Studies on Impact Strength of Concrete with Nano-Materials at Elevated Temperatures

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Abstract— Nano composites are produced by adding nano-particles to a material in order to improve the properties of material. Concrete is a material most widely used in construction industry. Concrete is a composite material made up of cement, sand, aggregate, water and mineral or chemical admixtures. The materials such as nano-silica, nano flyash, nano metakaolin are being combined with cement. There are also a limited number of investigations dealing with the manufacture of nano-cement. The use of finer particles (higher surface area) has advantages in terms of filling the cement matrix, densifying the structure, resulting in higher strength and faster chemical reactions i.e. hydration reactions. Nano-cement particles can accelerate cement hydration due to their high activity. Similarly, the incorporation of nano-particles can fill pores more effectively to enhance the overall strength and durability. Normally, the particle size ranges between 1nm to100nm, they are generally called as nano materials. The fineness can reach up to molecular level by special processing techniques. An experimental investigation has been carried out to determine the influence of concrete with nano-cement particles under elevated temperature. M20, M30 and M40 grades of concrete were cast. For each of grades of concrete, 10%, 20% and 30% of cement was replaced with nano-cement. The particle size of nano-cement was determined using a Scanning Electron Microscope (SEM). Impact strength of concrete with nano materials under various elevated temperature (250°C, 500°C, 750°C and 1000°C) were found by using Impact Testing Apparatus. Impact strength is found to be least for the concrete specimens with 30% replacement of nano-cement. It was also found that impact strength of M40 grade concrete specimens was low as compared to other grades of concrete (M20 & M30).

Key words: Nano-Materials, Casing of concrete

I. INTRODUCTION

Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep. In very high-strength concrete mixtures (greater than 70 MPa) the crushing strength of the aggregate can be a limiting factor to the ultimate compressive strength. The effect of fire on building members has an important role in the construction. The thermal behavior of the members subjected to temperature loads will give an over view about how they react with temperature. The field quality of fire protection materials is now getting deserved attention. It is a positive trend that engineers work with fire engineers to protect the structures, and the responsibility for fire-resistant design is delegated to the structural engineers. Due to the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire-damaged structures has become a topical interest. This is a specialized field involves expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials etc. Research and developmental efforts are being carried out in this area and other related disciplines. The reinforced concrete is the one of the most widely using construction material, and the fire will affect the members very badly in the form of spalling, exposing of reinforcement etc. The structural property of concrete that has been most widely studied as a function of temperature exposure is compressive strength.

In buildings, structural members are to satisfy fire resistance ratings prescribed in building codes. Fire resistance is the duration during which a structural member exhibits resistance with respect to strength, integrity and stability and depends on many factors including structural geometry, material used in construction and characteristics of fire. A fire resistance rating is the fire resistance of a member rounded off to nearest hour or half-hour. Concrete due to its low thermal conductivity, high thermal capacity and slower loss of strength and stiffness properties performs reasonably well under fire. Therefore, concrete structures are often used without any fire protection. It is necessary to understand the behaviors of structural elements subjected to fire. Although extensive experimental investigations and theoretical analyses have been conducted on structural materials and elements exposed to elevated temperature, to date, there are still many outstanding issues which have not been understood due to the complexity of structural fire resistance properties and the limitation of testing technique. At present, the fire-resistant design of most buildings is primarily based on these concepts resulting from the conventional design at room temperature or the previous simple test results. In practice, the design method with the help of detailing is still a main fire-resistant design method. Nearly all collapses in fire-damaged concrete structures are caused either by poor detailing or, in severe cases, by failure of the steel reinforcement. This is because the reinforcement is usually placed near the concrete member surface. Hence, the reinforcement is subjected to a greater temperature increase, and its strength is first affected in comparison to the main body of concrete. fineness increases, the surface area increases, which increases the 'reactivity' of the material. Nano-cement was produced in a high energy ball grinding mill and was used as a partial replacement to cement. Application of nano-cement in concrete can lead to significant improvements in the strength and life of concrete.

