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*Research Article*

# Influence of elevated temperatures on M20 grade concrete with colloidal silica

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**Abstract**

Concrete is a material which is mostly used next to water in the construction industry because of its ability to be cast into any shape and size. The rapid growth of technology in the construction field has developed new innovative modern concrete consisting of the alternative materials other than the constituents of the conventional concrete. Among these developments, nano concrete exhibits high performance and strength attained by the application of nano materials. These nano materials have nano sized particles having larger specific surface area which in turn helps in accelerating the pozzolanic reaction in concrete and making the concrete denser. There is also need for development of new concrete along with fire resistance characteristics by using nano material. Hence, it is aimed at the usage of colloidal silica of two types in concrete and to study strength characteristics of concrete of M20 grade when subjected to heat exposure at higher temperatures. The strength residue are measured in terms of modulus of rupture, compression and split tensile of M20 grade of concrete which are evaluated at different temperatures of 100, 200, 300, 400 and 500°C for time of 1, 2, 3 and 4 hours exposure durations to predict influence of colloidal silica on concrete mixes. The results are compared with conventional concrete and the utilization of colloidal silica has improved the residual strength parameters. Colloidal silica due to its pozzolanic nature, it has filled the voids in conventional concrete and developed a new innovative dense concrete with enhanced strength properties at elevated temperatures.



## 1. Introduction

Concrete acts as an important construction material among the various materials used in developing countries. It is also one of the best suitable and safest materials among the various building construction activities. Concrete is a leading structural material which is obtained by uniform mixture of aggregates, water, cement and necessary amount of mineral or chemical additives [15]. Strength and durability aspects resemble the quality and stability of concrete [22]. Concrete can be made less permeable with increased durability properties by utilization of various supplementary cementitious materials. These materials include nano materials in the recent developments of technology and construction field [21]. Various structural damages of concrete include the temperature effects when exposed to fire due to unforeseen circumstances. The structures get deteriorated due to the reaction of fire with concrete resulting in the loss of strength and durability. In the present study, effect of the nano material, colloidal silica is studied by considering the strength aspects in terms of compression, split tensile strength and modulus of rupture at various elevated temperatures. The major hydration products are affected during the

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exposure condition of structural members against fire at elevated temperatures resulting in the formation of cracks and loss of weight causing decrement in strengths. Concrete is fire resistant up to some extent when compared to other structural materials. Thus, the resistance can be improved by strengthening it using the nano materials which further increase the production of hydration product CSH gel. The resultant CSH gel in turn develops the excess strength up to certain temperature and further it decreases. Sreenivasulu and Srinivasa Rao had presented the temperatures effect on concrete compressive strength. These specimens subjected to elevated temperatures of 50, 100 ,150, 200 and 250°C for various time durations of 1, 2, 3 and 4 hours for every temperature. The results obtained were analyzed and the effects of elevated temperatures on these two properties were presented in their study [1]. Vasusmitha and Srinivasa Rao had assessed the properties of self-compacting concrete of M80 grade when subjected to temperatures of 200, 400 and 600 °C exposed to 4, 8 and 12 hours durations. The tests on fresh and hardened concrete mixes were performed for the self-compacting concrete and results were analyzed in their study [2].

Sreenivasulu and Srinivasa Rao had presented the variation of strength properties of concrete at different temperatures sustaining to duration of heating. Loss of weights and strengths were determined and analyzed from their study [3]. Shehab and Heba had investigated strength of concrete using fiber reinforced polymers. The heating effect on concrete is determined in terms of compression, split tensile and flexure by casting the specimens and heating to temperatures 100, 150 and 200 °C. Carbon fibre reinforced polymer was wrapped into specimens for strength tests [4]. Jagath Kumari and Srinivasa Rao had carried out an experimental work on concrete with large volume of fly ash. The specimens cured for 28 days were heated to the temperatures from 100°C to 800 °C at 1, 2 and 3 hours' time exposure. Concrete with OPC has shown more residual strengths for 1 and 2 hours durations. At 3 hours duration of exposure almost equal strength has been attained [5]. Madhavi et al. had discussed the changes of strength due to temperatures on strength by replacing fine aggregate. To understand concrete behavior under higher temperatures, strength parameters were to be considered. It was observed that reinforcement detailing and cover to the reinforcement were observed to be important aspects during the study [6]. Mohit Chachere et al. (2016) had conducted many experimental works on concrete to assess physical and chemical behavior along with the strength parameters [7]. Asif Husain et al. made a study to review on the effects on structural behavior at different temperatures for concrete structures. Also, the study had introduced many measures for controlling effects of weather on concrete in various civil engineering structures [8]. Aqeel Shams had dealt with the importance and meaning of fire rating and effect of fire on RCC members. The changes which occur in physical and chemical characteristics of RCC members were studied when exposed to fire. From the studies it was concluded that the suggestion on how to make structural concrete more resistant against fire and the guidelines provided by IS 456:2000 on securing the certain degree of fire resistance in concrete [9].

