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Thermal/Fire Resistance Studies on Cermabond-569 and Ldam Coated Concrete Structures at Elevated Temperature

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Abstract - RCC structures under elevated temperatures/ fire conditions, results in the structural damage and sometimes leads to structural collapse. It is very difficult to predict the behavior of a concrete at elevated temperatures because the fire spread is random and the heating profile is unpredictable. Excessive heating of concrete over long duration will degrade in mechanical properties and lead to structural failure. In the present study, thermal protection coatings have been explored to reduce the conduction of heat/fire into the core of concrete for protection of the concrete linings and reinforcing steel. Experiments are carried out using Cermabond-569 and Low density ablative material (LDAM) coatings on M30 and M40 concrete structures with 2mm and 4mm thickness as per the specification of Hydro carbon fire curve. The temperature profile across the front and back surface are measured as a function of time. From Temp-Time plots, the temperature difference (ΔT) between uncoated and coated samples was observed as 200^0C for Cermabond and it is 140^0C for LDAM coated samples. Increase in (ΔT), was observed with respect to thickness of coating. Cermabond-569 coating has good adhesion, low porosity and low thermal conductivity compared to LDAM coating. It is concluded that for M30 and M40 RCC structures, Cermabond-569 coating is most efficient for high thermal/fire resistance at elevated temperatures.

Keywords – RCC; Thermal protection coatings (TPC); and Low density ablative material (LDAM)**.**

INTRODUCTION

It is very difficult to predict the behavior of the concrete structures/ tunnels, often experiencing the failure due to fires caused by explosion /accidents of vehicles [1]. Since this kind of accidents is occurring in a confined space, the fires in this type of explosion are very random and they produce very high temperatures in short duration of time [2, 3]. Due to combustion of fossil fuels and also release huge amounts of smoke and toxic gases which will make the occupants difficult to evacuate in short time [4]. Many researchers are tried to find the physical, chemical and mechanical changes occurring in concrete when it is exposed fire but the complete understanding of concrete behavior on exposure to fire is yet to fulfill the requirements of the designer, resulting lack of confidence in the design of fire-resistant concrete structures especially for safety of tunnels. The use of thermal protection coatings (TPC) in concrete is limited to off-shore structures and also provides resistance to corrosion and chemical attack from the sea water too [5]. In the recent researches the hollow glass microspheres is mixed with the cement to reduce the thermal conductivity of concrete. Hollow glass microspheres when mixed with cement and water, the glass spheres absorb water and bulges creating a void space inside the samples. The heat transfer is reduced by the void space in the concrete, but due to formation of voids the strength of concrete is reduced. Matching the fire growth in the closed profile, different types of fire curves like RABT, ISO-834, Hydrocarbon and RWS curves are introduced to predict the fire behavior in the tunnels. Normally ISO-834 curves are used for the drive ways and the residential structures which is having the maximum temperature about 1150ºC [6, 7]. The hydrocarbon curves are also having the same maximum temperature as ISO-834, but the initial temperature rise is more for the hydrocarbon curves which indicates the fire scenario of tanker accidents, petrol blasts or explosives blast. The fire occurred in tunnel are different and the growth of fire more rapid in the tunnel and releases the toxic gases. RABT curves were introduced in Germany in 1994 especially for the tunnel fires which rise to peak temperature of 1200º C in 5 minutes and the peak temperature is applied nearly one hour and then gradually reduces to 120 minutes. The experimental results shown in this paper are conducted up to 1200º C by following the time-temperature profile of Hydrocarbon fire curve.

In the present study, the TPCs used to reduce the fire exposure of concrete are cermabond-569 and LDAM. Cermabond-569 is an industry made product that can sustain to a maximum temperature of 1650oc. LDAM is specially developed by DRDO, Hyderabad for metallic substrates with hollow glass microspheres as a main constituent that can sustain to 1200º C.

