Comparative Study of Effect of Replacement of Conventional Curing with Different Curing Methods at Elevated Temperature

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Abstract - *In the present work, constitutes of interaction and comparative case study for compressive strengths and water absorption of cement concrete cubes with different curing methods at elevated temperature. The experimental work being carried out using detailed strength and durability related tests such as compressive strength test of cubes, test for saturated water absorption. Concrete cubes were used and their performances at alternative method were compared to conventional curing. The cubes were heated for various temperature 100°C, 150°C, and 200°C and the effect of elevated temperature is recorded after curing cubes with different curing compounds.*

Key Words: Compressive Strength, Water Absorption, Curing Compounds, Paraffin Based, Acrylic Based, Elevated Temperature.

1. INTRODUCTION

This Curing being essential for concrete to perform the intended function over the design life of the structure or to be more precise it is the process of maintaining proper moisture content particularly within period of 28 days to promote optimum cement hydration immediately after placement. The properties of hardened concrete, including the durability, are greatly influenced by curing since it has a remarkable effect on the hydration of the cement. The rising construction and chemical industry have paved way for the development and use of new curing techniques and construction chemicals to reduce dependency over water such as curing compounds, membrane curing compounds, self-curing agents, wrapped curing, accelerators, water proofing compounds etc.

Performance of concrete at raised temperature has often been a point of concern and taken for granted considering its non-combustible nature and ability to function as a thermal barrier, preventing heat and fire spread. Design criteria mostly expressed in terms of required reinforcement cover. The general applicability and usefulness of this approach may be debated since the heating regimes in real-world fires may be quite different compared to those for experimental point of view. Considering the thermal properties, concrete being more complex as it's a composite material whose constituents have different properties but its properties also depends on moisture and porosity. Exposing concrete to elevated temperature affects its mechanical as well as physical properties. Most elements are subject to distort and displace and under certain conditions the concrete surface could spall due to the buildup of steam pressure. Temperature induced dimensional changes which includes, loss integrity of structural, release of moisture and gases resulting from the migration of free water adversely affect safety, a complete study for behavior of concrete with a long-term elevated-temperature exposure as well as both during and after a thermal excursion resulting from a postulated design basis accident condition is essential for reliable design evaluations and assessments.

The property variations result largely because of changes in the moisture condition of the concrete constituents and the progressive deterioration of the cement paste-aggregate bond, which has a significant difference in values for thermal expansion values for the cement paste and aggregate. With the growing scale of the project, conventional curing methods have proven not only to be a costly affair but at the same time cases for vertical structures, inaccessible areas such as high rise buildings, water scarce areas etc. have many practical issues with conventional mode of curing thus have been replaced by membrane curing compounds and self-curing agents up to some extent as they can be used in such inaccessible areas. With this paper effort has been made to understand the working, efficiency and consequences of using different practical and widely used curing methods which are generally adopted in the construction industry as compared with the conventional water curing method.

1.1 Objectives of the Study

The primary scope of this study is to save and minimize the use of natural resources in terms of water and at the same time to compare different factors governing between a conventional and non-conventional type of curing at elevated temperature. For reaching this aim, environmental management and conclusive study over different sets of concrete proportions plays an important role in protecting natural resources as well as the structure. The model will give compressive strength of cement concrete with different curing methods at elevated temperature ranging from 100°C, 150°C and 200°C. From these values the derived model will give the strength of concrete which will be helpful in design purposes.

2. EXPERIMENTAL PROGRAM

2.1 Material Characterization

2.1.1 Water

Water used for mixing and curing was clean and free from injurious amount of oils, acids, alkalis, salts, sugar, organic materials or other substances of pH 6.80 >6.0.

2.1.2 Aggregates

(A) Coarse aggregates (20 mm and 10mm size) from local quarry (Kakani) have been used.

S.No.	IS Sieve No	Weight retained(gm)	% retained	% Finer	% passing
1	40 mm	0.0	0.0	100	--
2	20mm	0.0	0.0	100	--
3	10mm	630	12.6	87.4	85-100
4	4.75mm	4822	96.44	3.56	0-20
5	Pan	5000	100.0	0.0	0-5

Table (1) Sieve analysis of 10 mm size aggregate

With the help of IS-2386(part I) 1963 aggregate was found 10 mm single size.

