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Effect of Ambient and Elevated Temperature on the Residual Splitting and Flexural Tensile Strength of Normal and High Strength Concrete

Ateequr Rehman, Amjad Masood, Sabih Akhtar, M. Shariq

***Abstract:** Experimental test have carried out to investigate the behavior of residual tensile strength of concrete prepared using normal and high strength concrete. For the same purpose, cylindrical and prism-shaped specimens of concrete were caste and consecutively subjected to heating and cooling condition in the laboratory-controlled environment. A hold period of three hours was provided to impart the heating-cooling phenomenon inside the electrical furnace at four different sets of temperatures. The elevated temperatures chosen for the present tensile behavior study are 200ºC, 400ºC, 600ºC, and 800ºC. Strength was also determined at the ambient environment for the purpose of comparing the effects of thermal loads on the behavior of strength. A significant loss in tensile strength has been observed in concrete mixes at various temperatures. The outcomes of the current experimental work are termed useful for understanding key mechanical characteristics of concrete under the effect of thermal loads.*

***Keywords:** Concrete; Experimental techniques; Mechanical behavior Residual Split Tensile Strength, Residual flexural Tensile Strength; Thermal loads*

I. INTRODUCTION

A Fire has its own peculiar nature which attacks building construction. The buildings undergo deterioration when exposed continuously against fire due to its high temperature. The buildings have been designed so as to provide protection to the life of living beings as well as to cause minimum deterioration when undergoes through these types of hazards. Prime importance has been given to increase evacuation timing for escaping the people when the building is subjected to fire. In recent times, the use of High strength concrete (HSC) in civil construction has been rigorously boomed while designing multi-storey buildings especially in the skyscraper, where structural resistance against fire has been taken as one of major design perception while discussing the safety of living beings. The phenomenon of concrete spallingisan another major concern while dealing with higher strength concrete members that have often been developed due to the presence of low ratios of water-cement in the concrete mixes. While reviewing the literature, it has been observed that various researchers all around the globe had observed the degrading pattern of various mechanical properties of concrete prepared using different ingredient mix proportions when divulged to severe temperature ranges. One of the many contributions has been provided by S.A.Abo-El-Encini[1] who studied the consequence of thermal loads on physical and mechanical characteristics of concrete mixed with silica fume. In another investigation, Phan and Carino [2] analyzed and compared various mechanical and physical characteristics of concrete having normal and higher strengths at exalted temperatures. After making on tedious experimental investigations, he found that the differences in strength characteristics are more arrested when the temperature amplitudes are in the spectrum of 25ºC and 400ºC. It has been also observed that strength reduction in HSC had shown at a higher slope when compared that of NSC. Another study carried out by Kodur [3] investigated the HSC'sstrength and durability performances followed up with the comparison with that of NSC's when used as a structural member. Moreover, Luo and Chan [4] discussed the effects of higher thermal loads on the remaining or say, the residual strength of pore structure in various high-performance concrete (HPC) contrasting with that to NSC. Other investigations in obtaining the performances of mechanical properties such as residual Young's modulus of elasticity, flexural behavior and compressive strength for various concrete mixes under fire had been performed by Cülfik and Özturan[5]. The temperature spectrum was chosen in the study to impart the thermal effects on specimens ranges between 300ºC to 900ºC while using higher strength mortars specimens. Authors visualized higher contraction in magnitudes of concrete flexural strength compressive strengths at exalted temperatures. A similar study has been performed by Li et al. [6] who investigated the degrading pattern of compressive performance, split tensile performance along with the bending strengths of NSC and HSC at exalted temperatures and successively concluded with plots showing decrements in the relative strength of concrete at different fire exposure conditions.

