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Evaluating Optimum Temperature and Mechanical Properties of Self Compacting Concrete Filled Steel Tubes under Compression

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Abstract — This paper presents the effect of Elevated Temperature on Mechanical properties of Self-Compacting Concrete (SCC) filled steel tube columns and to determine Optimum Temperature. The mechanical properties like Compressive Strength, Elastic Modulus and Thermal Elongation were measured in the temperature range of 20°C to 800°C. The experiments are conducted to determine the stress-strain curve at elevated temperature. The suitable formula is obtained from literature survey and verified with experimental results. An empirical study in which separate steel and concrete properties data were collected and later combined by considering confinement effect by using basic equation given by Mander, J. B., Priestley, M. J. N., and Park, R. (1984) and Wenjing Wang, Zhenyun Tang, Zhenbao Li and Hua Ma (2016). Also Grey Relational Analysis is carried out to find the optimum temperature of SCC filled steel tubes. The experimental and formula results shows variation of 10% to 15%.

Keywords- Optimum Temperature, Stress, Strain, Elastic Modulus, Grey Relational Analysis.

1. INTRODUCTION

Concrete filled steel tubular columns that have been widely used in the engineering applications have superior strength and ductility properties. When the traditional reinforced concrete columns are compared with the Concrete Filled Steel Tubular (CFST) columns, significant differences with respect to ductility and energy absorption capacity can be observed. Due to their outstanding static and dynamic characteristics, CFST columns have been commonly utilized in the various types of structures such as bridges, high-rise buildings, subway platforms, etc.

Experimental research program has been carried out during the years 1994-2001 in the Laboratory of Steel Structures at Helsinki University of Technology so as to explore mechanical properties of a few structural steels at raised temperatures by utilizing for the most part transient state tensile test method. The point is to deliver precise material information for the utilization in various structural investigations. The principle test results are open and they are accessible for different researchers [1].

Mander, J. B., Priestley, M. J. N., and Park, R (1984) have proposed stress strain approach for confined concrete material to both circular and rectangular shaped transverse reinforcement. The stress-strain model is illustrated in Fig. 1 and depends on a equation proposed by Popovics (1973) [8,9].

In this study, evaluating the optimum temperature and stress-strain-temperature behaviour of self-Compacting concrete filled circular steel tube under compression. For this several parameters were considered such as different L/d ratios, steel yield strength of steel tube, compressive strength of SCC core and temperature in experiments. A new technique of combining the effect of steel and concrete properties is carried out by following Mander, J. B., Priestley, M. J. N., and Park, R equation. A comparison of the analysis results based on both modified Mander formula and experimental results were performed for the composite columns under the action of compressive loading. Also, a Grey system theory is adopted to evaluate Optimum temperature.

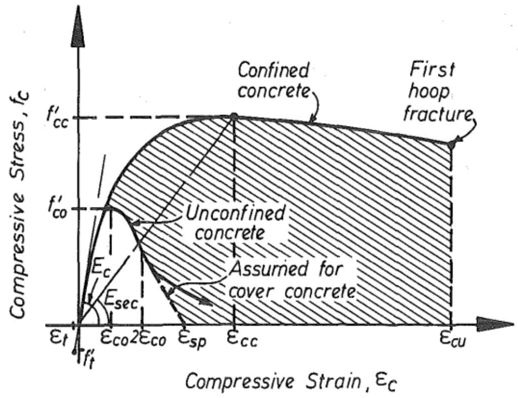

Figure 1. Stress-Strain model proposed for monotonic loading of confined and Unconfined Concrete[8,9]

2. MATERIAL PROPERTIES

A. General

For predicting fire response of SCC and Steel structures, both temperature profiles in the cross area and strength degradation coming about because of higher temperatures, are needed as function of temperature. For assessing such temperature profiles and strength degradation with temperature, high temperature properties of SCC and steel are needed [13].

B. Mechanical Properties of SCC

Compressive strength of concrete relies on water–concrete ratio, aggregate–paste interface transition zone, curing conditions, aggregate type and size, admixture types and type of stress [14]. In contrast to high temperature thermal properties, a few examinations are accessible on high temperature compressive strength of SCC. The ratio of compressive strength at indicated temperature to that at room temperature (f′c, T/f′c) as a component of temperature for SCC assembled from various references [15]. The strength gain somewhere in the range of 100 and 300 °C is seen by Fares [15] which is credited to rehydration of the parched network at early temperatures. This perception has additionally been reported by Dias [17] for HSC. The decrease in compressive strength with temperature saw by Persson is continuous with no spikes. It tends to be watched that the strength patterns of SCC are not reliable and there are critical varieties in strength loss, as reported by authors.