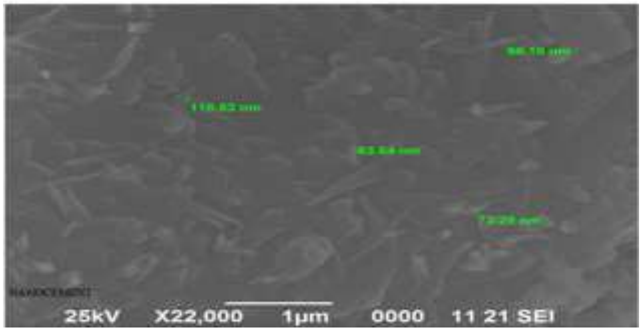
The mechanical behaviour of concrete materials depends to a great extent on structural elements and phenomena which are effective on a micro- and nano scale. The ability to target material modification at the nano structural level promises to deliver the optimization of material behaviour and performance needed to improve significantly the mechanical performance, volume. Nano composites are produced by adding nano-particles to a material in order to improve the properties of material. Concrete is a material most widely used in construction industry. Concrete is a composite material made up of cement, sand, aggregate, water and mineral or chemical admixtures. The materials such as nano-silica, nano flyash, nano metakaolin are being combined with cement. There are also a limited number of investigations dealing with the manufacture of nano-cement. The use of finer particles (higher surface area) has advantages in terms of filling the cement matrix, densifying the structure, resulting in higher strength and faster chemical reactions i.e. hydration reactions. Nano-cement particles can accelerate cement hydration due to their high activity. Similarly, the incorporation of nano-particles can fill pores more effectively to enhance the overall strength and durability**.**

II. MATERIALS

Material used are Ordinary Portland cement, locally available river sand, crushed granite coarse aggregate of maximum size 20 mm and having a specific gravity 2.64, water available in the college campus and Nano-cement produced by ball mill grainding instrument are used in this investigation.

III. EXPERIMENTAL PROGRAM

In this experimental work, concrete specimens were cast with different grades. The specimens were cast in this study consist of impact cylinders of size 150 * 64 mm. The nominal mix proportions used for casting the specimens were1: 1.85: 2.78: 0.50 (M20), 1: 1.6: 2.5: 0.45 (M30), and 1: 1.28: 2.19: 0.40 (M40) (cement: sand: coarse aggregate: water-cement ratio). The SEM analysis report is used to determine the particle size of nano – cement which was produced from the ball mill grainding apparatus.



A. Mixture Compositions and Placing

Mixing of nano-cement can be accomplished by many methods. The mix should have a uniform dispersion of the nano-cement in order to prevent segregation during mixing. Cement with 10%, 20%, 30% replacement of nano-cement and aggregates are mixed thoroughly by using rotary mixer machine. The total nano-cement volume fraction used for casting is 10%, 20%, & 30%. Compared to conventional concrete, nano-cement concrete mixes are generally characterized by higher cement factor, higher fine aggregate content, and smaller size coarse aggregate. External vibration is preferable to prevent fiber segregation. Metal trowels, tube floats, and rotating power floats can be used to finish the surface.

B. Casting & Curing Details

Casing of concrete is done so that the strength of concrete can be measured. The fully workable concrete in placed in impact cylinders. This concrete mould is placed to find the quality of concrete under specific curing conditions for 28 days. The quality of concrete also depends upon the no. of days it is kept in curing conditions before it becomes suitable to use.

IV. TESTING OF SPECIMENS UNDER ELEVATED TEMPERATURE

An electric furnace was used to heat the specimens. The inner dimensions of the furnace are 500mm x 500 mm x 500 mm. The sides and top are lined with electrical heating coils embedded in refractory bricks. The control panel has a temperature controller to prevent damage to the furnace by tripping off, if the temperature inside the furnace exceeds the specified temperature. The maximum operating temperature of the furnace is 1200°C. The concrete specimens were exposed to fire inside the furnace and the furnace was heated from 27°C to 1000°C. After exposing the specimens to desired temperature and duration, the furnace was switched off and the specimens were taken out of the furnace. The specimens were naturally allowed to reach the room temperature by air cooling and water cooling. Ultimate loads of the specimens were found at 28th day for the reference and other specimens that were subjected to elevated to temperature. After 28 days of curing the specimens taken out from the curing tank and kept out for one day to avoid moisture. Then the specimens were placed in the furnace. The specimens were heated up to a temperature of 1000°C. The specimens were naturally allowed to reach the room temperature by air cooling and water cooling.