S.No.	IS Sieve No	Weight retained(gm)	% retained	% Finer	% passing
1	40 mm	0.0	0.0	100	100
2	20mm	743	14.86	85.14	85-100
3	10mm	4930	98.60	1.40	0-20
4	4.75mm	4995	99.90	0.10	0-5
5	Pan	5000	100.0	0.0	--

Table (2) Sieve analysis of 20 mm size aggregate

With the help of IS-2386(part I) 1963 aggregate was found 20 mm single size.

Type of coarse aggregate	Specific gravity	void ratio
20 mm single size.	2.64	42.82%
10 mm single size.	2.64	44.12%

Table (3) Specific gravity and void ratio for coarse aggregate

(B) Fine aggregates from local river (Binawas) have been used.

	Specific gravity	void ratio
Fine aggregate	2.65	28.33%

Table (4) Specific gravity and void ratio for fine aggregate

S.No.	Sieve No	Weight retained(gm)	% retained	% Finer	Grading Zone III
1	4.75 mm	0.0	0	100.0	90-100
2	2.36 mm	35	3.5	96.5	85-100
3	1.18 mm	178	17.8	82.2	75-100
4	600 micron	343	34.3	**65.7**	**60-79**
5	300 micron	604	60.4	39.6	12-40
6	150 micron	956	95.6	4.4	0-10
7	Pan	1000	100.0	0	

Table (5) Sieve analysis of fine aggregate

Silt contents in F. A. was 0.6% < 2% and with the help of IS-2386-1963(Part I) fine aggregate was found of Zone III.

2.1.3 Curing Compounds.

Two curing compounds each with different bases were used.

(i) Paraffin dispersion based liquid curing compound for concrete (NORMET – Tam Crete CCW).

(ii) Elastomeric Acrylic based curing compound.

2.1.4 Cement

Ordinary Portland cement (OPC) 43 grade conforming IS-8112-1989 manufactured by WONDER CEMENT LIMITED is used. Cement is tested as per IS codes and results are as follows:-

(1)	Specific gravity of cement	3.14
(2)	Consistency of cement	26%
(3)	Initial setting time	40 min.
(4)	Final setting time	115 min.
(5)	Compressive strength of cement at 7 days	28.45 N/mm²
(6)	Compressive strength of cement at 28 days	44.47 N/mm²
(7)	Fineness of cement(90 micron sieve)	Residue 6.5%
(8)	Soundness of cement (le-chaterlier)	1 mm

Table (6) Test results of Ordinary Portland cement 43 grade

2.2 Performance of Cement Concrete with Different Curing Methods

There are a number of physical and chemical changes which occur in concrete subjected to curing. Porous concretes mostly contain a certain amount of liquid water. This begins to vaporize if the temperature exceeds 100°C, usually causing a build-up of pressure within the concrete. In practice, the boiling temperature range tends to extend from

100°C to about 140°C due to the pressure effects. Further the moisture plateau, as the temperature reaches to about 400°C, calcium hydroxide in the cement will starts to dehydrate, generating more water vapor and also bringing about a major reduction in the physical strength of the material.

Curing allows continuous hydration of cement and consequentially responsible for continuous gain in the strength, once curing stops strength gain of the concrete also stops. Maintaining proper moisture conditions is a important aspect as the hydration of the cement virtually ceases when the relative humidity within the capillaries drops below 80.With this insufficient water, the hydration begins to slow down and stops resulting concrete may not possess the desirable strength and impermeability. The formation of continuous pore structure on the near surface may also allow the ingress of deleterious agents and would cause various durability problems. More over due to early drying of the concrete micro-cracks or shrinkage cracks would develop on surface of the concrete. As soon as concrete is exposed to the environment evaporation of water takes place and loss of moisture will reduce the initial water cement ratio which will result in the incomplete hydration of the cement and ultimately lowering the quality of the concrete. Different factors such as wind velocity, relative humidity, atmospheric temperature, water cement ratio of the mix and type of the cement used in the mix effects the desired quality. Evaporation in the beginning stage leads to plastic shrinkage cracking and at the final stage of setting it leads to drying shrinkage cracking hence extra care is necessary.