SAMPLE PREPARATION AND EXPERIMENTAL TECHNIQUES

Preparation of samples

All the specimens are casted with normal weight of concrete mix with the target compressive strength of 30

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and 40 MPa. Six samples of M30 and M40 grades are prepared with standard size of 150 x 150 x 150 mm^3. The properties of aggregates and mixing ratios are mentioned in Table.1. During casting of concrete blocks, k-type thermocouples were inserted into the block at different depths across the thickness for measuring the temperature as a function of time as shown in Fig.1

Table.1: Properties of aggregates and mix proportion properties

S. No	Property	M30	M40
1	Coarse aggregate (Kg/m^3)	1117	890
2	Fine aggregate (kg/m^3)	797	769
3	Cement (kg/m^3)	289	282
4	Water (lit/m^3)	160	153
5	w/c ratio	0.46	0.42
6	Aggregate type	Crushed angular aggregates	Crushed angular aggregate
7	28-day Compressive strength (MPa)	41	62

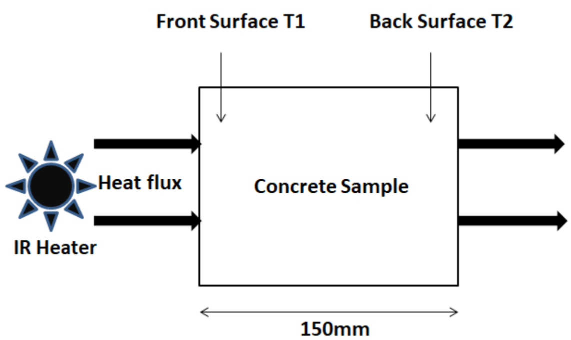

Fig.1. Typical Sample for temperature measurement

Types of Coatings

i). Cermabond-569 coating

The coating of Cermabond-569 is procured from M/s. AREMCO, is a ceramic based coating used for missiles and ships for protection from lasers beams and gas erosions **[11]**. It is a water soluble ceramic coating, and after application of coating, it is cured in ambient for 1 to 4 hours. The properties are mentioned in **Table. 2.**

Table. 2: Properties of Cermabond-569

S. No	Property	Value
1	Maximum temperature limit	1650 °C
2	Specific gravity	2.15 to 2.3 g/cc
3	Bonding	C-C, C-M
4	Self-life	6 months

ii). Low Density Ablative Material (LDAM)

LDAM is a special coating, developed by DRDO, Hyderabad with primary constituents are vinyl silicon resign, hollow glass micro spheres and Hydro carbon-based solvent. The properties are mentioned in Table. 3. The coated samples are shown in Fig. 2.

Table. 3: Properties of LDAM

S. No	Property	Value
1	Density	320 to 340 (Kg/m3)
2	Thermal conductivity	0.171 (W/m-K)
3	Specific heat	1310 (J/Kg-K)
4	Curing	3 to 4 hours at room temperature.

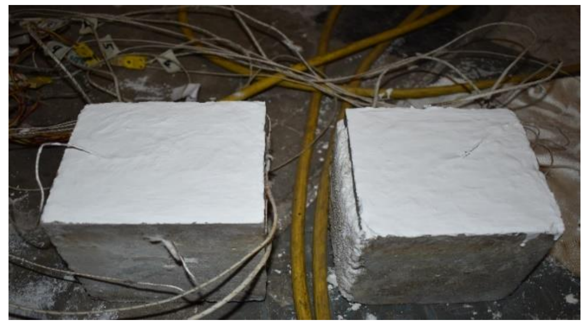

Fig. 2. Coated samples of Cermabond-569 and LDAM

Experimental Techniques

Thermal Properties of samples – DSC and TGA

Specific heat properties is measured for samples by measuring heat flow using DSC and weight loss as a function of time is measured using TGA. This can be calculated by the given equation (1):

$$Q = m^* C_p^* (dT/dt) * \Delta x \qquad (1)$$

where, Q: output power (w/cm^2), M: Density of concrete block (Kg/m^3), C_p: specific heat (J/g/°c), (dT/dt): Rate of change of temperature with time (°/sec) and Δx: depth of block (m). Specific heat and heat flow are measured using differential scanning calorimetry (DSC), thermal conductivity is measured by thermal constants analyzer (TCA) and weight loss of the concrete is measured using thermos-gravimetric analysis (TGA).