The mix design of SCC has done by following Nan Sua, Kung-Chung Hsub, His-Wen Chaic(2001) [26]. The suitable tests were carried out on SCC to know its workability as shown in table 1.

TABLE-1. WORKABILITY PROPERTIES OF SELF COMPACTING CONCRETE

Test	Units	Results	Range	
			Min	*Max*
L-Box	h2/h1	0.84	0.7	1.0
U-Box	h2/h1	0.66	0	30
T50-Slump Flow	sec	3	2	5
V-Funnel	sec	8 seconds	0	12
J-Ring	Mm	5mm	0	10
Slump Flow-Abram'S Cone	mm	710	650	800


Figure 2. L-box


Figure 3. U-box


Figure 4..T50-Slump Flow


Figure 5. V-Funnel


Figure 6. J-RING


Figure 7. Slump flow ABRAM'S cone


Figure 8. Cube & Cylinder casting


Figure 9. Curing


Figure 10. Cube & Cylinder Testing

Table-2. compressive strength of self compacting concrete

Identification Mark	Grade	Area (cm²)	Load (Ton)	Compressive Strength (N/mm²)
A1	M25	225	49	21.77
A2	M25	225	59	26.22
A3	M25	225	53	23.05
B1	M30	225	71	31.55
B2	M30	225	74	32.88
B3	M30	225	73	32.44
C1	M40	225	94	41.77
C2	M40	225	93	41.33
C3	M40	225	95	42.22

Table-3. split tensile strength of SCC at 28 days

Identification Mark	Grade	Load (Ton)	Split tensile Strength (N/mm²)
A1	M25	10	1.41
A2	M25	12	1.69
A3	M25	9	1.27
B1	M30	13	1.84
B2	M30	15	2.12
B3	M30	16	2.26
C1	M40	18	2.54
C2	M40	15	2.12
C3	M40	17	2.40

C. Mechanical Properties of Steel

The studied material is common structural steel grade with nominal yield strength 350N/mm². The actual yield strength significantly has to be taken into account which has 355N/mm² as shown in figure 11. The mechanical material properties i.e. elasticity modulus and yield strength, can be determined from the stress-strain curves. The strain value of $\varepsilon_{y,\theta}$ stands for 2 % total strain [1].

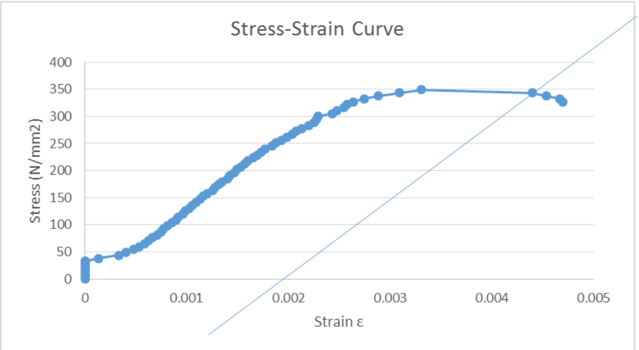

Figure 11. Stress-Strain Curve of steel tube

3. TEST PROGRAM

In this experimental investigation total 36 specimens were tested, in which 27 steel tubes are filled with self-compacting concrete of various grades (M25, M30, and M40) and remaining 9 Specimens are hollow tubes. The specimens were observed under temperature subjected from 20°C to 800°C. Information produced from tests was used to describe the high temperature properties of SCC filled steel tube.

TABLE-4. GEOMETRICAL PROPERTIES OF SPECIMENS

Grade	Dia (mm)	D/t	L/d	t (mm)	L (mm)
Hollow	50	25	6	2	300
	50	25	8	2	400
	50	25	10	2	500
M25	50	25	6	2	300
	50	25	8	2	400
	50	25	10	2	500
M30	50	25	6	2	300
	50	25	8	2	400
	50	25	10	2	500
M40	50	25	6	2	300
	50	25	8	2	400

Grade	Dia (mm)	D/t	L/d	t (mm)	L (mm)
	50	25	10	2	500

D. Test specimens

In the present investigation Mild Steel Tubes, with actual Yield strength of 355Mpa are used. These tubes are seam welded. Circular Steel tubes diameters 50mm with Thickness 2.0mm, lengths (300mm, 400mm & 500mm), and L/d ratio (6-10) are selected for testing. Experiments were carried out on Thirty six different specimens at different temperature.

While placing the SCC, steel tubes are kept in upright position. Bottom end of the steel tubes is covered with polythene sheet tightly and SCC is poured from the top. SCC is filled in the steel tube in gentle compaction. Top of the SCC is trimmed off using a trowel and steel tube is kept undisturbed.

