STRUCTURAL HEALTH MONITORING OF RC STRUCTURAL ELEMENTS EXPOSED TO HIGH TEMPERATURE USING IOT AND RETROFITTING OF TEMPERATURE DAMAGED STRUCTURAL ELEMENTS ADOPTING SUSTAINABLE MATERIALS

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Introduction:

Structural Health Monitoring is concerned with continuous monitoring of building structures to enhance human safety and helps in obtaining data related to the structure when subjected to different forms of loading from a remote location. The implementation of SHM system by the IoT paradigm permits new technologies to be adopted to improve the efficiency and the reliability of the developed monitoring system. Typically, IoT systems use wireless networks to share data among smart systems and the sensitivity of the detection of the structural damage and continuous monitoring permits the timely detection of dangerous states and the storing of monitoring information. When concrete is exposed to high temperature in the event of fire, with increase in temperature and time of exposure, the strength of concrete decreases that leads to reduced strength and reduced load carrying capacity and reduced stiffness in the structural members exposed to high temperature leading towards instability. Hence it is necessary to assess the degree of damage taken place in structural elements that have been exposed to high temperature, which makes it possible to decide whether to demolish or to carry out retrofit the structure.

Objectives:

1. To monitor reinforced concrete beams exposed to high temperature using wireless temperature sensors (embedded at different depths) to under the temperature distribution across the cross section and along the length of the structural member and to further retrofit such damaged reinforced concrete beams (due to temperature) adopting RC jacketing made up of sustainable

materials (Ground granulated blast furnace slag and fly ash) to restore the stiffness and load carrying capacity of such thermally damaged beams.

2. To carry out finite element analysis to validate the material model and finite element model with respect to the experimental results, to further carry out parametric studies by varying the beam length and thickness of RC jacket.

Methodology:

1. In the present study, reinforced concrete (RC) beams have been considered. The RC beams are cast adopting M25 grade concrete and Fe 550 grade reinforcing steel.

2. Companion cubes having the size 150mm side length (9 numbers) and cylinders having a diameter of 100mm and 300mm height are cast to validate the M25 grade concrete mix as per mix design procedures conferring to (IS 10262-2019) as shown below in Fig1.

M25 grade for w/c ratio of 0.54			
Trail mix 2			
	Compressive Strength in N/mm2		
		7 days	28days
Cube	1	15.26	22.24
	2	17.66	27.03
	3	16.35	28.12
		16.42	25.80

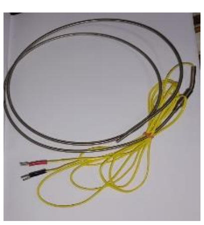
Split tensile strength in N/mm2			
		7 days	28days
Cylinder(150*300)	1	1.52	1.874
	2	1.68	1.56
	3	1.72	2.36
		1.64	1.93

Fig1. Test results of trail mix for M25 grade

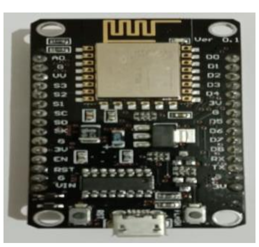
3. Seven reinforced concrete beam test specimens having a size (150x150x1500) mm have been cast adopting the above validated trail mix as shown in the Fig.2 and cured for 28 days. The RC beams have the main reinforcement on the bottom tension face is 2 numbers of 10mm diameter and 2 numbers of 8mm diameter rebars on the top face. Two legged 8mm diameter rebars have been provided as stirrups at 150mm center to center.