Thermal Properties of samples – IR Heaters Set up

The error in temperature measurement for thermocouple is measured using M/s. AMTEK calibration instruments and PID controller as shown in Table. 4.

Table. 4: Measurement in errors of thermocouple

S. No	Calibration (°C)	Deviation (°C)
1	0	1.5
2	200	1.5
3	400	1.6
4	600	2.4
5	800	3.2
6	1000	4
7	1200	9

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The test procedure is carried out as per the Temp-Time profile of the hydrocarbon fire curve. The heater consists of 24 Infra-Red lamps in a row made of quartz glass and tungsten martial in it which produces the heat. Concrete blocks with thermocouples are placed In front of the heater at a distance 75mm from face. The concrete blocks are covered with silica material to avoid the loss of heat and the heater releases the heat to maintain the desired temperature on the surface. Temperature is raised from room temperature to 1200^{o} C at the rate 1^{0} C/sec, after reaching the 1200^{o} C and temperature is maintained for 1000 seconds. Input temperature profile and thermocouple readings of a concrete blocks coated with various thickness of the coatings are measured using data acquisition system from M/s. National Instruments. M30 and M40 blocks coated with 2mm and 4mm thickness of coating were tested [8, 9].

Fig. 3. Experimental set up for Un-coated and Coated samples M30 and M40 blocks coated with 2mm and 4mm thickness of coating were tested.

RESULTS and DISCUSSION

Thermal properties by DSC and TGA

The samples of M30 and M40 are subjected to heat capacity, heat flow and thermal conductivity studies and the profiles are shown in Figs. 4 to 6.

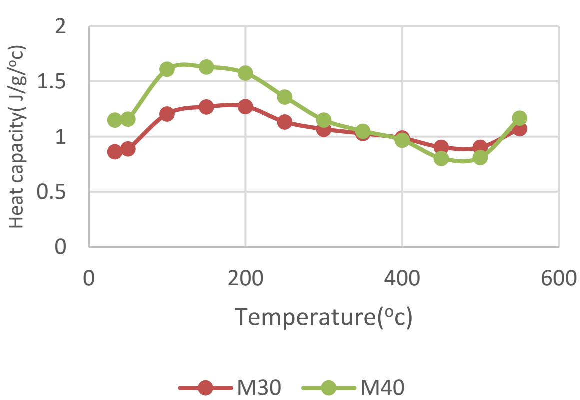

Fig.4. Heat capacity of M30 and M40 samples

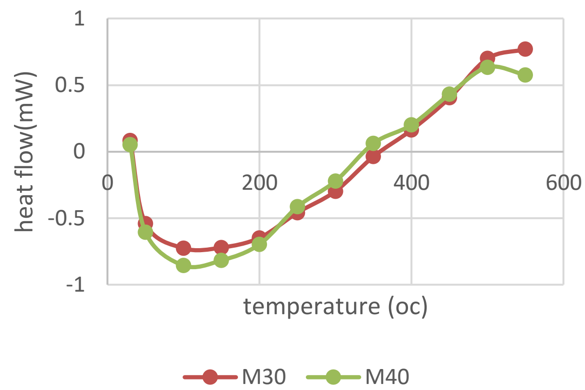

Fig. 5. Heat flow curves of M30 and M40

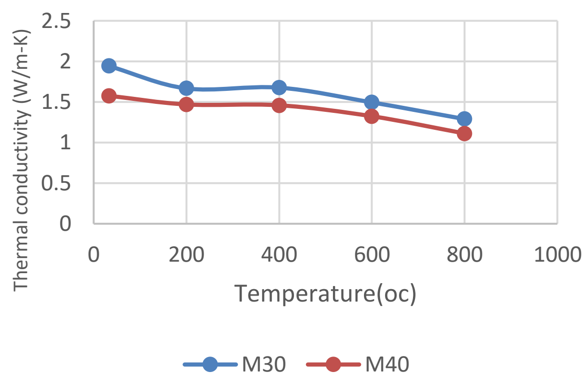

Fig. 6. Thermal conductivity curves of M30 and M40

Figs 4 and 5 show that, M30 samples have low heat flow and high heat capacity due to its high loading of coarse and fine aggregates. It has high packing density of stone, results in difficulty in penetration of heat wave and low absorption of heat. Due to low packing factor of M40 and small size of aggregate, it conducts heat most effectively. Therefore M30 samples have high heat capacity compared to M40.