Curing temperature being a major factor affects the strength development rate. At raised temperature ordinary concrete losses its strength due to the formation of the cracks between two thermally incompatible ingredients, aggregates and cement paste. The fact that concrete cured at raised temperature develops a high early strength than the one produced and cured at lower temperature, but strength is generally lowered at 28 days and later stage. Maintaining a uniform temperature through the concrete section to avoid thermal cracking is an important aspect. Tests from laboratory shows that concrete in dry environment can lose up to 50 percent of its potential strength then compared to similar concrete that is moist cured. Moist-curing period being another important aspect governs the curing of concrete as the longer the moist-curing period higher the strength of the concrete assuming that the hydration of the cement particles will go on. A minimum curing period corresponding to concrete attaining 70% of the specified compressive strength is recommended by American Concrete Institute (ACI) Committee 301.

A strong influence is created by curing regarding different properties of hardened concrete; proper curing will increase the strength, durability, volume stability, impermeability, abrasion resistance and resistance to freezing and thawing. "Internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water." As stated by ACI-308 Code. By term conventional, curing concrete it means creating conditions such that water is not lost from the surface i.e., curing is taken to happen from the 'outside to inside'. In contrast, 'internal curing' it is totally reveres i.e. accessing curing from the 'inside to outside' by the help of internal reservoirs created either in the form of saturated lightweight fine aggregates, superabsorbent polymers, or saturated wood fibers. 'Internal curing' is often also referred as 'Self–curing'. Thus, whilst the compressive strength of concrete is rapidly lost beyond a critical temperature, which is not too dissimilar to the equivalent temperature for loss of steel strength, structural effectiveness is not affected as long as the bulk of the material reaches the same temperature. Thus this requires an analysis of the thermal response of the entire structural element.

Ambient atmospheric conditions can adversely influence the thermal and moisture structure of freshly poured concrete. If concrete becomes too warm or temperature gradients too large during the first several days after the concrete is poured or if there is insufficient water in the concrete, the concrete may crack or may not develop its maximum potential strength, reducing its long-term durability. Surface drying may even affect the underlying concrete, as water will be drawn from the lower levels into the dry surface concrete. Any significant internal drying also will slow or stop hydration and the structure may not gain adequate strength. For continuing the hydration, the relative humidity inside the concrete has to be maintained at a minimum of 80%. There will be little movement of water between the concrete and the ambient air and no active curing is needed to ensure continuation of hydration only if the relative humidity of the ambient air is that high. Prevention of the loss of water from the concrete is of also a bigger challenge not only because the loss adversely affects the development of strength, but also because it leads to increased permeability, plastic shrinkage and reduced resistance to abrasion.

2.3 Development of Concrete Mixes

After getting results from basic test of concrete ingredients like cement, sand, coarse aggregate etc. one mix was designed as per IS 10262-2009 to achieve M-20 grade of concrete. To study the effect of curing on cement concrete the methodology of curing was altered keeping the proportion (0.50:1.0:1.58:3.21)

Water cement ratio	0.45
Cement	372 kg/m^3
Water	196 kg/m^3
Fine aggregates	589 kg/m^3
Coarse aggregates	1197 kg/m^3

Mix (C)

Proportion of 20mm and 10mm size coarse aggregate is taken as (40%+60%) and rests were kept same.

2.4 Casting of Cubes

All required raw materials were populated at laboratory. Moulds for cube of 150mmx150mmx150mm were taken as per specification by IS 456:2000. Burnt oil was applied on sides of moulds for easy de-molding of cubes. Electrically operated mixer as per IS 1791:1968 and vibrator as per IS2505:1980 were used for casting.

2.5 Curing

Each set of cubes were demoulded after 24 hrs. of casting and placed in water curing tank for 7days and 28 days. Curing of concrete was at laboratory temperature. Cubes were taken out and kept in laboratory after 7 days and 28 days curing period.

2.5.1 Mix C-1-M (Dry-Air Curing). Totally uncured types (open air) This method is the types where the cubes were left outside in the open air without any curing applied to it throughout the curing period, which tend to affect the cubes strength.