Durga Rama Naidu et al. have done study on M20 grade concrete compressive strength subjected to different exposure durations. The structural aspects of concrete at various temperatures and changes including strength and physical properties were observed in their study [10]. Forood Torabian Isfahani et al. have analyzed the impact of nano particles of silica on different substages of hydration of cement such as initial reaction, dormant period and acceleration period [20]. The Thermal Gravimetric Analysis on the concrete specimens for 28 days curing was carried out and revealed that addition of silica particles has increased the hydration rate [11]. Yewale et al. have presented influence of 150°C and 250°C temperatures on M20 grade concrete for two hours. After heating, the specimens were taken out and cooled by air and water quenching. The values of compressive strength of cube specimens with and without heating were compared with control specimens used in their study [12]. Sivaji and Haritha had analyzed the effect of temperatures on M20 grade specimens of concrete. These specimens were exposed to temperatures varying from room temperature to 1000°C for 3 hours exposure at an interval of 100°C. Color change and weight loss of specimens were studied by considering initial and final weights and change of color from one state to other state. The values of strength obtained from the non-destructive tests were compared with the results of destructive tests in their study [13]. Kiran Kumar et al. have attempted to study the structural behavior of concrete of grades M20, M40 and M60 grades of concrete when exposed to 200 to 800°C for every 200°C interval at one hour duration. Concrete compressive strength was determined at various temperatures and are compared with the strengths obtained from the non-destructive testing method using Rebound Hammer test [14]. From the previous literature studies and results, it is observed that there is a research gap regarding the strength aspects of concrete and their behavior at elevated temperatures by using nano materials i.e., colloidal silica. And also, colloidal silica of different nano solids content is utilized in the study for assessment of temperature effects on concrete at certain temperatures.

The present study aims to investigate M20 grade concrete behavior with nano material colloidal silica having two different percentages of nano solids content at different temperatures by using the raw materials [16,17]. Investigations made on concrete at 28 days curing heated from 100, 200, 300, 400 and 500°C for 1 hour to 4 hours durations of exposure. The heated concrete is allowed for air cooling and the strength parameters are studied.

## 2. Methodology and Experimental Investigation

### 2.1 Materials

Cement, river sand and coarse aggregate are the major raw materials used in the present study. Cement utilized in the study is of 43 grade ordinary Portland type having specific gravity of 3.10 and fineness of 4%. Fine aggregate is natural river sand corresponding to zone-II as per IS 383 coal provisions. The specific gravity of sand is 2.63. Coarse aggregate of 20 and 10 mm are considered in the work in proportions of 60 and 40 % respectively. Specific gravity of 20 and 10 mm are 2.78 and 2.74. The main nano material colloidal silica of two types having different percentages of nano solids content is adopted for the experimental investigation for development of new innovative nano concrete. These two types are having 30 and 40 % nano solids content. The colloidal silica is used as a replacement material for cement and the weight of colloidal silica is taken as 2.5 % by weight of cement in the study. As the colloidal silica considered is of liquid form which is combination of nano solids content and dispersion liquid, the weights are balanced by both cement and water in the concrete mixes. The various properties of colloidal silica are present in Table 1 which is provided by the manufacturer.

Table 1. Characteristics of colloidal silica

| S. No. | Property | CSTX | CSFX |
|---|---|---|---|
| 1 | Nano solids content | 30% | 40% |
| 2 | Specific gravity | 1.21 | 1.30 |
| 3 | pH | 9 | 10 |
| 4 | Viscosity | 5 cp | 7cp |