Fig2. Beams with sensors embedded within

4. K type thermocouples connected to wireless IOT system are used to measure and acquire the temperature in the reinforced concrete beams that is exposed to high temperatures.
5. The reinforced concrete beams are exposed to the following range of high temperatures, namely, 325°C, 450°C and 575°C for an exposure duration of two hours. The temperature developed across the cross section and length of reinforced concrete beams exposed to the above said temperatures are monitored and acquired using IOT based wireless temperature sensors (K type Thermocouples).
6. Strain gauges are embedded in the bottom cover region of the RC beams to measure vertical displacements in the beam. The vertical displacements were acquired through the wireless mode at a remote data acquiring system.
7. Strain gauges have been adhered to the top surface of the reinforced concrete beams to measure the compressive strains after the beams have attained room temperatures.
8. The temperature sensors are embedded within the beam at different depths across the cross section along the length. The wireless sensors that measure displacements that are embedded in the bottom cover region of the RC beams contains an embedded microprocessor, whose functions are signal processing, transferring the signals to the data acquisition system and the data is interpretated for acquiring the vertical displacement in the structural member.
9. The thermocouple (K-type) based wireless temperature sensor system and the wireless sensor system measuring vertical displacements are individually connected to the main board from which the data is wirelessly transmitted to a receiver via a Wi-Fi module. The main board is connected to the Lithium polymer battery which is used as a power source.
10. Node MCU (Microcontroller unit) ESP8266 is used as the microcontroller to process the temperature and vertical displacement data individually and transfer the same data through the wireless mode to the external remote receiving host.

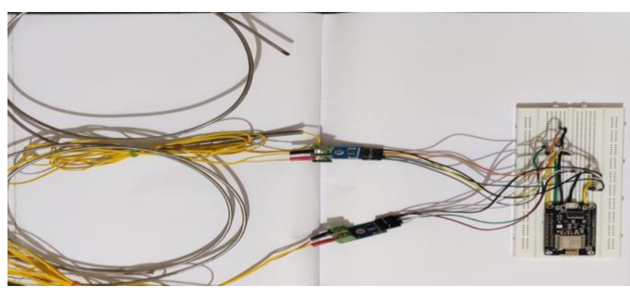


K type Thermocouples



NodeMCU ESP8266 WiFi module

Max 6675 module



Circuit of ESP8266 module with max 6675

The reinforced concrete beams that have undergone thermal damage that were exposed to following range of high temperatures namely, 325°C, 450°C and 575°C are subjected to four point loading up to failure to assess their individual load carrying capacities.

11. Retrofitting of companion RC beams that have undergone thermal damage due to high temperature exposure
12. RC jackets made up of alkali activated concrete having a compressive strength of 35N/mm^2 and Fe500 grade reinforcing steel. The Alkali activated concrete is made up of GGBS and Class-F fly ash that are mixed with an activator solution that is made up of 10M NaOH solution and mixed with sodium silicate solution.
13. The RC jacket considered in the present work has a thickness of 75mm and has 3 of 12mm diameter at the bottom face and 2 of 10mm diameter at the top face. Stirrups having a diameter of 8mm spaced at 125mm center to center is provided in the RC jacket.
14. The finite element analysis is carried out to validate the material model and finite element model with respect to the experimental results.
15. Parametric study is further carried out for various thicknesses of the RC jacket retrofit applied in the finite element analysis after the validation of the material and finite element model.

Conclusions:

1. The wireless sensors adopted for measuring and acquiring temperature and vertical displacements help in assessing the degree of damage taken place in RC structural elements that have been exposed to high temperature and that have undergone displacements due to externally applied loading.
2. The alkali activated concrete adopted in the RC jacket is a sustainable material used to retrofit is found to have better thermal resistance and helps in enhancing the stiffness and load carrying capacity of the thermally damaged RC beams, that can be applied in design and construction practices.

Scope for Future work:

1. Adopting wireless smart systems in Structural health monitoring of buildings enhances the reliability of monitoring system as the monitored information is remotely accessible.
2. In Fire vulnerable structures, monitoring of high temperature using K type thermocouples makes it possible to assess the degree of damage taken place in the structural elements.
3. Adopting alkali activated geopolymer concrete using sustainable materials such as GGBS and Fly ash to retrofit the thermally damaged structural element increases fire resistive properties of the structural member.