setting Time	127
4	Final Setting Time	320
5	Average Compressive Strength (MPa) 7 days 28 days	 38.2 57.2

C. Water

Water is also an important ingredient in the concrete as it actively participates in the chemical reaction with the cement. It helps to form the strength giving cement gel.

D. Methodology

Box-Behnken Design was used for minimizing the number of experiments that needs to be carried out. It's a kind of Reponse surface methodology which is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which a response of interest is influenced by several variables. In this investigation 3 set of factors are involved namely water-cement ratio, tile aggregate percentage, and temperature. Box–Behnken is a spherical, revolving design viewed as a cube, it consists of a central point and the middle points of the edges. It design does not contain any points at the vertices of the cubic region created by the upper and lower limits for each variable; which means the reduced number of required runs. The low, middle, and high levels of each variable were designated as -1, 0, and +1 respectively. It is a second-order designs based on three-level incomplete factorial designs. Three levels of variables used in the experimental study is shown in Table III. And according to the results obtained regression analysis were carried out in Microsoft Excel 2007. The quality of the fit of the polynomial model equation was expressed by the coefficient of determination, R^2. The model designed will be of the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \quad (1)$$

Where y is the predicted response, β_0 is model constant; x_1, x_2 and x_3 independent variables; β_1, β_2 and β_3 are linear coefficients; β_{12}, β_{13} and β_{23} are cross product coefficients and β_{11}, β_{22} and β_{33} are the quadratic coefficients.

TABLE III
THREE LEVELS OF VARIABLES

Sl. No.	w/c	% of CTA	Temperature
-1	0.50	0	Ambient
0	0.45	50	200°C
1	0.40	100	400°C

D. Mix Proportioning and casting

Mix designing was done as per IS: 10262-1982. Mix designing was carried out to arrive at the quantities required for 1 m^3 of concrete and is shown in Table IV. After mixing the slump was found and the test specimens were cast in cubic moulds (150 x 150 x 150) and cylinders (dia-150 & hgt-300) by hand compaction. The specimens were removed from the moulds after approximately 24 hrs and kept for 28days of water curing. Casting compaction and curing were carried out according to IS: 516-1959.

The specimens were tested for compressive strength and splitting tension test after curing in a 200 T capacity compression testing machine. The strength for each mixture was obtained from average of three cubic specimens.

TABLE IV
CALCULATED QUANTITIES OF MATERIALS

w/c	Proportion of CA_2	Water (kg)	Cement (kg)	F_A (kg)	C_{A1} (kg)	C_{A2} (kg)
0.5	0	180	360	840	1060	0
	0.5	180	360	840	530	470
	1	180	360	840	0	950
0.4	0	180	400	830	4040	0
	0.5	180	400	830	520	460
	1	180	400	830	0	93
0.45	0	180	450	810	1010	0
	0.5	180	450	810	510	450
	1	180	450	810	0	910

E. Details of specimens

To study the effect of elevated temperature, cubes of size 150mm x150mmx150mm and cylinders of diameter 150mm and height 300mm were tested in order to determine the compressive strength and spilt tensile strength respectively. According to Box Behnken Design, 39 set of cube specimens and 39 set of cylinder specimens were casted. The details of casted cubes and cylinders and their corresponding designations are as shown in Table V.

TABLE V
DETAILS OF CASTED SPECIMENS

Observations	w/c	% replacement of NCA with CTA	Temperature (°C)	Designation for cubes	Designation for cylinders
1	0.5	0	200	C1T0,200	L1T0,200
2	0.5	50	A	C1T0.5A	L1T0.5A
3	0.5	50	400	C1T0.5,400	L1T0.5,400
4	0.5	100	200	C1T1,200	L1T1,200
5	0.45	0	A	C2T0A	L2T0A
6	0.45	0	400	C2T0,400	L2T0,400
7	0.45	50	200	C2T0.5,200	L2T0.5,200
8	0.45	100	A	C2T1A	L2T1A
9	0.45	100	400	C2T1,400	L2T1,400
10	0.4	0	200	C3T0,200	L3T0,200
11	0.4	50	A	C3T0.5,A	L3T0.5A
12	0.4	50	400	C3T0.5,400	L3T0.5,400
13	0.4	100	200	C3T1,200	L3T1,200

IV. RESULTS AND DISCUSSIONS

A. Slump

Table VI shows the values of slump obtained for different mixes. From the results it can be seen that slump value of CTAC (Crushed Tile Aggregate Concrete) is decreasing with increased CTA% and it may be due to the higher water absorption of CTA compared to NCA which resulted in lesser slump value. Also it can be seen from the result that, as the w/c decreases, the slump value also decreases due to the fact that, as the w/c decreases, cement content increases, which increases the water requirement resulting in low slump value.