A. Test of Specimens

Experimental investigation was carried out to determine the effect of grade M20, M30, M40 of concrete. After 28 days of curing, all the specimens were air dried prior to high temperature exposure. The specimens were subjected to elevated temperatures and cooled by air and water. Then specimens were tested by impact behavior as impact strength of concrete.

B. Impact Strength Behavior of Concrete

Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. The studies were extended to present the ductile characteristics of M20, M30 and M40 grade concrete under impact. The drop weight impact testing apparatus was fabricated in the laboratory as per ACI544 committee's recommendations. Equations were developed to determine the first crack strength of concrete with elevated temperature.

C. *Experimental setup and Test Procedure*

The size of the specimen recommended by the ACI committee is 150 mm in diameter and 64 mm in height. The equipment consists of a standard manually operated 4.4 Kg compaction hammer with an 18 inch drop (457mm) a 44mm diameter hardened steel ball and a flat base 32 plate with positioning bracket. In addition to the above equipment, a mould to cast 150mm diameter and 64mm thick concrete specimens is needed. Thickness of the specimens is recorded to the nearest millimeter at its center and at the ends of a diameter prior to the test. The specimen is placed on the base plate with the finished face up and positioned within two legs of the impact testing equipment. The bracket with the cylindrical sleeve is fixed in place and the hardened steel ball is placed on the top of the specimen within the bracket. The drop hammer is then placed with its base upon the steel ball and held vertically. The hammer is dropped repeatedly, and the number of blows required for the first visible crack to form at the top surface of the specimen and for ultimate failure is to be recorded. The first crack was based on visual observation. White washing the surface of the test specimen facilitated the identification of this crack. Ultimate failure is defined in terms of the number of blows required to open the cracks in the specimen sufficiently to enable fractured pieces to touch three of the two positioning legs on the base plate. The stages of ultimate failure are clearly recognized by the fractured specimen butting against the legs of the base plate.

Fig 1: Impact testing of specimens

D. *Impact Energy*

The impact energy is calculated by the formula;

$$E = W \times h \times n \text{ (N-m)}$$

Where;

W = wt. of hammer (N).

h = height of fall (m).

n = no. of blows required for complete failure.

V. IMPACT TEST RESULTS

A. *Energy Absorption for First Crack*

TEMP	M20					
IN	10%		20%		30%	
DEG	AC	WC	AC	WC	AC	WC
27	552.5	552.5	450.2	450.2	368	368
250	675.3	368.3	347.8	204	245	163
500	204.6	163.7	81.8	122	102	81.8
750	81.8	81.8	102.3	40.9	20.4	20.4
1000	20.4	20.4	20.4	20.4	20.4	0

Table 1: Energy absorption for first crack m20 grade

TEMP	M30					
IN	10%		20%		30%	
DEG	AC	WC	AC	WC	AC	WC
27	1248	1248	1145	1145	1064	1064
250	1391	1186	695	613	327	204.5
500	286	204	81.8	81.8	225	102.3
750	61.3	40.9	40.9	20.4	40.9	20.4
1000	20.4	20.4	20.4	20.4	20.4	0

TABLE 2: Energy absorption for first crack m30 grade

TEMP	M40					
IN	10%		20%		30%	
DEG	AC	WC	AC	WC	AC	WC
27	2005	2005	1903	1903	1821	1821
250	2128	1718	1145	982	634.3	470.6
500	450	388	81.8	81.8	81.8	102.3
750	61.3	40.9	61.3	20.4	20.4	20.4
1000	20.4	20.4	20.4	20.4	20.4	0