### 2.2 Methodology

The concrete specimens are cast as per the mix proportions obtained from M20 mix design consisting of cement, river sand, water, colloidal silica and coarse aggregate after mixing in a concrete mixer and compacted for required workability of fresh concrete. The slump of concrete is maintained at 50 mm for all the concrete mixes by using a super plasticizer Conplast SP 430. The slump values of concrete with colloidal silica are observed to be decreased when compared to conventional concrete as nano particles in silica has the property of filling the voids and binds the concrete resulting in denser material. The cast specimens are cured under water for 28 days period and are tested for elevated temperatures. Strength characteristics of M20 grade of concrete and Conventional Aggregate concrete are studied by performing tests on hardened cubes, cylinders and prisms after 28days of curing by exposing them to temperatures of 100, 200, 300, 400 and 500°C in Bogie Hearth Furnace for exposure time from 1 hour to 4 hours at an interval of one hour duration. These specimens are gradually heated up to the elevated temperatures selected for the study for exposure durations mentioned above. The concrete specimens are cast and cured for 28 days curing period and exposed to different temperatures up to 500°C from room temperature 27°C at an interval of 100°C for heating time varying from 1 hour to 4 hours. Specimens are placed on the rails in the heating chamber of the furnace and then the door is locked with the provided screws. The required temperature is set on the control panel which is beside the furnace door as shown in Fig.1. After the required duration of heating for the desired temperature, the specimens are taken out. There are two standard methods of cooling the heated specimens such as water quenching and air cooling. In the present study air cooling method is adopted. After exposure to heat, the specimens are left cooled for 10 hours and then the strength tests are performed. Then the specimens are tested for strength aspects based on their shape and size. The results obtained from the tests are compared to draw effective conclusions. The furnace used in the study is as shown in Fig. 2.


Fig. 1. Bogie Hearth furnace setup for heating specimens up to 500°C

Fig. 2. Specimens placed in furnace for heating the specimens

## 2.3 Experimental Investigation

After heating and air-cooling process, the concrete specimens such as cubes, cylinders and prisms are tested for compressive, split tensile and flexural strength with and without considering the effect of elevated temperatures. The entire strength tests are carried out as per coal provisions of IS 516 Part 1 Sec :1 2021. The compressive strength test is performed on 150 mm size cubes in 10-ton Compression testing machine. The strength is calculated from the ratio of maximum load and corresponding area of specimen. The split tensile strength test is performed on 150 mm diameter and 300mm height size cylinders in 10-ton Compression testing machine. The strength is calculated from the ratio of maximum load and corresponding surface area of specimen. The modulus of ruptures (flexural strength) test is performed on 500 x 100x 100 mm size prisms in 10-ton Universal testing machine. Based on the crack width, the flexural strength is calculated as per coal parameters.

## 3. Results and Discussions

The residual compressive, modulus of rupture and split tensile strength values obtained from conducted tests on the concrete specimens using testing machines [18,19]. M20CS0 represents conventional concrete. Whereas M20CSTX2.5 and M20CSFX2.5 represents concrete mixes with 2.5 % colloidal silica having 30 % and 40 % nano solids content respectively. Residual values of modulus of rupture, split tensile and compressive strength of M20 grade concrete for various temperatures 100, 200, 300, 400 and 500°C for various duration exposure conditions are shown in Figs. 3 to 11.

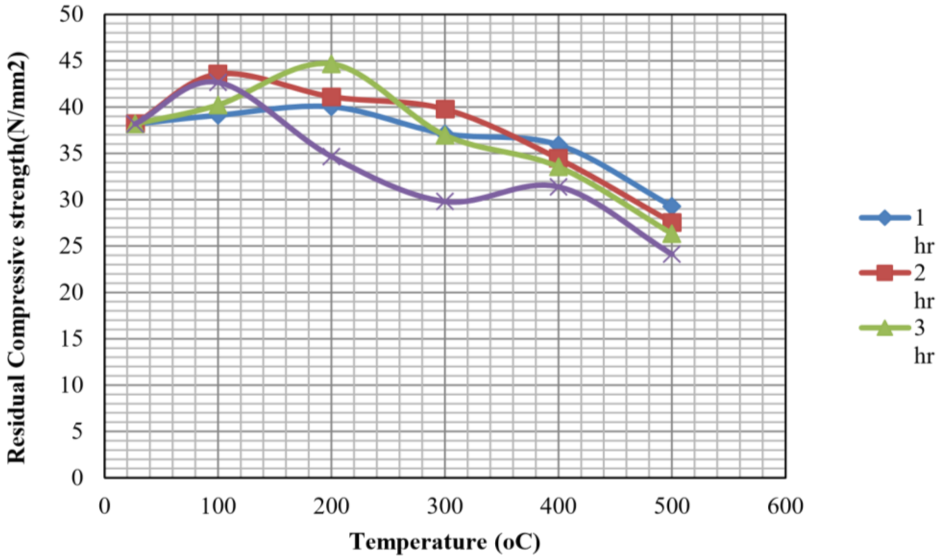


Fig. 3. Variation of residual compressive strength of M20CS0 mix with temperatures and duration exposures