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* Correspondence Author
Ateequr Rehman*, Research Scholar, Deptt.of Civil Engg., AMU, Aligarh, India. **Email id:** ateeq6434@gmail.com
Amjad Masood, Professor, Deptt.of Civil Engg., AMU, Aligarh, India, **Email id:** amjadmasood1@rediffmail.com
Sabih Akhtar, Professor, Deptt.of Civil Engg., AMU, Aligarh, India, **Email id:** sabihced@yahoo.co.in
M. Shariq, Assistant Professor, Deptt. of Civil Engg., AMU, Aligarh, India, **Email id:** mshariqdce@gmail.com

Phan and Carino [7,8] determined the mechanical and physical characteristics of concrete at higher thermal loads by performing the experimentations under stressed and unstressed conditions. The investigation done by Xiao and Gert[9] revealed a significant reduction in residual strength at 400 degrees Celsius consecutively expanded to 75% loss at 800 degree Celsius fire exposure. In another study, Kodur and Phan [10] reported that the fire strength performance in concrete structures has dependencies on fire timing, its types, the heat evolved and the location and area affected. While dealing with exalted thermal load, another key finding on remaining compressive strength of concretes of different grades along with its consecutive mechanical performance after adding different percent of Silica fume and different water-cement ratios (w/c) had been investigated byBehnood and Ziari [11]. Authors identified that the concrete mixed with silica fumes shows lesser reduction in strength depended characteristics than the ordinary concrete up to 600ºC. Fire effect on pozzolanic mixed concrete composites had been studied by Alidoust et al. [12] whereas Hachemi [13] reported decrement in mass and density of concrete while studying fire resistant behavior of NSC and HSC under exalted temperatures.

The present study investigates the characteristic variation of NSC and HSC when subjected to thermal loading at five different temperatures, hence evaluating the residual strength and corresponding fire-resisting performance of various concrete mixes. The future objectives may include in obtaining the mathematical relations of strength at any future point of time with respect of having dependencies on fire characteristics and ingredient percentages use for preparing mixes. The study also aids future designers in developing appropriate solutions against fire effect HSC members that may help in prolonging the structural life and mitigations purposes.

II. EXPERIMENTAL PROGRAM

A. Material Properties

Ordinary Portland cement of Grade-43 has been utilized for preparing the concrete mixes throughout the current investigation having its cements properties conforming to Indian codal provision, IS-4031 [14] (see Table 1). Micro-silica procuring Grade 920 U (i.e. Content of silica >92 %) along with river sand as fine aggregate acquiring modulus of fineness 3.27 mixed with well-graded crushed granite stone pieces of 20 mm (max.)and sp. Gravity of 2.69 g/cm^3 were used for the experimental program. The physical characteristics of both the fine and coarse aggregates are conformed to Indian codal provision, IS-383 [15]. For the purpose of hydrating the mix content, the potable water free from hazardous or deleterious elements has been used having a recommendation to IS: 456 [16]. The admixture, Glenium 51 has been mixed to provide workability of HSC concrete mixes.

Table 1. Physical characteristics of cement utilized in preparing concrete specimens.

Characteristics	Results obtained	Specified Value (as per IS:8112-1989)
Specific gravity	3.14	**3.15**
Soundness (mm) (Le Chatelier's Test)	1.00	**10 (maximum)**
Autoclave expansion (%)	0.056	**0.8 (maximum)**
Normal consistency (%) (percent of cement by weight)	31	**30**
Setting time (Min.) **(1) Initial** **(2) Final**	 140 360	 **30 (minimum)** **600 (maximum)**
Compressive strength (MPa) **3-days** **7-days** **28-days**	 **24** **33** **43**	 **23** **33** **43**

B. Proportioning of NSC and HSC mix

Sticking to the guidelines and clauses mentioned in Indian code IS: 10262 [17], two different mixes were prepared. The NSC mix for obtaining characteristics compressive strength of magnitude 20 Mpa and HSC mix prepared for obtaining characteristic strength of magnitude 60 Mpa were prepared applying the hit and trial meth. The dosage of superplasticizers was taken as 2% by weight of cement. The detailed proportion of various mixes has been tabulated in Table- 2.