After curing the specimens are kept for drying 24hr at room temperature, then heated using oven LAWRENCE AND MAYO (1000°C) of dimensions 45cm x 45cm x 44cm at required temperature and then placed upright for compression loading in Universal testing machine with closed box as shown in figure 12. The specimen is tightly fixed and then axial load is applied gradually.

Figure 12. Experiments under progress

4. RESULTS

E. Experimental results

TABLE-5. STRESS-STRAIN-TEMPERATURE AND ULTIMATE LOAD (L=300MM, D=50MM, T=2MM, M40)

Temp (°C)	L/d	A_{st}	A_c	Stress (Mpa)	Strain	Load (KN)
20	6	301.16	1661.90	281.84	0.0049	85.00
100	8	301.16	1661.90	271.89	0.0059	82.00
200	10	301.16	1661.90	253.49	0.0070	76.45
300	6	301.16	1661.90	215.52	0.0150	65.00
400	8	301.16	1661.90	203.09	0.0300	61.25
500	10	301.16	1661.90	161.01	0.0370	48.56
600	6	301.16	1661.90	105.44	0.0383	31.80
700	8	301.16	1661.90	66.31	0.0488	20.00
800	10	301.16	1661.90	38.13	0.1200	11.50

** In same way the tables are tabulated for L/d=8,10 & M30 and M25 grade of Concrete.

F. Numerical results

TABLE-6. STRESS-STRAIN-TEMPERATURE AND ULTIMATE LOAD (L=300MM, D=50MM, T=2MM, M40)

Temp (°C)	L/d	A_{st}	A_c	F_c (Mpa)	F_y (Mpa)	F_{sz} (Mpa)	Fcc (MPa)	Strain	Load (KN)
20	6	301.16	1661.90	40	350	281.84	24.15	0.0239	94.15
100	8	301.16	1661.90	31.8	350	271.89	20.61	0.0277	88.26
200	10	301.16	1661.90	23.6	340	253.49	16.64	0.0265	80.13
300	6	301.16	1661.90	23.2	333	215.52	16.34	0.0308	78.54
400	8	301.16	1661.90	21.2	298	203.09	14.83	0.0343	70.64
500	10	301.16	1661.90	19.2	228	161.01	12.74	0.0377	56.36
600	6	301.16	1661.90	17.2	112	105.44	9.50	0.0383	33.08
700	8	301.16	1661.90	15.2	63	66.31	7.37	0.0492	21.96
800	10	301.16	1661.90	13.2	26	38.13	5.22	0.1146	12.70