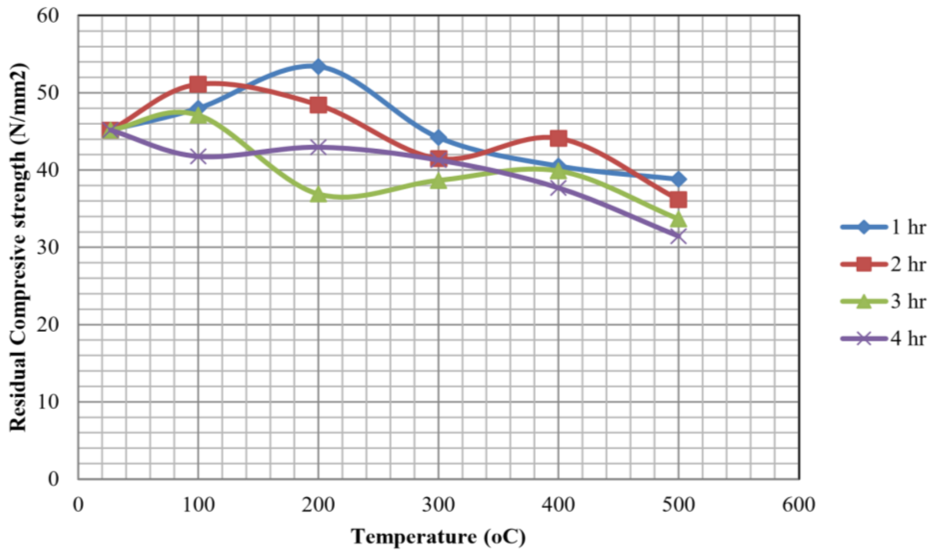


Fig. 4. Variation of residual compressive strength of M20CSTX2.5 mix with temperatures and duration exposures

From Figs. 3 to 5, the percentage increase is maximum by 16.97 % for M20CS0 mix at curing period of 28 days at elevated temperature of 200°C for heat exposure duration of 3 hours when compared to 28 days compressive strength of reference concrete. The maximum percentage loss of residual compressive strength is 36.83 % at elevated temperature of 500°C for the exposed duration of 4 hours heating. For M20CSTX2.5, maximum percentage increase is 18.22 % at elevated temperature of 200°C for heat exposure duration of 1 hour and the maximum percentage loss of residual compressive strength is 30.39 % obtained at 500°C for the exposed duration of 4 hours heating. For

M20CSFX2.5, maximum percentage increase is 18.40 % for elevated temperature 100$^{o}$C for heat exposure duration of 3 hours and the maximum percentage loss of residual compressive strength is 27.32 % obtained at 500$^{o}$C for the exposed duration of 4 hours heating.

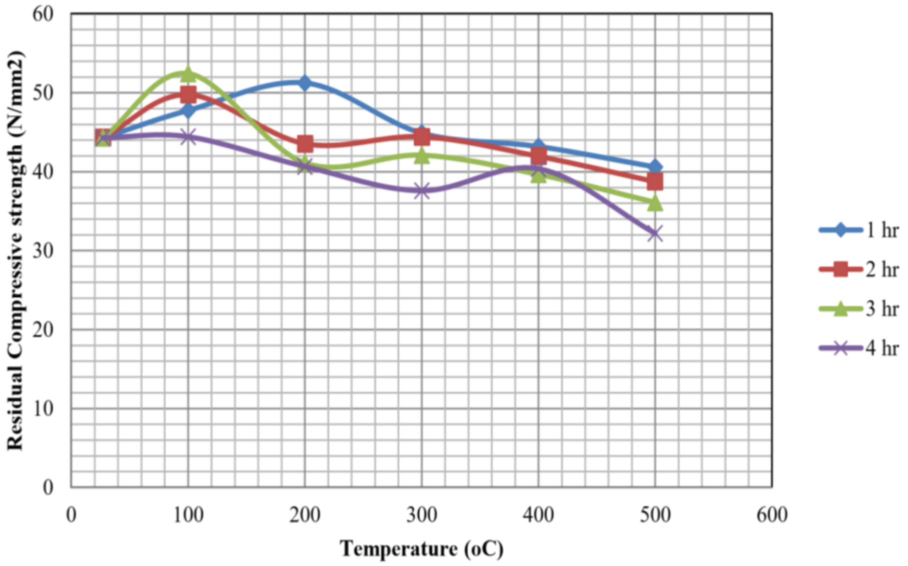


Fig. 5. Variation of residual compressive strength of M20CSFX2.5 mix with temperatures and duration exposures