Table- 2: Proportioning of concrete mixes.

Mix	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water cement ratio	Silica fume (kg/m^3)	Superplasticizer (% by weight of cement	Slump (mm)
NSC	350	630	1235	0.50	-	-	50
HSC	600	624	1050	0.34	49.8	2	30

C. Casting and Testing Procedure

The 28 days split and flexural tensile strength of specimens prepared utilizing NSC and HSC mixes by testing cylinders of size150mm × 300mmand prism 100mm×100mm×500mm sticking to codal provisions IS: 516 [18]and IS:5816 [19]. For the purpose of mixing the ingredient, firstly the coarse aggregate were placed inside the electricity-driven –mixer followed by adding 1/3rdof water quantity. The remaining ingredients were added to the mixer fine aggregates, cementitious materials, appropriate quantity of silica fumes, and then the remaining quantity of water maintain a gradual mixing procedure. The specimens inside the moulds were demoulded after 24 hours and are cured using potable water for 28 days after which these NSC and HSC specimens are subjected to testing at ambient and exalted temperatures for different regimes of heating-cooling cycles.

D. Heating and cooling regime

The electric controlled furnace depicted in Figure 1was utilized for thermal loading concrete cubes, cylinders, and prism. The furnace includes the heating elements owing to the heating rates 5°C per min fixed from two inside sideways while having a refractory lining on all six faces.

The furnace dimensioning has been done in such a way so as to provide internal clear spaces of about 1000mm ×760mm ×510mm (length × width × height). A hole having dia. of 20mm has been provided in front of the furnace to release fumes. This hole apart of providing prevention from blasting also has been utilized in placing thermocouples inside the furnace. The current electric furnace comprises a programmable microprocessor that acts as a temperature controller for the instrument. The temperature inside the furnace has a rating of 1150˚C (max.) that is designated standardized using a fire curve of standard fires.

Figure 1. Electric based furnace used in the experimental study for controlling temperature environment.

To pass a single cycle of heating and cooling, the specimens from each mix were placed in the furnace and heated from ambient temperature (25±°C) to 200°C, 400°C, 600°C and 800°C at the average rate of 5°C/min. The specimens were then held at the desired temperature for approximately 3 hours (as shown in Fig. 2)

