International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Thermal Behavior and Structural Integrity of Structures

Reshma S Raju[1], Remya Raju[2]
[1]P.G. Student, Department of Civil Engineering, Ilahia College of Engineering & Technology, Mulavoor, Kerala, India-686673
[2]Professor, Department of Civil Engineering, Ilahia College of Engineering & Technology, Mulavoor, Kerala, India-686673

Abstract— *Unwanted fire has become one of the greatest threats to buildings. Concrete has very good behavior under fire due to its low thermal conductivity and non-combustibility. Concrete act as a protective cover to steel reinforcement and thus reinforced cement concrete shows good behavior under fire. However, there is a major problem caused by elevated temperatures that is the break of concrete masses from the surface of the concrete element, spalling phenomenon. Early thermal cracking of concrete often cause serious serviceability and durability problems, and thus should be carefully analysed and properly controlled. In power plant containment structure thermal loading has a noticeable influence on the loading-capability of the structure. It is shown even a pure thermal load, i.e., a 150◦C temperature variation across the containment wall, can cause some damage to the concrete containment. The damage is further deepened by a simultaneous thermal loading. So using rubberized concrete in these structures helps to improve both thermal and mechanical behavior. In this study, an analysis of the mechanical and thermal properties of a sustainable concrete incorporating crumb rubber (CR) and steel or plastic fibers partially coated with rubber (FCR) is presented. CR is good as an aggregate because it dissipates impact energy, it reduces the risk of high-strength concrete spalling with fire. On the other hand, it reduces concrete stiffness without a high strength loss. CR presents a good thermal and sound absorption in concrete, so it can be also used in many construction composites. Detailed three-dimensional finite element models were set up to study the dynamic response and the possible damage of the power plant containment dome for different proportion of CR and FCR ie, 20%, 40%, 60%, 80%, 100% by the replacement of course aggregate. In addition, the influence of the thermal loading was investigated by setting up a thermal-mechanical coupling finite element model exposed to fire is presented.*

Keywords— *ANSYS software, crumb rubber, power plant containment dome, steel fibre, thermal conductivity.*

I. Introduction

In a hypothetical severe accident of core melt-down in pressurized water power plants (PWRs), the primary cooling system could fail and a very high temperature would be reached (up to 3300 K). In this case, the materials of the nuclear power plant could melt to form complex mixtures called corium. When the molten corium comes into contact with the coolant water in the reactor cavity, an intense and rapid heat is transferred from the melt to the water. Considering the timescale for heat transfer is shorter than the timescale for pressure relief, this can lead to the formation of shock waves and the blast loadings may endanger the surrounding structures and even the containment building. Although a steam explosion event in nuclear reactor systems is considered to be a very high probability hypothetical event, it is an important nuclear safety issue because the consequence can be catastrophic considering any direct or by-passed loss of the containment integrity can lead to radioactive material release into the environment, threatening the safety of the general public. The aim of the study is to evaluate the integrity of the containment building of the power plants. A detailed three-dimensional finite element model is set up to study the dynamic response and the possible damage of the containment. In addition to the pure mechanical loading, the influence of thermal loadings is also investigated by setting up a thermal-mechanical coupling finite element model. The deformation and the damage of the structures are calculated.

Power plant containment thermal and mechanical behaviour can be improved by using rubberized concrete. Crumb Rubber (CR) is commercialized and used as aggregate in plasters, mortars, concrete and asphalts. CR is good as an aggregate because it dissipates impact energy it reduces the risk of high-strength concrete spalling with fire. On the other hand, it reduces concrete stiffness without a high strength loss. CR presents a good thermal and sound absorption in concrete, so it can be also used in many construction composites. On the other hand, steel fibres recovered from waste tyres are used as reinforcement in concrete, due to their good bonding to concrete matrix and tensile strength. Recycled fibre reinforced concrete presents increased toughness or fracture energy in comparison with plain concrete. Fibbers coated with rubber (FCR) is a new sustainable derivative obtained from tyres. CR and FCR from tyre recycling are successfully used as aggregate in concrete to improve the thermal property. With this type of concrete for thermal rehabilitation of power plants containments are analysed using ANSYS software.