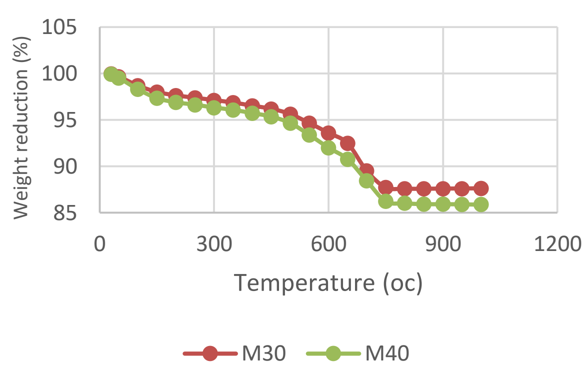

Fig. 7. Percentage Weight loss curves of M30 and M40

The weight loss trend in M30 and M40 samples are shown in **Fig.7.** The weight loss trend and degradation behavior depends on cement to water ratio and independent on aggregate percentage. Hence the degradation curves are

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similar. The cement is losing its weight around 15% at 750^{0}C. This is attributed to evolution of water vapours from the samples while heating.

Thermal /Fire testing of the samples by IR heaters

The temperature profile of the samples as a function of time is shown for Cermabond 569 coated samples in Figs. 8 to 11 and Figs. 12 and 15 indicate for LDAM coated samples. The curves indicate the temperature profile of the samples at a depth of 2mm from the front surface.