TABLE 3: Energy absorption for first crack m40 grade

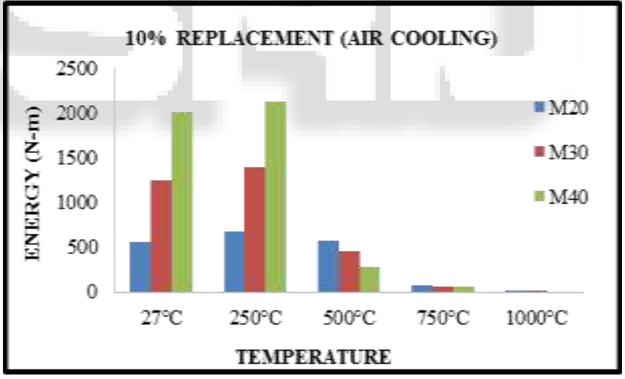


Fig. 2 Impact energy for different grades of concrete with varying temperature at 10% replacement of nano-cement (air cooling) for first crack

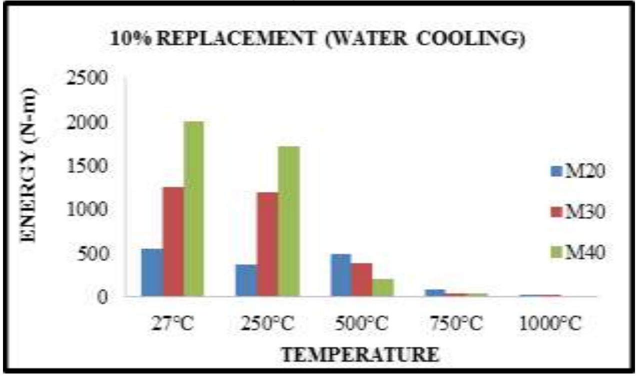


Fig. 3 Impact energy for different grades of concrete with varying temperature at 10% replacement of nano-cement (water cooling) for first crack

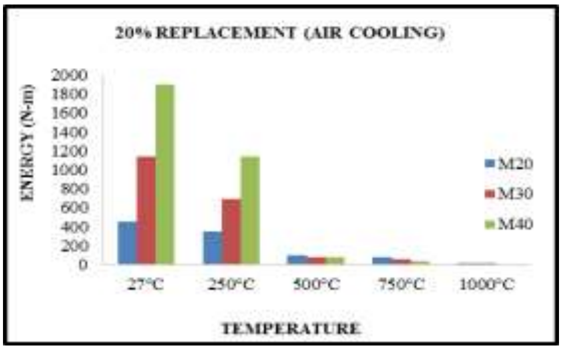


Fig. 4 Impact energy for different grades of concrete with varying temperature at 20% replacement of nano-cement (air cooling) for first crack

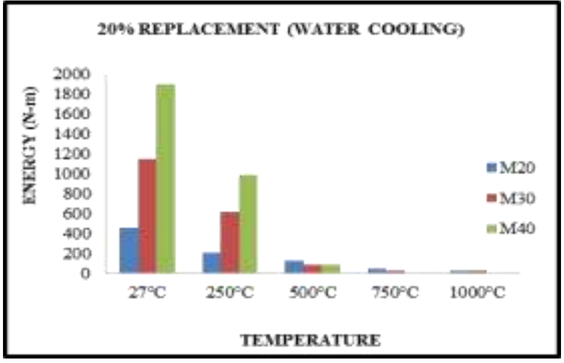


Fig. 5 Impact energy for different grades of concrete with varying temperature at 20% replacement of nano-cement (water cooling) for first crack

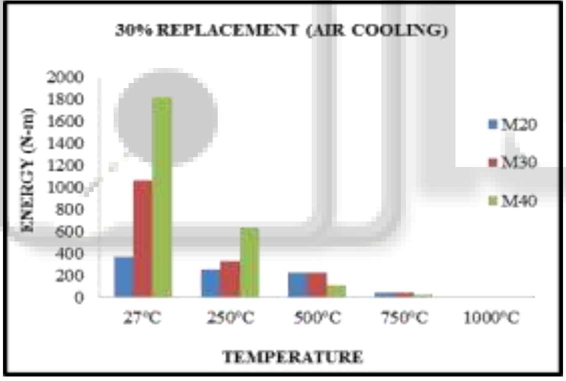


Fig. 6 Impact energy for different grades of concrete with varying temperature at 30% replacement of nano-cement (air cooling) for first crack