II. Modeling

A. Structure

Thermal power plant containment dome radius is 24m and height 15m. 10mm diameter bars at 134mm centre to centre is provided in both circumferential and meridian direction of dome. Ring beam of size200mm×200mm is reinforced with 4 numbers of 10mm diameter bars and stirrups of 8mm diameter provided 160mm spacing.

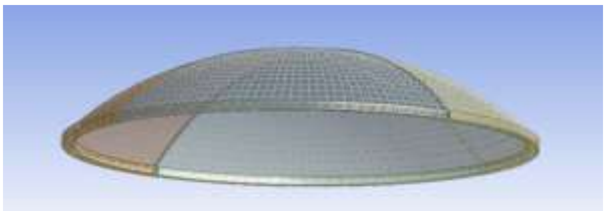

Fig. 1. Geometry of the power plant containment dome.

Reshma S Raju and Remya Raju, "Thermal behavior and structural integrity of structures," *International Research Journal of Advanced Engineering and Science*, Volume 3, Issue 2, pp. 157-159, 2018.

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Power plant containment model is prepared for different concrete mix containing CR and FCR by replacing the course aggregative in different volume fraction (VF). The materials used in the containment structure and their material properties are listed in table I.

TABLE I. Material properties of different concrete mix.

CR and FCR substitution (%)	Bulk density (kg/m^3)	Ultrasonic modulus (GPa)	Bulk porosity (%)	Compressive strength (MPa)	Young's modulus (GPa)
0% CR	2422	49.5	9.04	47.78	8.88
20%CR	2264	42.1	8.97	27.71	5.91
40%CR	2156	31.2	9.29	17.71	3.93
60%CR	2026	27.5	9.11	13.58	3.80
80%CR	1858	18.9	9.68	8.60	1.06
100%CR	1742	13.4	11.54	6.33	0.39
20%FCR	2313	44.0	9.17	30.09	5.71
40%FCR	2139	34.4	11.38	22.84	4.63
60%FCR	2032	28.5	14.01	15.82	3.60
80%FCR	1851	22.3	18.31	9.60	2.05
100%FCR	1668	7.30	21.37	4.64	0.77

III. Boundary Condition

The boundary condition provided as fixed support condition on ring beam.

IV. Analysis Conducted for Present Study

Thermal-mechanical coupling finite element analysis conducted. For the analysis all the models are subjected to self-weight, wind load and thermal loading of IOS 834.

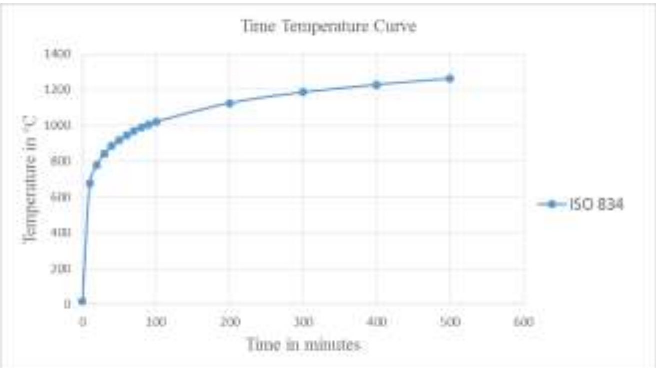

Fig. 2. ISO 834 Time-Temperature curves.

V. Results and Discussion

The results of thermal-mechanical coupling finite element analysis of power plant containment dome have been discussed. The analysis was conducted to obtain best containment dome that can resist both thermal and mechanical loading. The analysis was done for obtaining maximum deflection, maximum stress, temperature distribution and thermal conductivity.

A. Maximum Deflection

The poer plant containment dome is analyzed under thermal and mechanical loading analysis. After the analysis the deflection results obtained is listed in table II.

TABLE II. Deflection in containment dome.

VF (%)	Deflection (mm)	
	CR	FCR
0	2.04	2.04
20	1.26	0.5
40	3.05	2.63
60	7.05	3.61
80	10.75	6.91
100	12.60	16.32

From above table II it is clear that deflection was minimum in 20% replacement of course aggregate by FCR, and also it is clear that the deflection was minimum for 20% replacement of aggregate by CR when compared to other parentage replacement.

B. Maximum Stress

For the same thermal-mechanical loading, the stress resultant is observed for the containment dome is listed in table III.

TABLE III. Stresses in containment dome.