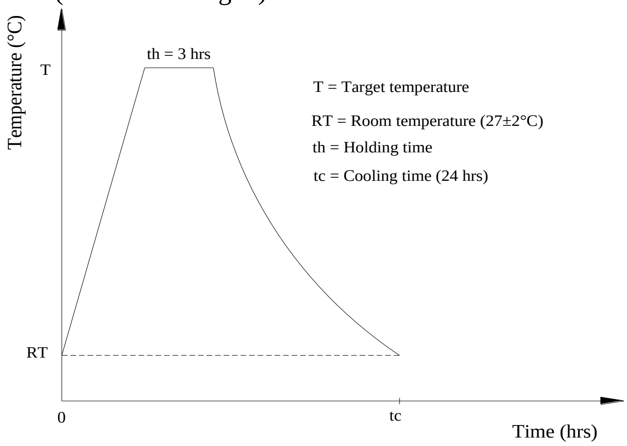

Figure 2. Single heating-cooling cycle curve

III. RESULTS AND DISCUSSION

EFFECT OF TEMPERATURE ON RESIDUAL CONCRETE'S COMPRESSIVE STRENGTH

The performance of NSC and HSC concrete mixes at ambient and higher temperatures has been plotted as shown in Figure3 and Figure 4. The residual strengths of NSC and HSC specimens has been observed about 28.66 and 61.38MPa respectively at ambient temperature, and it decreases gradually with increasing thermal loads. The figures shown below perpetuates that NSC specimens observed the least strength at all temperatures regimes. With increments in thermal loads, a minimal loss in residual strength under compression has been observed in this mix. NSC cubes show a gradual fall in the strength of 82.79%, 55.3%, and 19.81% strength, at 200, 400 and 600°C temperature respectively. Moreover, in the case of cylinder-shaped specimens, the strength at these temperatures was observed to acquire lower values when compared to cube-shaped specimens. On the other hand, the strength of HSC cubes was found to be decreasing gradually from87.29%, 64.09%, 45.19%and 18.80%at 200°C, 400oC, 600°Cand 800°C temperatures respectively. A significant amount of decrement in the strength of specimens of HSC mix has been observed while increasing temperature up to 400°C, which is marginal in the case of NSC. At 400°C, both the cube and cylinder compressive strength in HSC specimens is approximately the same. Due to the development of extensive cracks in HSC specimens, both cubes and cylinder strength have been observed near about (Figure5 and Figure 6). After 400°C, the strength of HSC was observed to lose strength rapidly up to a temperature of 800°C, the compressive strength of NSC at 600°C is very low in the cubes. These specimens did not depict any value of strength after this temperature. No strength beyond 600°Cin NSC cylinders has been observed in the present work.

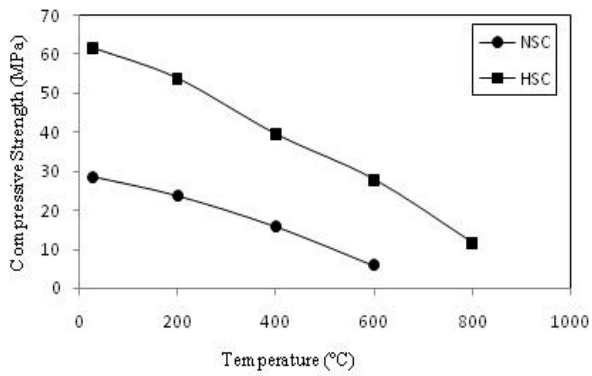

Figure 3. Residual cube compressive strength for different concrete mixes at exalted thermal loads

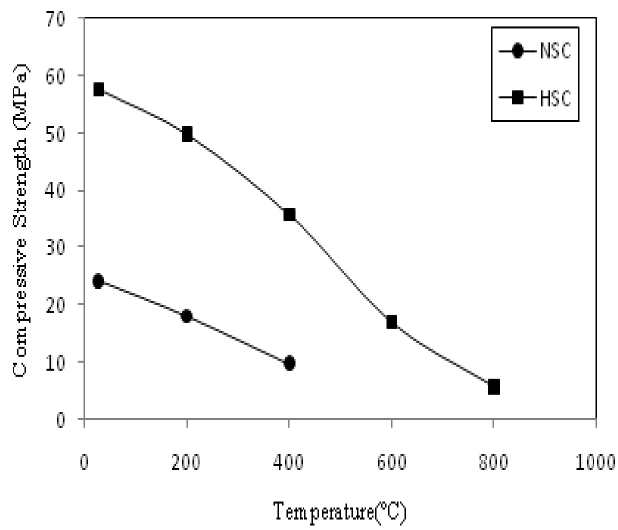

Figure 4. Residual cylinder compressive strength for different concrete mixes at exalted thermal loads

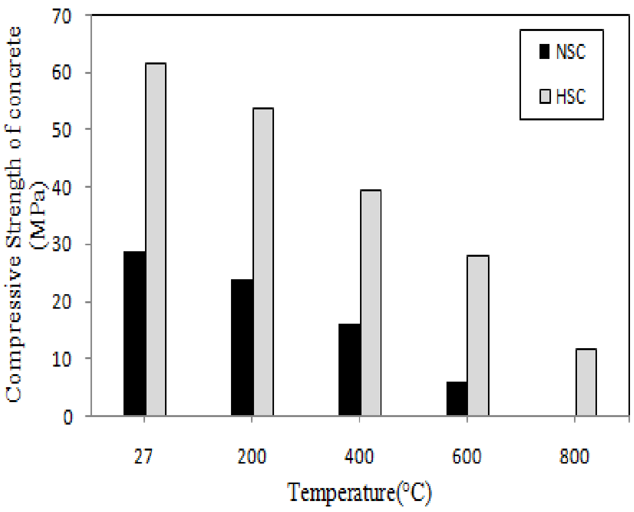

Figure 5. Residual cube compressive strength in MPa for various concrete mixes at the exalted temperature