TABLE VI
SLUMP OBTAINED FOR DIFFERENT MIXES

w/c	Percentage of CA_2	Designations	Slump in mm
0.5	0	C1T0	150
	50	C1T0.5	135
	100	C1T1	115
0.4	0	C2T0	140
	50	C2T0.5	125
	100	C2T1	110
0.45	0	C3T0	130
	50	C3T0.5	110
	100	C3T1	90

B. Compressive Strength

Cube specimen placed for testing after heating and compressive strength obtained after testing with 100% and 50% tile aggregate is respectively shown in Fig. 1 and Fig. 2. The obtained compressive strength are as shown in table VII.

TABLE VII
COMPRESSIVE STRENGTH

Observations	Designation for cubes	Compressive strength (MPa)
1	C1T0,200	24.44
2	C1T0.5A	26.13
3	C1T0.5,400	19.48
4	C1T1,200	18.58
5	C2T0A	46.82
6	C2T0,400	27.93
7	C2T0.5,200	23.73
8	C2T1A	27.56
9	C2T1,400	16.37
10	C3T0,200	46.52
11	C3T0.5,A	35.93
12	C3T0.5,400	28.60
13	C3T1,200	25.63

Fig. 1 Cube with 100 % tile aggregate

Fig. 2 Cube with 50 % tile aggregate

According to the results obtained after testing, for each of the mix, the compressive strength of the specimens reduced with the increase in temperature and CTA percentage. In the case of elevated heating conditions, aggregate experience expansions during the heating while cement paste experience shrinkage and this difference in thermal behaviour leads to weakening and disruption of concrete at higher temperature. When NCA was replaced with 50% CTA, target strength was not achieved and this was attributed to the low specific gravity of CTA. And the reason for a higher strength reduction at temperature of 400°C compared with 200°C may be attributed to the fact that, there is not much significant change in aggregate-mortar interphase up to 300°C but volume changes occurs at higher temperature which results in weakening of concrete bond. The strength reduction between ambient and specimen subjected to temperature of fully replaced CTAC is only 23.9 % while in the case of 0% CTA, strength reduction is 40.34% and this higher performance of CTAC may be due to lower thermal conductivity coefficient of CTAC than the thermal conductivity coefficient of NAC (Natural Aggregate Concrete) At higher mixes the strength reduction was much lesser due to low w/c. With the lower or w/c ratio, the porosity of the paste-aggregate interface zone decreases and bond strength between paste and aggregate is improved.
For obtaining the results for Box-Behnken design, analysis of variance has been calculated to analyse the accessibility of the model and was carried in Microsoft Office Excel 2007. By applying multiple regression analysis on the experimental

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

data, the following second degree polynomial as shown in equation 2 was found to represent the relationship between the compressive strength and w/c, aggregate replacement rates and temperature adequately.

$$f_{cu} = 255.209 - 728.252X_1 - 1.00592X_2 - 0.08605X_3 + 1.503X_1X_2 + 0.028064X_1X_3 + 0.000202X_2X_3 + 585.75X_1^2 + 0.001439X_2^2 + 7.92\,x\,10^{-5}X_3^2 \quad (2)$$

Box-Behnken method can be successfully employed if experimental values and the predicted values are in perfect match. The coefficient of determination (R^2) is defined as the ratio of the explained variation to the total variation, and is a measure of the degree of fit. A good model fit should yield an R^2 of at least 0.8. The closer the values of R to 1, better the correlation between the experimental and predicted values. This means that the response model evaluated in this study can explain the compressive strength very well, with an R^2 of 0.956 and an Adj-R^2 of 0.825 at a confidence level of 95%. The model is validated by comparing the predicted values and actual values. From the Fig.5 it is clear that majority of the model values falls on the red line which indicates that predicted values and actual values are the same. Below the red line it is seen that the model underestimates the strength value and above the red line the model overestimates the value.

C. Split tensile strength

Split tensile strength was found according to IS: 5816–1999 [31] and for the same three cylindrical specimens were heated to desired temperature and tested and the obtained values are shown in Table VIII. And the split surface after testing with 100% and 50% CTA is as shown in Fig 3 and Fig 4. From the test results of split tensile strength, it can be seen that, as the temperature increases, split tensile strength decreases for all the mix and this may be attributed to the fact that, different coefficient of thermal expansion between aggregate and cement paste creates residual stresses that would cause cracks at the interface between the aggregates and cement matrix after cooling from elevated to ambient temperatures [12]. A drastic reduction can be observed in the lower mix between ambient tested specimen and temperature subjected specimen which can be the result of thermal incompatibility of concrete components and it appears because of the differences between the coefficients of thermal expansion of the cement paste and aggregate. Reduced w/c created stronger aggregate mortar bonding at room temperatures and prevented loss in aggregate-mortar bonding at elevated temperature upto 250°C.