VF (%)	Maximum Stress (N/mm2)	
	CR	FCR
0	5.33	5.33
20	2.24	0.87
40	3.28	3.71
60	2.93	2.91
80	2.07	2.39
100	1.77	1.70

From above table III it is clear that stress distribution is minimum in dome having 20% FCR in coupling finite element analysis. Also stress decreases with increase in percentage replacement.

C. Thermal Conductivity

The thermal conductivity value obtained with different volume fraction of CR and FCR is shown in Fig 3.

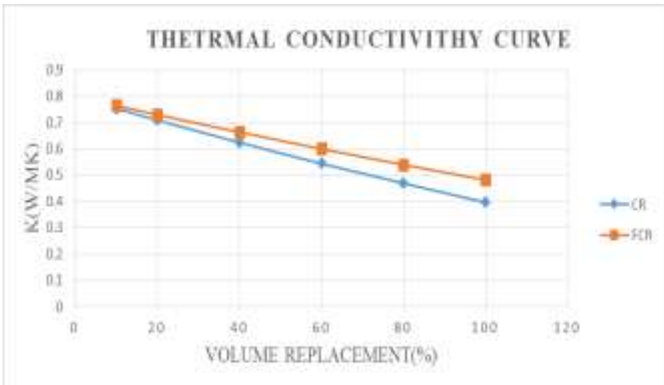

Fig. 3. Thermal conductivity curve.

Fig. 3 presents the thermal conductivity coefficient (k) of concrete with different volumes of CR and FCR as aggregate. The thermal conductivity of concrete is reduced when the VF of CR and FCR is increased, mainly with CR aggregate. The lowest thermal conductivity coefficients are achieved with the total substitution of stone aggregate by rubber. Concrete with 100% CR has reduced the k value from plain concrete 0.8

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W/mK to 0.39 W/mK, and those with 100% FCR to 0.48 W/mK. This means a thermal conductivity reduction of 50% and of 40% respectively, compared to reference concrete.

C. Temperature Distribution

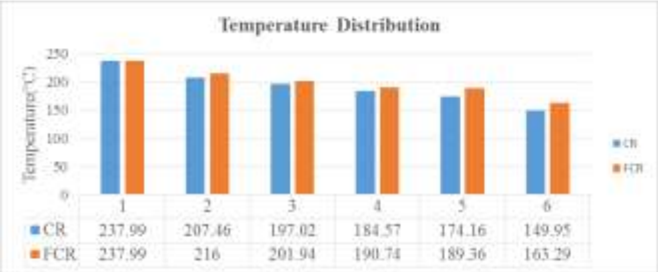

Fig. 4. Comparison for temperature distribution of dome for different concrete mix.

The thermal conductivity value of CR and FCR is smaller than concrete so that different percentage replacement of aggregate by CR and FCR in domes shows better performance in thermal loading. When comparing CR and FCR, CR shows better resistance in thermal loading as shown in Fig 4

VI. CONCLUSIONS

Results are obtained for thermal-mechanical coupling finite element analysis. From the results obtained for maximum deflection, maximum stress, thermal conductivity and temperature distribution the performance of each type dome is compared.

1. For coupling analysis deflection, stress is less in domes with 20% replacement of course aggregate by CR and FCR.
2. Steel and plastic fibers coated with crumb rubber (FCR) recovered from waste tyres have been used as aggregate to produce rubberized concrete. They have better strengths than conventional rubberized concrete with crumb rubber, which usually has less than 20% of rubber aggregates by volume.
3. Concerning thermal properties, the results have shown that increasing the percentage of rubber used as aggregate in concrete, concrete k is reduced. Concrete with 100% of CR and 100% of FCR have shown the lowest k values, 0.39 and 0.48 W/mK respectively.
4. Detailed three-dimensional finite element models were set up to study the dynamic response and the possible damage of containment dome, CR and FCR incorporated containment domes shows good thermal mechanical behavior than conventional dome.

ACKNOWLEDGMENT

I wish to thank the Management, Principal, and Head of Civil Engineering Department of Ilahia College of engineering and technology, affiliated by Kerala Technological University for their support. This paper is based on the work carried out by me (Reshma S Raju), as part of my PG course, under the guidance of Remya Raju (Assistant Professor, Ilahia College of engineering and technology Muvattupuzha, Kerala, India). I express my gratitude towards her for her valuable guidance.

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