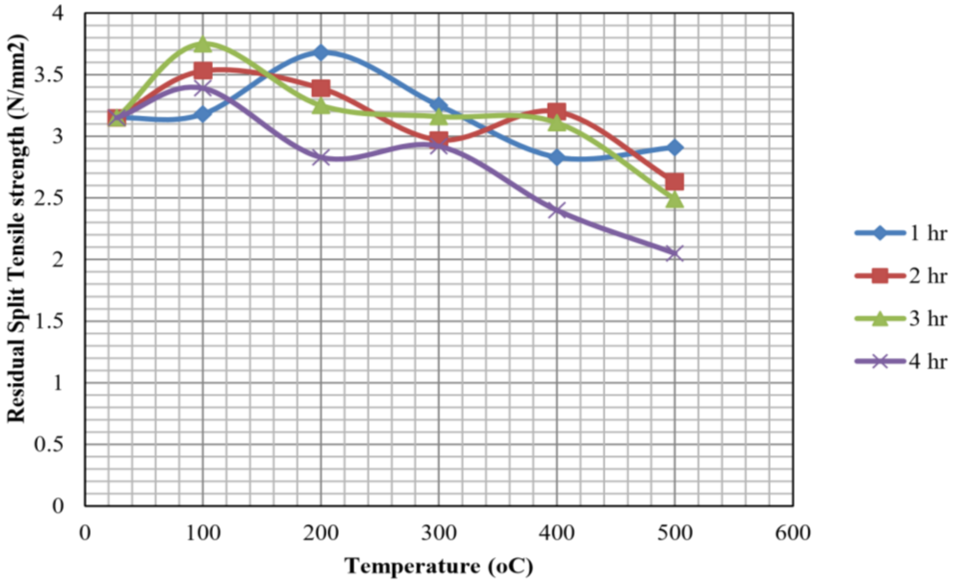


Fig. 6. Variation of residual split tensile strength of M20CS0 mix with temperatures and duration exposures

From Figs. 6 to 8, maximum increase in residual split tensile strength of M20CS0 is 19.05 % at elevated temperature of 100$^{o}$C for 3 hours heat exposure duration and the percentage loss in residual split tensile strength is maximum by 34.92 % at elevated temperature of 500$^{o}$C for 4 hours exposure duration. For M20CSTX2.5, the maximum increase in residual split tensile strength is 8.22 % at elevated temperature of 100$^{o}$C for 2 hours heat exposure duration and the maximum percentage loss in residual split tensile strength is 35.98 % at elevated temperature of 400$^{o}$C for 3 hours exposure duration of heating. For M20CSFX2.5, the maximum increase is 15.38 % for 300$^{o}$C at 1 hour heat exposure duration and the maximum percentage loss is 16.62 % for elevated temperature of 200$^{o}$C for 2 hours exposure duration.

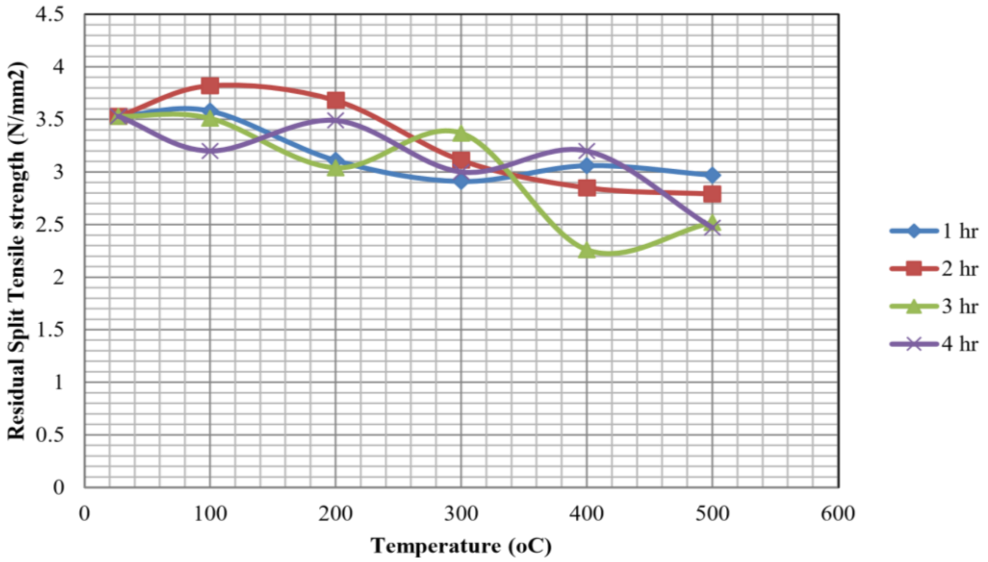


Fig. 7. Variation of residual split tensile strength of M20CSTX2.5 mix with temperatures and duration exposures