2.5.2 Mix C-2-M (Conventional Curing). The casted cubes were totally immersed in-side water, throughout the curing period; the curing water was maintained at an average laboratory temperature of 28^{o}C (82.4^{o}F) to prevent thermal stresses that could result in cracking.

2.5.3 Mix C-3-M (Paraffin dispersion based liquid curing compound). In this type TAM CRETE CCW curing compound was used, which is paraffin dispersion based liquid curing compound. The compound was applied within 30 minutes of demoulding the cube, with the help of brush along all the faces of cube. Finally leaving the cubes to dry without any further application throughout the curing period.

2.5.4 Mix C-4-M (Elastomeric Acrylic based curing compound). In this type Elastomeric Acrylic based curing compound was used, which is Acrylic based liquid curing compound. The compound was prepared with mixture of cement and water for thinking in a ratio of (1:0.5:0.5) where one being compound. The compound was applied within 30 minutes of demoulding the cube, with the help of brush along all the faces of cube. Finally leaving the cubes to dry without any further applications throughout the curing period.

2.6 Heating of Cubes

After curing for 7 days and 28 days cubes were heated in Muffle Furnace for 120 minutes. Temperature to which cubes were exposed was 100^{o}C, 150^{o}C and 200^{o}C (temperature was rose according to time temperature curve). It was noted that the variation in temperature of Furnace after reaching to desired temperature was +/- (10^{o}c). Oil based furnace was used for heating the cubes. The furnace was controlled by controlling temperature and duration with digital controller cum indicator and safety alarm setup provided with furnace system. Cubes were placed in staggered pattern with a maximum of four rows having muffle dimension 200mm * 200mm * 790mm Electric Power-09KW@415 V, 03Phase, 50Hz.

2.7 Testing of Specimens

After exposed to temperature cubes were cooled down to laboratory temperature and compressive strength was determined.

2.7.1 Compressive Strength Test

Compressive strength of cubes was determined with the help of gradual loading by a calibrated compression testing machine. The compression testing machine was “Aimil Series of Digital Compression Testing Machines” Aimil Compression Testing Machines conform to IS: 14858(2000) and calibrated with an accuracy of ± 1 % as per the requirement of 1828 (Class1). It can also be supplied as per BS: 1881 and other associated International Standards. These machines are available in 50KN, 100KN, 500KN, 1000KN, 2000KN, 3000KN & 5000KN Capacities.

2.7.2 Water Absorption Test

Water absorption of cubes was done with the help of Muffle Furnace at temperature 100-115°C for 60 Minutes to 120 Minutes with Digital controller cum indicator and Safety Alarm. Having Muffle Dimension 200mm * 200mm * 790mm Electric Power-09KW@415 V, 03Phase, 50Hz.

(Digital Compression Testing Machines)

(Muffle Furnace)

(Slump for Concrete)

(Moulds for cubes)

(Application of Curing Compound)

(Curing of cubes)

3. RESULTS

Into this study M-20 mix were used. These concrete cubes were than exposed to different curing methods including dry curing, conventional water curing, paraffin based curing compound, acrylic based curing compound. The results from this study are:

- The maximum values for 7 and 28 Days of compressive strength and water absorption was found to be for C-2-M i.e. for conventionally cured cubes.
- The variation for Percentage loss of 7 Days compressive strength was as much as 27.72% higher for C-1-M i.e. Dry-Air cured and 16.59% higher for C-3-M i.e. Paraffin based compound cured than that compared to strength of conventionally cured cubes.
- The variation for Percentage loss of 7 Days Compressive strength was found to be lower for about 7.3% in case of C-4-M i.e. Elastomeric acrylic based cured cubes, when compared to strength of conventionally cured cubes.
- The Percentage loss of 7 Days Compressive Strength when heated for 120 minutes at 100oC, 150oC and 200oC was found to be maximum for C-1-M about 27.4%, 27.72%, & 27.88% and C-3-M about 14.64%, 20.83%, & 22.12%. For C-4-M the same values range to about 4.1%, 5.27% & 6.63% for respective temperatures.
- The variation for Percentage loss of 28 Days compressive strength was as much as 20.19% higher for C-1-M i.e. Dry-Air cured and 16.61% higher for C-3-M i.e. Paraffin based compound cured than that compared to strength of conventionally cured cubes.
- The variation for Percentage loss of 7 Days Compressive strength was found to be lower for about 7.31% in case of C-4-M i.e. Elastomeric acrylic based cured cubes, when compared to strength of conventionally cured cubes.
- The Percentage loss of 28 Days Compressive Strength when heated for 120 minutes at 100oC, 150oC and 200oC was found to be maximum for C-1-M about 19.9%, 20.19%, & 20.37% and C-3-M about 14.62%, 17.91%, & 20.97%. For C-4-M the same values range to about 4.09%, 5.26% & 6.65% for respective temperatures.