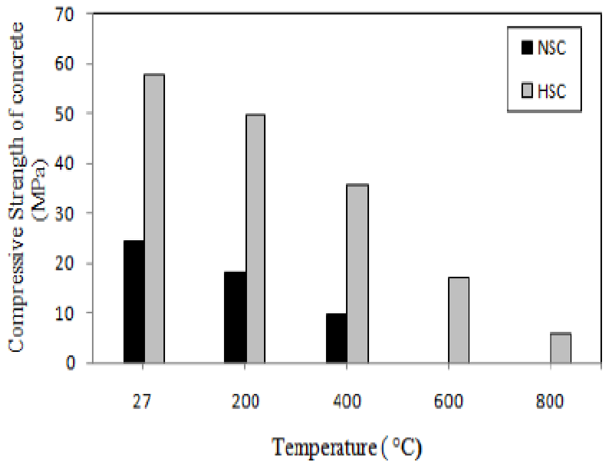

Figure 6. Residual cylinder compressive strength in MPa for various concrete mixes at the exalted temperature

Effect of elevated temperature on splitting tensile strength

Effect of elevated temperature on splitting tensile strength of normal strength (NSC) and high strength concrete (HSC)for a cylinder-shaped specimen of the first phase is shown in Fig. 7. It is evident from the figure that on increasing temperature, splitting tensile strength decreases as witnessed in different grades of the concrete mix. However, all grades of the concrete mixes on testing exhibited better splitting tensile strength as relative to flexural tensile strength. Moreover, the decline in splitting strength was found to be quite low in comparison to flexural tensile strength.

The split tensile strength of NSC and HSC were found to be 3.68 and 4.52 MPa respectively at ambient temperature. HSC has shown good splitting tensile strength at ambient temperature. It might be said that to achieve maximum splitting tensile strength, higher strength can be more useful.

The split tensile strength of normal strength (NSC) has the least value at ambient temperature as well as elevated temperatures. The split tensile strength of the mix is about 76.90%, 36.68%, 9.59% MPa respectively at 200, 400 and 600ºC.

High strength (HSC) has shown tensile strength of 82.74%, 50.06%, 34.42% and 17.21% MPa between 200 to 800ºC. The split tensile strength of this concrete is the highest at most of the temperatures. But the split tensile strength of high strength (HSC) reduces more sharply as compared to the other mix.

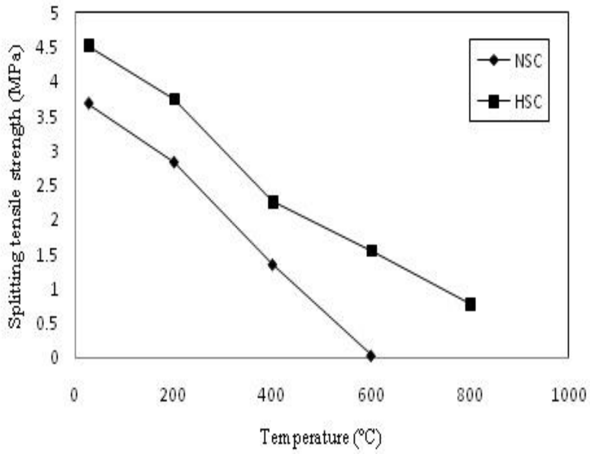

Figure 7. Residual splitting tensile strength of different concrete mixes

Effect of elevated temperature on residual flexural tensile strength

The Effect of elevated temperature on residual flexural tensile strength has a direct relation with ductility. As the compressive strength of concrete rises, generally, its brittle behavior also escalates, resulting in the reduction of residual flexural tensile strength. Fig 8 shows the trend of residual flexural strength on varying temperatures for the concrete mixes. It can be observed that the reduction of the tensile strength in all the concrete mixes is sharper as compared to the reduction in compressive strength at the same temperatures. It was found that no residual tensile strength was left for all the concrete mixes after 600ºC temperature.