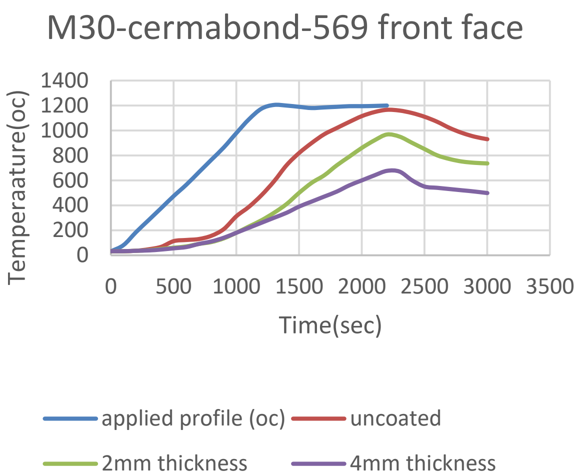

Fig. 8 M30-Cermabond569- Front surface

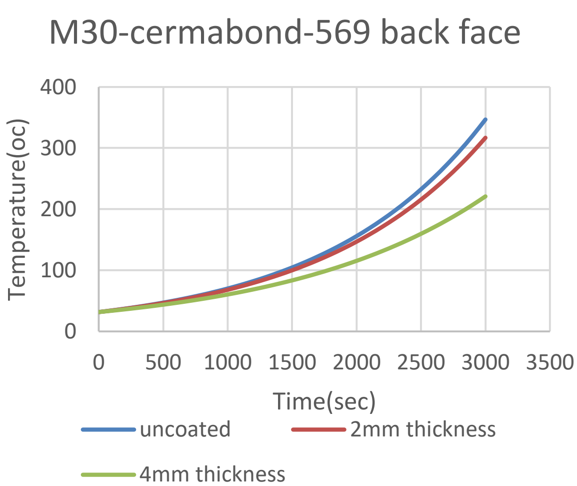

Fig. 9. M30-Cermabond569- Back surface

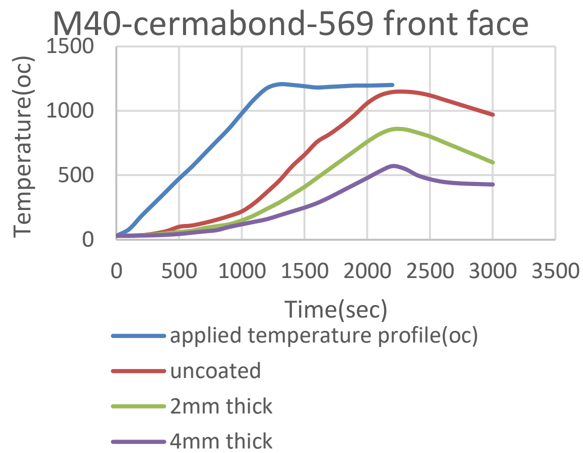

Fig. 10. M40-Cermabond569- Front surface

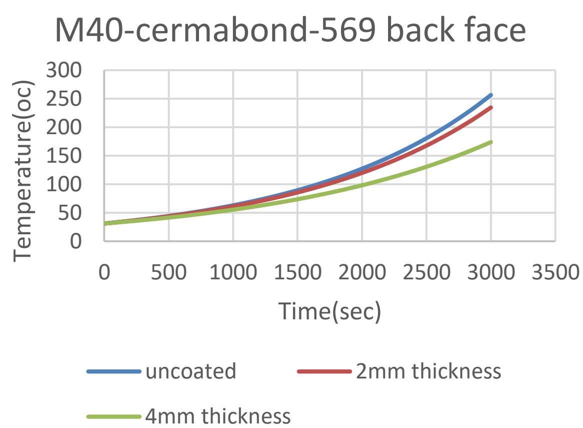

Fig. 11. M40-Cermabond569- Back surface

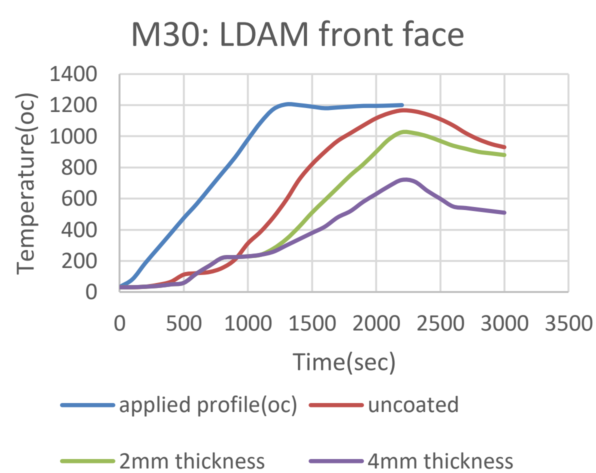

Fig. 12. M30-LDAM- Front surface

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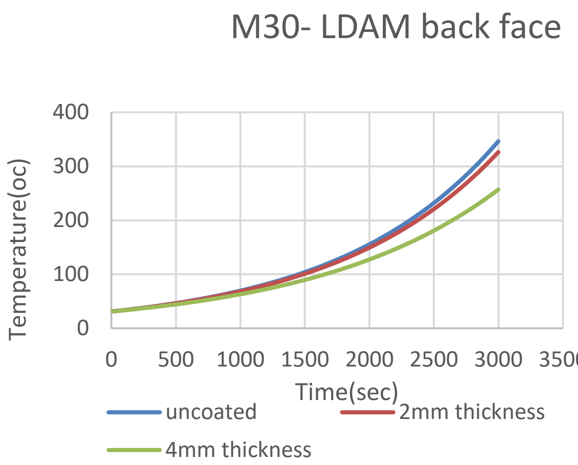