Based on the discussion above, the following conclusions can be made with respect to curing application and performance of the concrete materials can be improved by following ways:

1. Irrespective of curing compounds employed and methodology of their application used conventional curing method of curing is recommended to be the best of all the curing methods. Since the method gives higher strength and lower permeability than compared with curing compounds. i.e. efficiency of curing compounds as compared with wet curing is less than 100% both for strength and durability.

2. The performances of Elastomeric Acrylic based curing compound comes out with greater degree as compared to that paraffin based curing compound, applied immediately after demoulding. Significant role for the application time and temperature of curing compound on the various mechanical (strength and hardness) and durability related properties (sorptivity and porosity). Thus an early application of curing compound is preferable, to achieve the best possible properties of concrete.

3. Both the curing compounds proved more efficient in when compared with totally dry concrete samples. This is found true from both strength and durability points of view. Areas with shortage of water, sustainability of water can be achieved by using suitable chemical compounds for curing of concrete. The average efficiency of the curing compound increases with curing age initially but reduces at later age.

4. Result shows a good performance against the loss of strength for thermal variation with use Elastomeric acrylic

based curing compound then compared to paraffin based compound or dry-air curing.

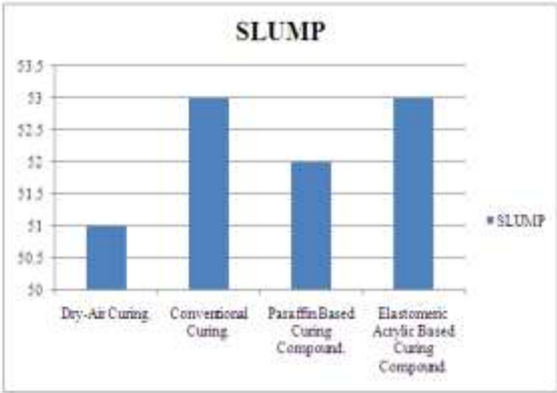

Figure (1) Slump for different mixes

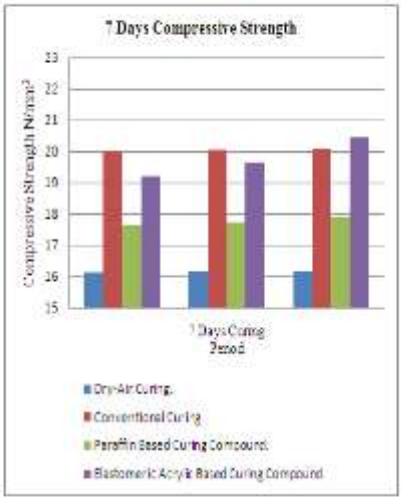

Figure (2) 7 Days compressive strength for differently cured concrete C-1-M to C-4-M