** In same way the tables are tabulated for L/d=8,10 & M30 and M25 grade of Concrete.

G. Plots (Experimental and Numerical)

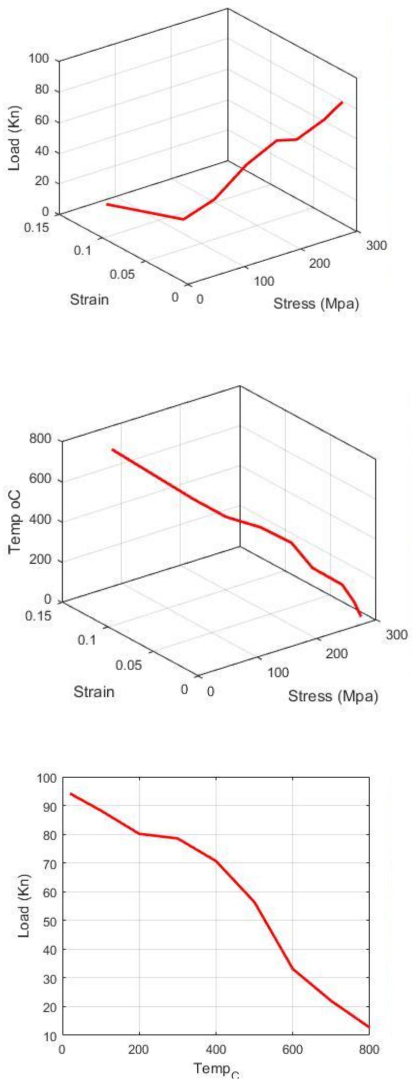

Figure 13. Stress-Strain-Temp behaviour from experiments

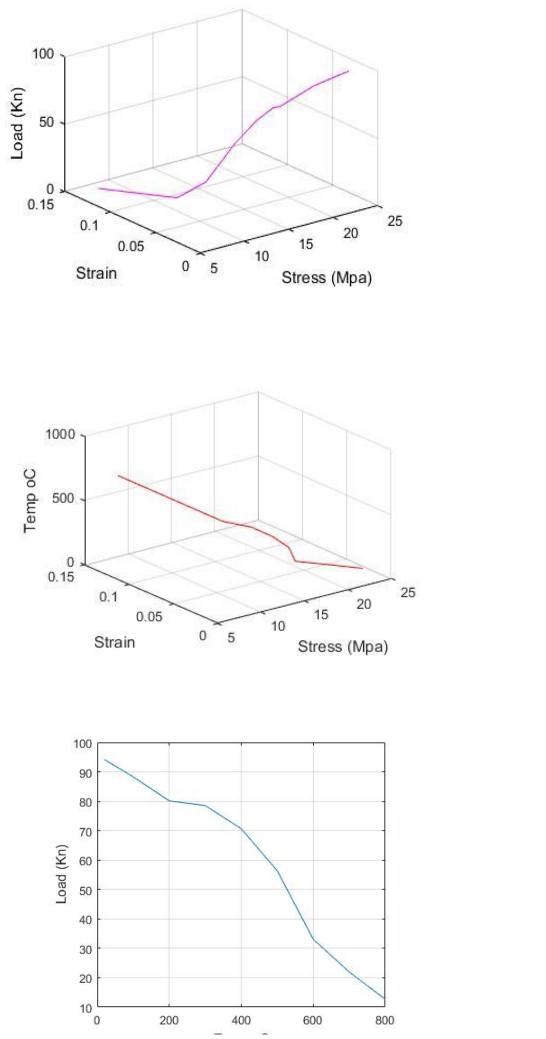

Figure 14. Stress-Strain-Temp behaviour from Numerical formula

From the above plots it is clear that with increase in temperature the mechanical properties of SCC filled steel tabular decreases. The strength of columns drastically fall down between 500 °C to 800 °C.

5. Optimum temperature

H. Grey Relational Analysis

In multi-response problem, the influence and relationship between various parameters are perplexing and not clear. This is named as grey which signifies poor and unsure data. This proposed methodology (grey relational analysis) analyzes this complicated uncertainty among the multiresponse in a given system and optimize it with the help of grey relational grade. In this manner a multiresponse optimization problem is decreased to a single response optimization problem called single relational grade [23].

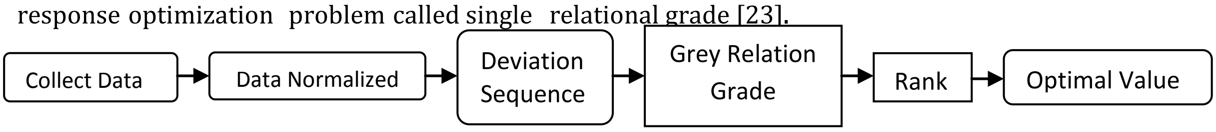

TABLE-7. PERFORMING GREY RELATIONAL ANALYSIS

1. Normalized Value				2. Deviation Sequence				3. Grey relation Co efficient			
Temp	*F_{cc}*	*Strain*	*Load*	*Temp*	*F_{cc}*	*Strain*	*Load*	*Temp*	*F_{cc}*	*Strain*	*Load*
0.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.333	1.000	1.000	1.000
0.103	0.814	0.042	0.934	0.897	0.186	0.958	0.066	0.358	0.729	0.343	0.884
0.231	0.606	0.029	0.840	0.769	0.394	0.971	0.160	0.394	0.560	0.340	0.758
0.359	0.590	0.077	0.821	0.641	0.410	0.923	0.179	0.438	0.550	0.351	0.736
0.487	0.511	0.108	0.723	0.513	0.489	0.892	0.277	0.494	0.506	0.359	0.643
0.615	0.400	0.153	0.544	0.385	0.600	0.847	0.456	0.565	0.454	0.371	0.523
0.744	0.227	0.159	0.252	0.256	0.773	0.841	0.748	0.661	0.393	0.373	0.401
0.872	0.114	0.280	0.114	0.128	0.886	0.720	0.886	0.796	0.361	0.410	0.361
1.000	0.000	1.000	0.000	0.000	1.000	0.000	1.000	1.000	0.333	1.000	0.333

GRG	Rank
0.833	1
0.578	3
0.513	5
0.519	4
0.500	6
0.478	8
0.457	9
0.482	7
0.667	2

** From above Grey relation analysis rank ONE is the optimal value that is experiment number 1.

6. Conclusions

- The load carrying capacity of self-compacting concrete steel tubes decreases by 40% to 45% up to 500 °C temperature.
- Circular self-compacting concrete steel tube column experience significant thermal expansion with increase in temperature.

- It was observed that after 500 °C drastically decrease in mechanical properties (Stress, Strain, Load carrying capacity).
- The optimal temperature found to be 20°C is better than the other temperatures from Grey Relational Analysis (GRA).
- The experimental results are well agreed with Mander et al. (1984) and Wenjing Wang et al. (2016).

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