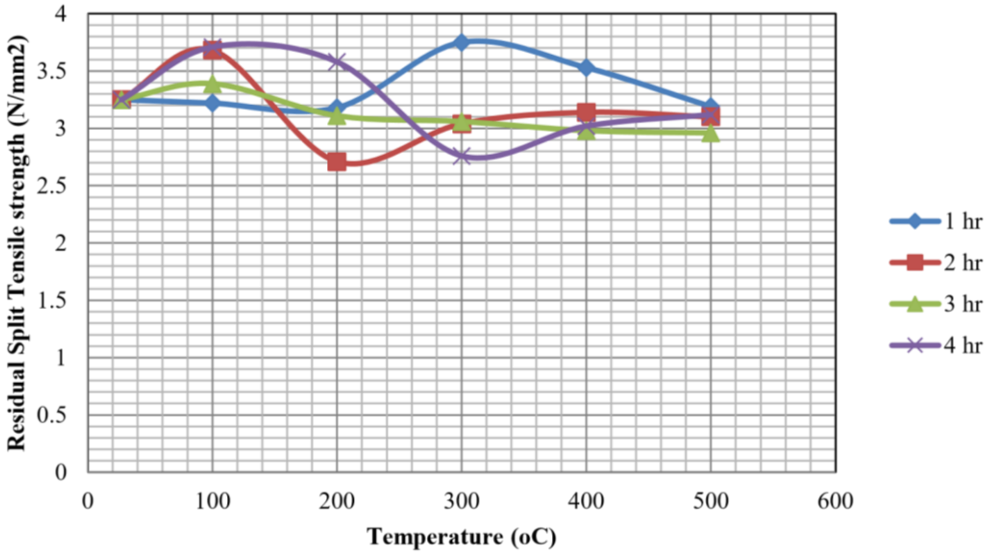


Fig. 8. Variation of residual split tensile strength of M20CSFX2.5 mix with temperatures and duration exposures

From Figs. 9 to 11, the maximum gain in residual modulus of rupture of M20CS0 is 59.10 % at elevated temperature of 100°C for 1 hour duration of heat exposure and the percentage loss in residual modulus of rupture is maximum by 18.42% at elevated temperature of 500°C for 4 hours heat exposure duration. For M20CSTX2.5, the maximum gain in residual modulus of rupture is 28.71 % at elevated temperature of 100°C for 2 hours duration of heat exposure and the percentage loss in residual modulus of rupture is maximum by 16.16 % at elevated temperature 500°C for 4 hours heat exposure duration. For M20CSFX2.5, the maximum gain in residual modulus of rupture of M20CSFX2.5 is 33.98 % at elevated temperature of 100°C for 1 hour duration of heat exposure and the percentage loss in residual modulus of rupture is maximum by 22.33 % at elevated temperature of 400°C for 2 hours heat exposure duration.

The observed strength changes regarding the elevated temperatures are increase and decrease trends w.r.t. normal concrete. The increase in strengths is identified for 100 and 200°C at various exposure durations due to evaporation of moisture from the pores of concrete resulting in increase of strength. And also, in concrete with colloidal silica, silica particles interact with hydration products in order to form additional CSH gel which in turn develops the strength of concrete. On further increase of strengths along with duration of exposure, the strength parameters reduce due to underlying physical and chemical mechanisms, such as delayed hydration, decomposition of C-S-H gel and increase of moisture content induced micro cracking.

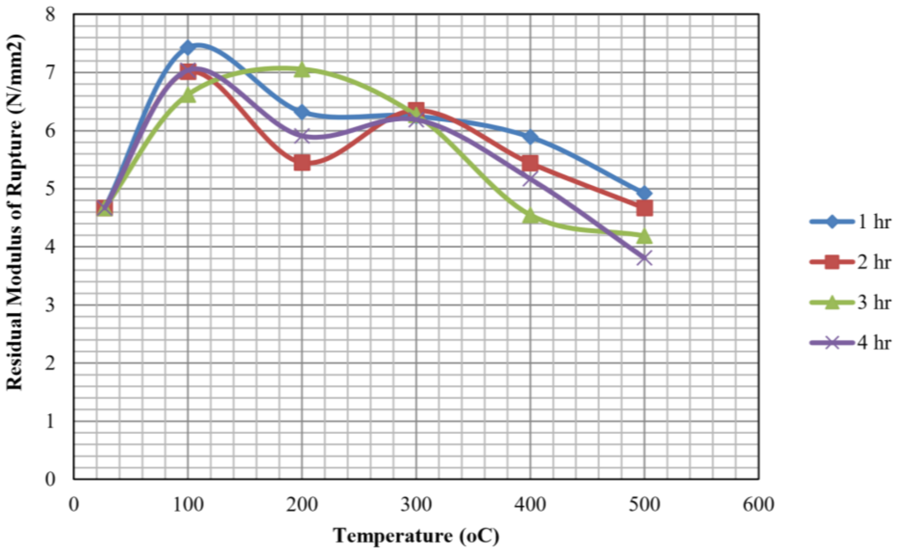


Fig. 9. Variation of residual modulus of rupture of M20CS0 mix with temperatures and duration exposures