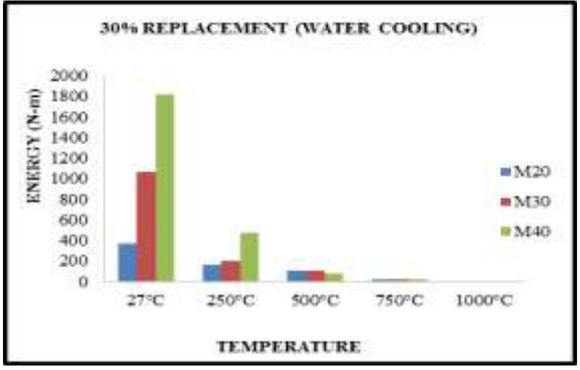


Fig. 7 Impact energy for different grades of concrete with varying temperature at 30% replacement of nano-cement (water cooling) for first crack

B. Energy absorption for Final Crack

TEMP	**M20**					
IN	**10%**		**20%**		**30%**	
DEG	**AC**	**WC**	**AC**	**WC**	**AC**	**WC**
27	593.4	593.4	491.1	491.1	409.2	409.2
250	736.6	409.2	388.8	245.5	286	204.6
500	225.1	184.1	102.3	143.2	122	102.3
750	102.3	102.3	122.7	61.3	40.9	40.9
1000	61.4	20.4	40.9	20.4	20.4	0

Table 4: Energy Absorption For Final Crack M20 Grade

TEMP	**M30**					
IN	**10%**		**20%**		**30%**	
DEG	**AC**	**WC**	**AC**	**WC**	**AC**	**WC**
27	1289.2	1289.2	1186.9	1186.9	1105	1105
250	1473	1268	736	654	368	245.5
500	327	245	102	102	245	122.7
750	81.8	61.3	81.8	20.4	61.3	40.9
1000	20.4	20.4	20.4	20.4	20.4	0

Table 5: Energy absorption for final crack m30 grade

TEMP	**M40**					
IN	**10%**		**20%**		**30%**	
DEG	**AC**	**WC**	**AC**	**WC**	**AC**	**WC**
27	2087.3	2087.3	1944	1944	1841.7	1841.7
250	2210	1800	1186	1023	675	511
500	491	429	102	102	102	122
750	81.3	61.3	81.3	20.4	40.9	40.9
1000	40.9	20.4	20.4	20.4	20.4	0

Table 6: Energy Absorption For Final Crack M40 Grade

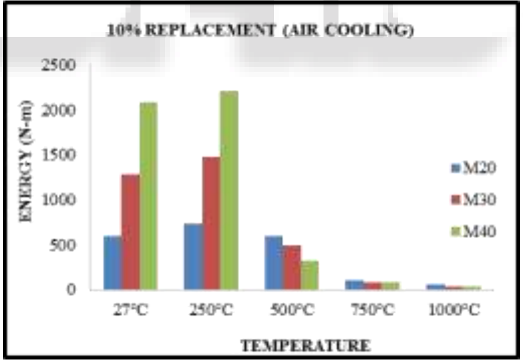


Fig. 8 Impact energy for different grades of concrete with varying temperature at 10% replacement of nano-cement (air cooling) for final failure

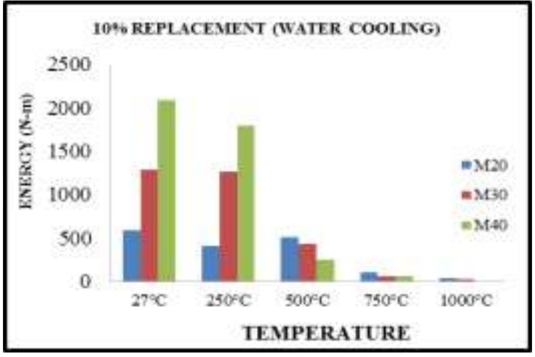


Fig. 9 Impact energy for different grades of concrete with varying temperature at 10% replacement of nano-cement (water cooling) for final failure