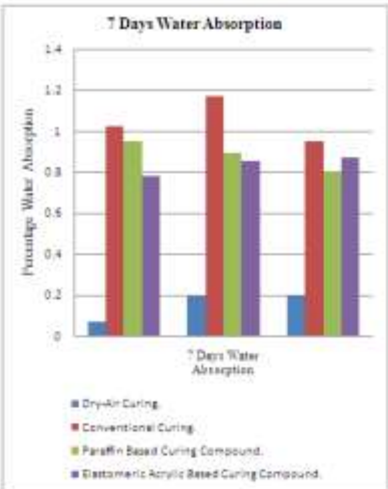

Figure (3) 7 Days Water Absorption for differently cured concrete C-1-M to C-4-M

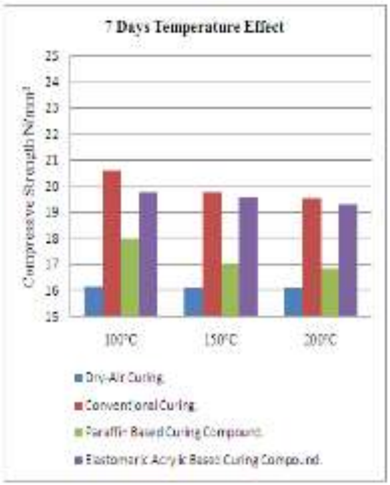

Figure (4) 7 Days temperature effect by compressive strength for differently cured concrete C-1-M to C-4-M

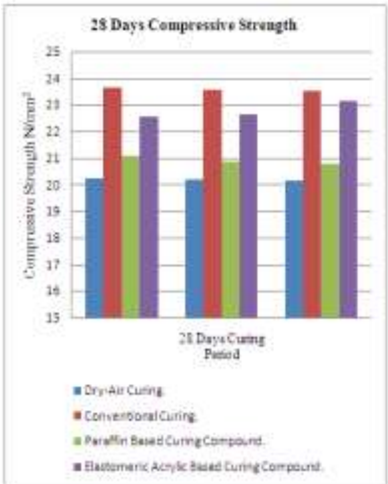

Figure (5) 28 Days Compressive strength for differently cured concrete C-1-M to C-4-M

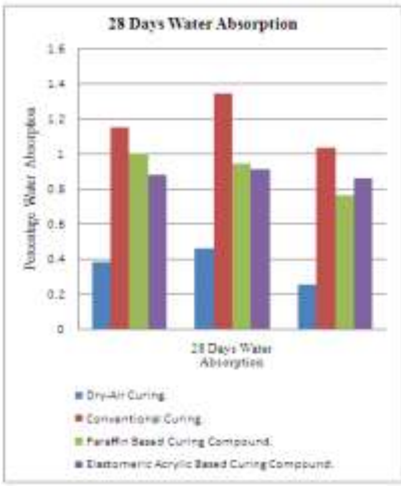

Figure (6) 28 Days Water Absorption for differently cured concrete C-1-M to C-4-M

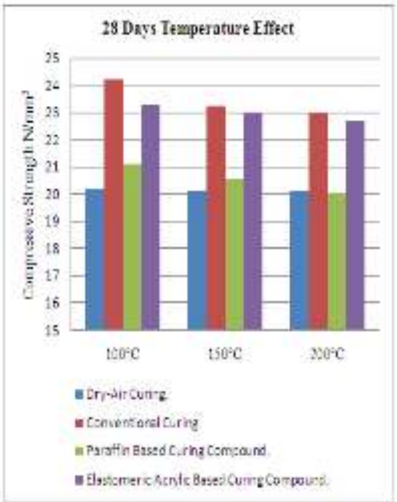

Figure (7) 28 Days temperature effect by compressive strength for differently cured concrete C-1-M to C-4-M