The flexural tensile strength of normal strength (NSC) and high strength (HSC) is 4.0 and 5.8 MPa respectively at ambient temperature. Due to the brittle behavior of high strength (HSC), the tensile strength of the said mix and normal strength (NSC) is very close at ambient temperature.

At high temperatures reduction of flexural tensile strength is observed in all the grade concrete mixes. At 200°C, the flexural tensile strength of 45% MPa is observed in NSC. The flexural strength of HSC is 72.41% and 27.58% at 200 and 400ºC respectively. The tensile strength reduces slightly in high strength (HSC) up to 200ºC as compared to normal strength (NSC). The loss of strength in normal strength (NSC) and high strength (HSC) is 55% and 27.59% respectively at these temperatures.

At200ºC, the loss of flexural tensile strength is rapid in high strength (HSC) as compared to normal strength (NSC). HSC showed an abrupt reduction in flexural tensile strength between 200 to 400ºC. On applying the tensile load, the cracks and channels develop in the concrete matrix, which led to the early collapse of concrete. The brittle behavior of high strength(HSC) and the pattern of the cracks obtained, follow the same pattern.

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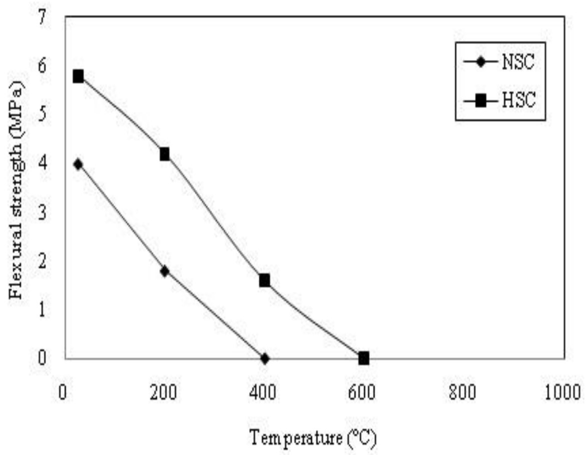

Figure 8 . Residual flexural tensile strength of NSC and HSC

IV. CONCLUSIONS

The experimental investigation has been carried out efficiently under lab-controlled conditions to obtain the results evaluating the mechanical performance of concrete behavior under overburdened thermal loads. The point-to-point conclusions drawn after visualizing behavior evaluating the thermal behavior of concrete of different mixes are as given below:

- The grades of mixes used for obtaining normal strength (NSC) and high strength (HSC) in concrete are 28.66 MPa and 61.38 MPa respectively.
- Exposure of concrete to higher thermal loads reduces the compressive strength effectively. Further, the losses in the strength of concrete mixes have been found varying directly with respect to temperatures.
- In a temperature ranging between 27°C to 400°C, HSC pertains to a higher loss in compression strength when compared to that of the specimen having normal strength.
- It has been also observed that above 400°C, the specimens that were prepared using HSC loss a significant in its compressive strength was observed when compared with specimens tested at ambient temperature conditions. The mean loss in strength at 600°C has been evaluated by about 80.15% in specimens prepared using NSC.
- In a similar manner, an average loss of about 81.2% strength at 800°C has been observed.
- Specimens prepared using higher strength concrete mixes has been found more valuable when exposed to severe thermal loading conditions when compared to the other normal strength mix. The study will help the future researcher in the field of investigating the mechanical characteristics of concrete mixes under elevated thermal loading to obtain a precise estimation of failure strengths.
- When exposed to 200°C, normal strength (NSC) showed losses of up to 55% in flexural strength, while high strength (HSC) showed a loss of 27.58%. At 400°C in high strength (HSC) losses reached up to 72.42% of the initial flexural strength. When the temperature increased up to 800°C, almost all of the flexural strength is lost.
- After 400°C, to 600°C, normal strength (NSC) showed losses of up to 90.41% in split tensile strength, while high strength (HSC) showed a loss of 65.58%. At 800°C in high strength (HSC) losses reached up to 82.79% of the initial splitting tensile strength.