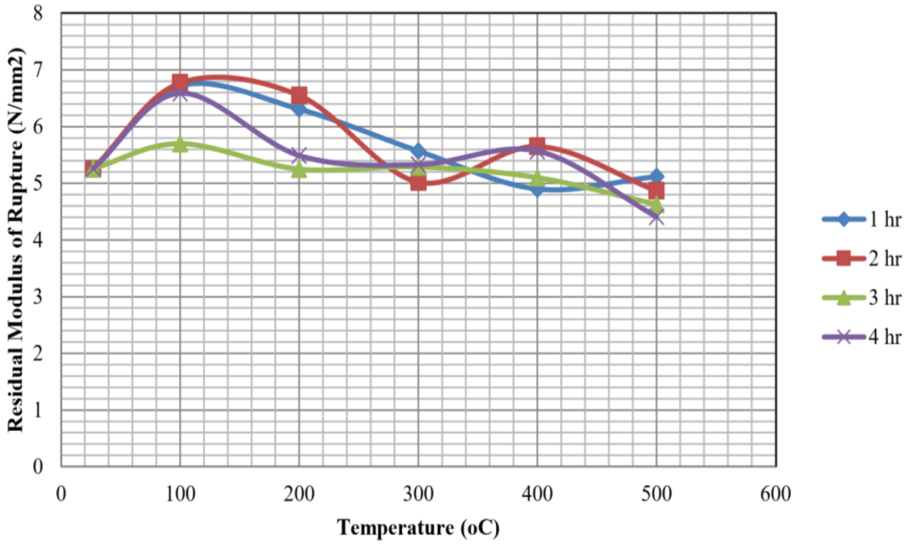


Fig.10 Variation of residual modulus of rupture of M20CSTX2.5 mix with temperatures and duration exposures

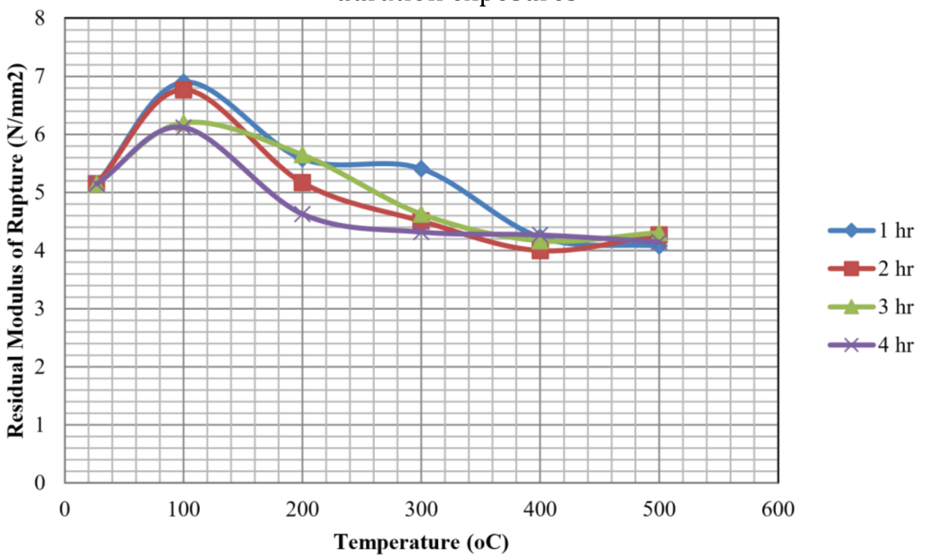


Fig. 11. Variation of residual modulus of rupture of M20CSFX2.5 mix with temperatures and duration exposures

## 4. Conclusions

Air cooling method is adopted for testing the specimens exposed to various temperatures of 100°C, 200°C, 300°C, 400°C and 500°C at durations of 1, 2, 3 and 4 hours. The residual strengths are compared in terms of compressive strength, modulus of rupture and split tensile strength. The following are the conclusions obtained from the results:

- There is no remarkable change in color of the concrete specimens which are exposed to 200°C and the color change is clearly observed for the concrete specimens which are heated at temperatures from 300°C to 500°C.
- The concrete made with colloidal silica has shown higher retention of residual strengths when compared to normal concrete.
- The usage of nano material colloidal silica in concrete has resisted higher temperatures in all the three strength aspects compared to the values obtained for the concrete without any nano material.
- The utilization of colloidal silica in turn develops the secondary hydration process resulting in formation of additional CSH gel by completely reacting with unhydrated calcium hydroxide.
- The behavior of M20 grade concrete with colloidal silica has retained higher residual strengths when compared to normal concrete when exposed to elevated temperatures for various heat durations.
- The two nano materials CSTX and CSFX having 30 % and 40 % nano solids content utilized in the present study have exhibited a better improvement in the mechanical properties of concrete under elevated temperatures by increasing the bond strength as well as crack resistance during heating of specimens. Hence, they can be employed in modern concrete for developing the sustainable properties along with the application of nano technology in civil engineering.
- The experimental study can be recommended for the further studies along with different grades of concrete, various sustainable materials, other elevated temperatures, durability aspects and suitable nano materials.