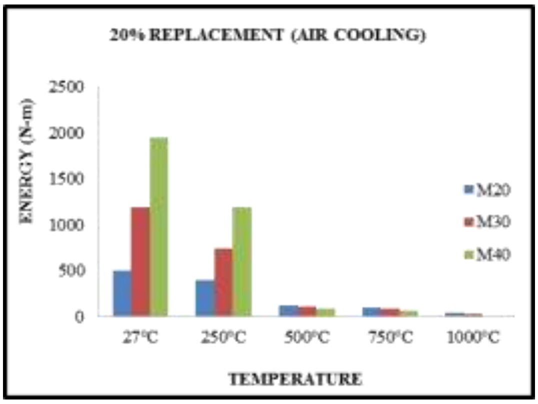


Fig. 10 Impact energy for different grades of concrete with varying temperature at 20% replacement of nano-cement (air cooling) for final failure

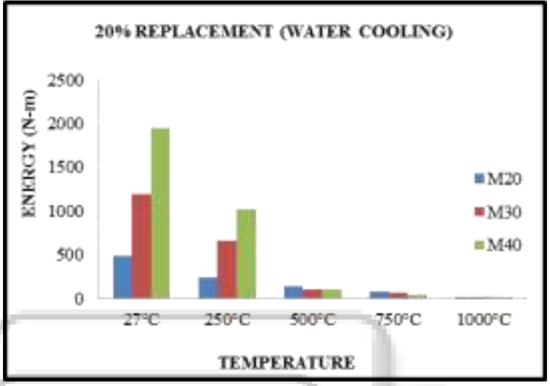


Fig. 11 Impact energy for different grades of concrete with varying temperature at 20% replacement of nano-cement (water cooling) for final failure

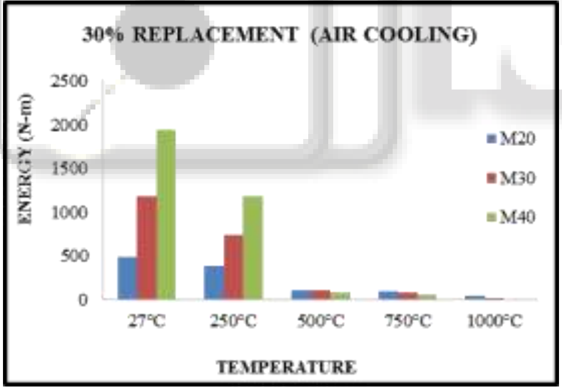


Fig. 12 Impact energy for different grades of concrete with varying temperature at 30% replacement of nano-cement (air cooling) for final failure

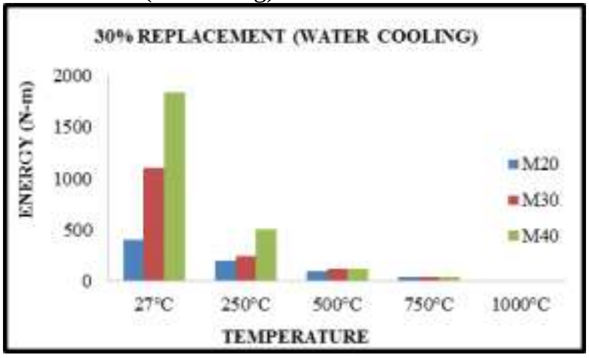


Fig. 13: Impact energy for different grades of concrete with varying temperature at 30% replacement of nano-cement (water cooling) for final failure

VI. CONCLUSIONS

Based on the experimental investigation the impact strength of heated specimens at 250°C increases in case of air cooling about 76%, 83%, 89% and 95% for the specimens with M20, M30 and M40 grades respectively at 10% replacement of cement with nano-cement compared to reference specimens. The impact strength of heated specimens at 250°C decreases in case of water cooling about 81%, 89%, 93% and 98% for the specimens with M20, M30 and M40 grades respectively at 10% replacement of cement with nano-cement compared to reference specimens. The impact strength of heated specimens at 250°C decreases in case of both air and water cooling with M20, M30 and M40 grades with 20% & 30% replacement of cement with nano-cement compared to reference specimens. The impact strength of heated specimens at 500°C, 750°C, 1000°C decreases in both air and water cooling for the specimens with M20, M30 and M40 grades respectively for 10%, 20% & 30% replacement of cement with nano-cement compared to reference specimens. The specimens heated up to 1000°C with 30% replacement of cement with nano cement and cooled by water failed before impact test for all the grades of concrete.

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