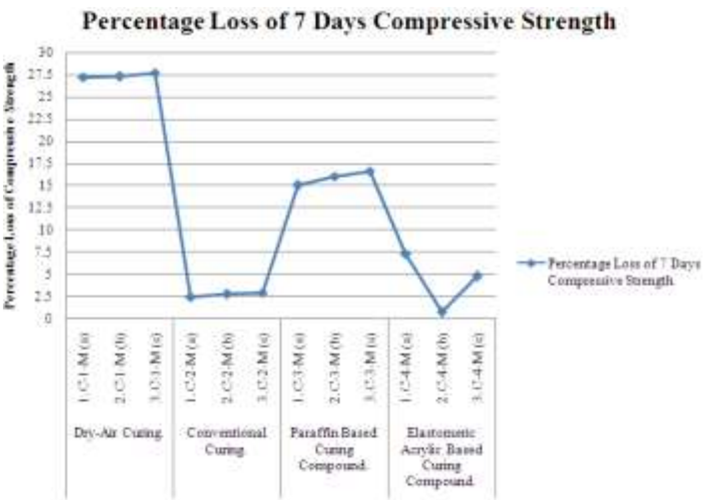

Figure (8) Percentage Loss of 7 Days Compressive Strength

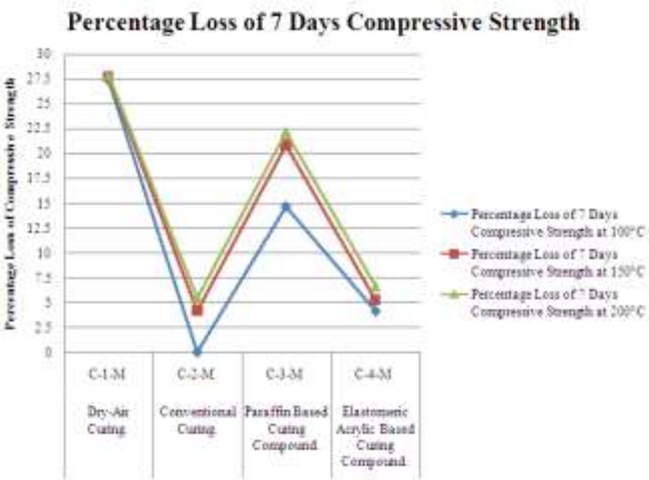

Figure (9) Percentage Loss of 7 Days Compressive Strength at 100°C, 150°C and 200°C

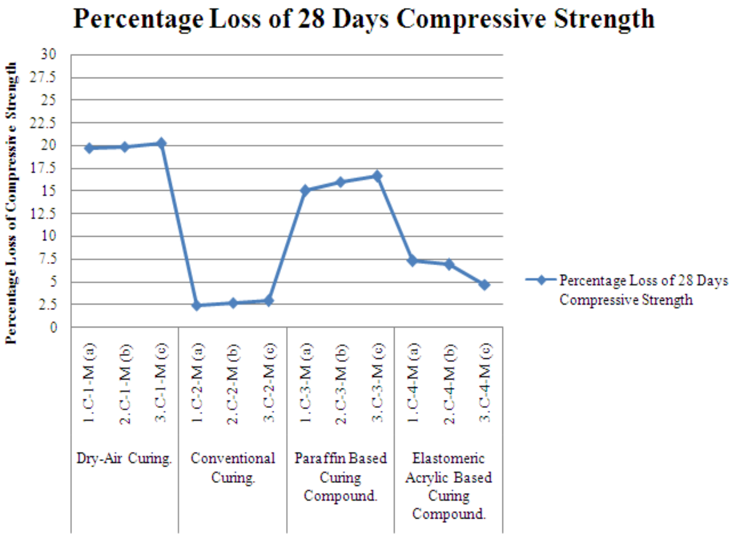

Figure (10) Percentage Loss of 28 Days Compressive Strength

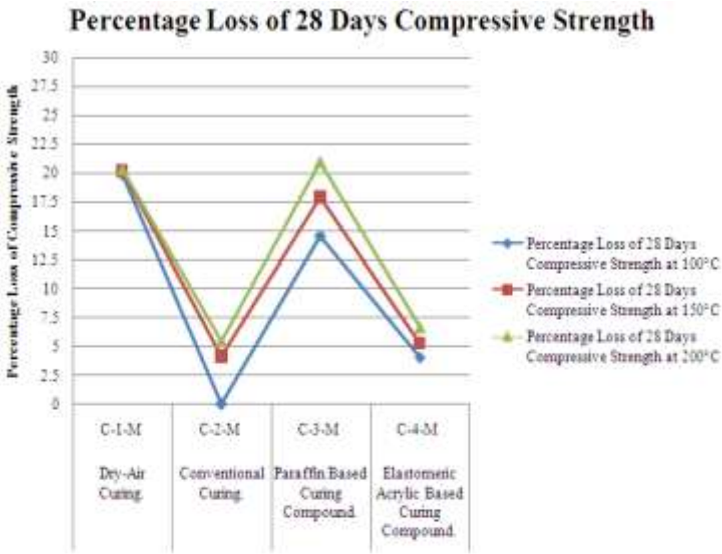

Figure (11) Percentage Loss of 28 Days Compressive Strength at 100°C, 150°C and 200°C

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