Fig. 13. M30-LDAM- Back surface

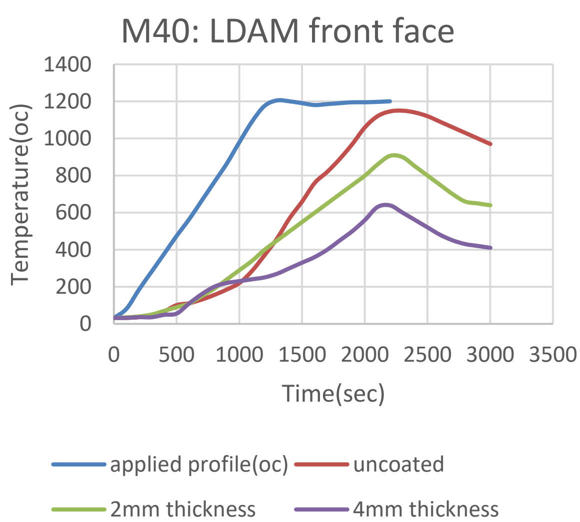

Fig. 14. M40-LDAM- Front surface

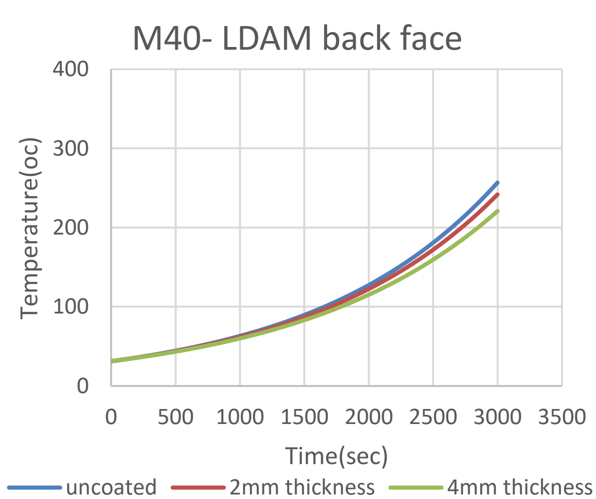

Fig.15. M40-LDAM- Back surface

The front surface and back surface temperatures are compared to M30 and M40 grades. The coated and uncoated samples with Cermabond and LDAM are compared to 2mm and 4mm thicknesses of coating as shown in Tables 5 and 6.

Table. 5. Cermabond-569 coated samples

Sample	**M30 sample at 1200^{0}C**		**M40 sample at 1200^0 C**	
	Front face (° C)	Back face (° C)	Front face (° C)	Back face (° C)
Uncoated	1166	346	1150	256
Coated -2mm- cermabond-569	967	316	856	234
Coated- 4mm - cermabond-569	676	220	572	173

Table. 6. LDAM coated samples

Sample	**M30 sample at 1200^{0}C**		**M40 sample at 1200^0 C**	
	Front face (° C)	Back face (° C)	Front face (° C)	Back face (° C)
Uncoated	1166	346	1150	256
Coated- 2mm- LDAM	1026	326	907	256
Coated- 4mm- LDAM	720	256	639	220

From the temperature profile of front and back surfaces of the samples the following observations are made. Cermabond-569 is a ceramic coating which has low thermal conductivity due to silica mixture whereas LDAM is a combination of vinyl silicon resin, hollow glass micro spheres and Hydro carbon-based solvent. Hence during coating of Cermabond-569, the formation of pores is minimum and it has good adhesive strength where as in case LDAM after coating on the substrate, the resin produces hollow glass micro spheres while curing of coating and produces considerable number of pores. Due to formation of microspheres the porosity increases in LDAM, results in poor adhesion between coating and substrate. Therefore the poor adhesive strength and porosity are causing more damage to the surface while heating the LDAM coated sample. Due to porosity, LDAM is acting as partial heat transfer medium for heat propagation and the temperature difference (ΔT) is reduced to 140^{0}C [10, 12].
Cermabond is a water soluble ceramic mixture and has good adhesion to M30 and M40 samples due to ability to form chemical bonds (i.e. ceramic-ceramic bonds) is high. It produces low porosity compared to LDAM and hence it acts as barrier to heat wave penetration with minimum heat transfer ability [10, 12]. As the surface temperature increases, the heat wave cannot propagate easily across the thickness of sample and hence the temperature difference (ΔT) is high i.e., 200^0 C.

Conclusions

A study on Cermabond-569 and LDAM coatings was carried out on M30 and M40 samples for thermal/fire resistant properties. The temperature difference (ΔT) between uncoated and coated samples was observed as 200^0 C and 1400^0 C, respectively for Cermabond-569 and LDAM samples. An increase in (ΔT), was observed with respect to increase in thickness of coating. The coating of Cermabond-569 is recommended for M30 and M40 RCC structures due to good adhesion, low porosity and heat barrier properties against heat/fire protection. The results of the study is implemented as concrete liners in tunnel for increase its safety.

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