TABLE VIII
TENSILE STRENGTH

Observations	Designation for cubes	Compressive strength (MPa)
1	L1T0,200	2.93
2	L1T0.5A	2.91
3	L1T0.5,400	1.66
4	L1T1,200	1.77
5	L2T0A	3.44
6	L2T0,400	2.39
7	L2T0.5,200	2.66
8	L2T1A	2.91
9	L2T1,400	2.14
10	L3T0,200	3.37
11	L3T0.5,A	3.53
12	L3T0.5,400	2.12
13	L3T1,200	2.73

Fig. 3Cylinder with 100 % tile aggregate

Fig. 4 Cylinder with 50 % tile aggregate

By applying multiple regression analysis on the experimental data, the following second degree polynomial as shown in equation 6.2 was found to represent the relationship between the tensile strength and w/c, aggregate replacement rates and temperature adequately.

$$f_{ct} = 0.772 + 17.868X_1 + 0.0111X_2 - 0.0054X_3 - 0.052X_1X_2 + 0.005X_3 + 8.47\,x\,10^{-6}X_2X_3 - 24.9X_1^2 + 4.09\,x10^{-5}\,X_2^2 - 5\,x\,10^{-8}X_3^2 \tag{3}$$

The response model evaluated in this study can explain the tensile strength very well, with an R^2 of 0.950 and an Adj-R^2 of 0.801 at a confidence level of 95% and the values of R is closer to 1, better the correlation between the experimental and predicted values. Also from the Fig. 5 it is clear that majority of the model values falls on the red line which indicates that predicted values and actual values are the same.

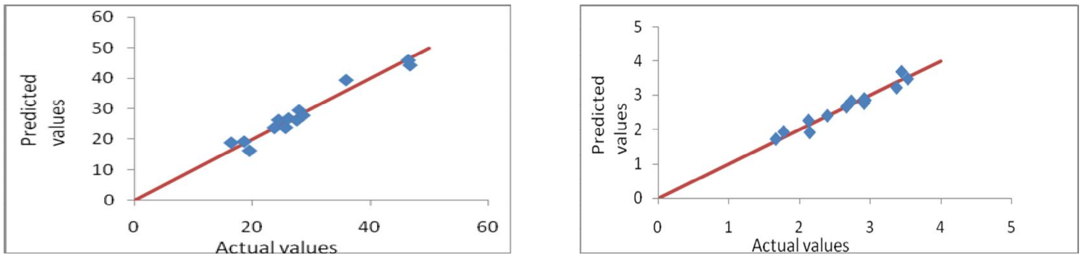

Fig. 5 Comparison of predicted and experimental compressive and tensile strength

V. Conclusions

This study was conducted on a presumption that, as the tile aggregates are considered as fire resistant aggregate as they are manufactured under high temperature in comparison to normal coarse aggregate. Also in addition to adding the fire resistant aggregate, these experiments contribute to waste management, recycling and environmental protection. Test results of fire resistance of crushed roof tile aggregate in relation to fire behaviour of normal coarse aggregate are discussed. Box Behnken design was successfully adopted and the experiments were designed choosing the input variables for the levels selected. With minimum number of experiments data was collected and the models were developed. Analysis of variance was carried out to analyse the Box-Behnken Design.

From the present investigation and the results obtained it can be concluded as following:

- The slump value decreased with decrease in w/c and increase in CTA %.
- With the increase of temperature, the compressive strength and tensile strength decreases.
- Compared to conventional concrete, the strength of CTAC also decreases with the increase in the temperature but the difference in decrease of compressive strength of NAC is higher than CTAC.
- While comparing lower mix and higher mix, the decrease in tensile strength of 100%CTAC subjected to 200°C, the decrease was much lesser for higher mix which shows a better tensile performance of CTAC at higher mixes.
- Also when compared with NAC, the difference in decrease of tensile strength of NAC is higher than CTAC.
- In the case of lower mix, there is a drastic decrease in the split tensile strength with the increase of replacement of tile aggregate.
- But in the case of higher mixes, the decrease in split tensile strength is much lesser
- Due to the different thermal properties of matrix-aggregate interface in CTAC compared to NAC, the incorporation of CTA influences the thermal response of the material.
- Reduction in compressive strength appears to decrease in a systematic manner with increase in temperature and aggregate replacement rates compared to tensile strength. And this difference may be due to the dissimilar nature of mechanical properties.
- Box-Behnken design proved very effective and time saving model for studying the influence of process parameters on response factor. Box–Behnken design also proved to an economical way of obtaining the maximum amount of information in a short period of time and with the fewest number of experiments.
- The strong agreement between the yield predicted by the final quadratic model and the experimental results indicate that the accuracy and general ability of the polynomial model are satisfactory

Acknowledgment

I thank God, the almighty for his blessings without which nothing would have been possible. I also wish to extend my heartfelt thanks to Dr. JobThomas,Asst. Professor, Department of Civil Engineering, School of Engineering, CUSAT for his cooperation, guidance and most generous help for completing the work. I extend my thanks to all the faulty members of Civil Engineering Department and to all my friends and family for their valuable support.

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