Conflict of Interest

The authors whose names are listed in this paper have no affiliations or involvement in any organization with any financial or personal interest.

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AUTHORS PROFILE

Ateequr Rehman, Research Scholar, Deptt.of Civil Engg., AMU, Aligarh, India**.**

Amjad Masood, Professor, Deptt.of Civil Engg., AMU, Aligarh, India , Ph.D thesis from renowned Earthquake Engineering Department at IIT-Roorkee are as under, which is my area of interest. Topic of M.Sc Engg Dissertation: Seismic Response of Single Storey Masonry Building with Sliding Sub-Structure Topic of Ph.D. Thesis: Out-of-plane Behaviour of Unreinforced Masonry Infill Panels. My current research is on macro and micro study of high and normal strength concrete at elevated temperatures along with the use and study of recycling of Waste materials for construction. I had UPCST and AICTE sponsored projects in these areas. Set up a lab for the study of materials at elevated temperatures. My research work includes study of Seismic Response, Design and Modeling of UR Masonry Structures I am engaging Courses the following courses at Undergraduate and post graduate level Design of Concrete Structures-I Design of Steel Structures Bridge Engineering Earthquake Resistant Design of Structures I have published papers in the following refereed International Journals given below,Bulletin Indian Society of Earthquake & Tech., Roorkee, India Journal of Ferrocement, Bankok, Thailand Indian Concrete Journal,Journal of Institution of Engineers, Journal for Environmental Engineering and Policy Springer, University of Cincinnati, Pennsylvania, U.S.A, Pergamon Elsevier Science Ltd, Cement and Concrete Research-An International Journal, USA, Science Direct, Elsevier Science Ltd, Construction and Building Materials-An International Journal, USA

Sabih Akhtar, Professor, Deptt.of Civil Engg., AMU, Aligarh, India , Ph. D. from A.M.U, Aligarh, India Topic: Improvement in Durability of Ferrocement through Corrosion Inhibitors Research Interest: Corrosion control in structures, Cementitious composites, Low-cost and light-weight construction material,Earthquakeand wind resistant structures .Teaching Interest: Structural analysis, Reinforced concrete design, Advanced construction material, Strengthening and rehabilitation of structures, Earthquake resistant structures. Journal of Ferrocement,, Cement and Concrete Research, Journal of Structural Engineering, Journal of Institution of Engineers (India), Arabian Journal for Science and Engineering,. Journal of Steel Structures and Construction.

M. Shariq, Assistant Professor, Deptt. of Civil Engg., AMU, Aligarh, India, Ph.D. (Structural Engg.) from IIT Roorkee. He has also worked as planning engineer in Afcons Infra structure limited on Delhi Metro Rail Corporation (DMRC) project. His research areas are long-term properties of admixture based concretes, concretes at elevated temperature, sustainable concrete. He has published research papers in various International and National journals and conferences such as Cement and Concrete Composites (Elsevier), Magazine of concrete research, Construction and building materials (Elsevier), Building and environment (Elsevier), Computers & Concrete (Techno-Press), Indian concrete journal and Journal of structural engineering (SERC). He is reviewer of ACI Material Journal, Construction and Building Materials (Elsevier Publication), Computers & Concrete, Propulsion and Power Research (Elsevier Publication), International Journal of Pavement Engineering (Taylor & Francis), International Journal of Concrete Structures and Materials (Springer)

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