## References

[1] Sreenivasulu A, Srinivasa Rao K. Mechanical properties of heated concrete of M100 grade. Int J Eng Res Appl. 2012;2(4):1944-8.
[2] Vasusmitha R, Srinivasa Rao P. Effect of elevated temperature on mechanical properties of high strength self-compacting concrete. Int J Eng Res Technol (IJERT). 2012;1(8):1-10.
[3] Sreenivasulu A, Srinivasa Rao K. The effect of temperature on mechanical properties of M100 concrete. Am J Eng Res (AJER). 2013;2(3):152-7.
[4] Shehab EI-Din, Mohamed HA. Effect of temperature on strength of concrete strengthening with CFRP. Int J Eng Sci Innov Technol. 2013;2(5):285-92.
[5] Dungi J, Srinivasa Rao K. Effect of elevated temperatures on compressive strength of high-volume fly ash concrete. Int J Sci Eng Res. 2018;6(12):150-3. https://doi.org/10.70729/IJSER18510
[6] Madhavi TC, Ran KPK. Effects of temperature on concrete. ARPN J Eng Appl Sci. 2016;11(9):5590-2.
[7] Chachere M, Varghese V, Vaidya. Effect of various temperatures on the strength of concrete. J Emerg Technol Innov Res. 2016;3(8):35-7.
[8] Husain A, Ahmad J, Mujeeb A, Ahmed R. Effects of temperature on concrete. Int J Adv Res Sci Eng. 2016;3(5):33-42.
[9] Shams A. Fire resistance of concrete. Int J Eng Technol Sci Res. 2016;3(3):143-51.
[10] Naidu DRG, Kumar MP, Kumar PG, Prasad HD. Behaviour of M20 grade concrete at different temperatures. Int J Civil Eng Technol (IJCIET). 2017;8(3):1043-8.
[11] Isfahani FT, Redaelli E, Li W, Sun Y. Effects of nano silica on early age stages of cement hydration. J Nanomater. 2017;2017:1-9. https://doi.org/10.1155/2017/4687484
[12] Yewale DS, Pawar DB, Sath P. Compressive strength of concrete subjected to elevated temperature. Int J Adv Eng Res Dev. 2018;5(Spec Issue 04):1-4.
[13] Sivaji K, Haritha. M20 grade concrete subjected to elevated temperatures. AIJREAS. 2018;3(4):184-8.
[14] Poloju KK, Manchiryal RK, Rahul C. Strength studies on different grades of concrete considering fire exposure. Am J Civil Eng. 2018;6(1):16-23. https://doi.org/10.11648/j.ajce.20180601.14

[15] Bureau of Indian Standards. IS 269:2015 Ordinary Portland Cement - Specification (Sixth revision). New Delhi: BIS; 2015.
[16] Bureau of Indian Standards. IS 383:2016 Coarse and fine aggregate for concrete - Specification (Third revision). New Delhi: BIS; 2016.
[17] Bureau of Indian Standards. IS 9103:1999 Concrete admixtures - Specification (First revision). New Delhi: BIS; 1999.
[18] Bureau of Indian Standards. IS 516 (Part 1/Sec 1):2021 Hardened concrete - Methods of test. Part 1: Testing of strength of hardened concrete, Section 1: Compressive, flexural and split tensile strength (First revision). New Delhi: BIS; 2021.
[19] Bureau of Indian Standards. IS 456:2000 Plain and reinforced concrete - Code of practice (Fourth revision). New Delhi: BIS; 2000.
[20] Bureau of Indian Standards. IS 8112:1989 Specification for 43 grade ordinary Portland cement. New Delhi: BIS; 1989.
[21] Murty KSS, Rao RGV, Adiseshu S. Experimental study on the effect of colloidal nano silica in self-compacting concrete containing ground granulated blast furnace slag. Res Eng Struct Mater. 2024;10(4):1467-81. https://doi.org/10.17515/resm2024.105me1204rs
[22] Ozmen HB, Inel M. Effect of concrete strength and detailing properties on seismic damage for RC structures. Res Design. 2024;1(1):1-11. https://doi.org/10.17515/rede2024-005en1124rs