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PERFORMANCE EVALUATION OF COIR PITH ASH BLENDED CEMENT CONCRETE EXPOSED TO ELEVATED TEMPERATURE

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Graphical abstract

Abstract

The concrete characteristics exposed to elevated temperature are gaining importance in terms of structural stability and serviceability state assessment of the structure. This paper deals with the study on behavior of coir pith ash (CPA) blended concrete exposed to elevated temperatures. Concrete specimens were prepared by replacing cement with CPA by percentages ranging from 0% to 20%. The specimens were then subjected to thermal treatment by exposing to temperatures of 200 °C, 400 °C, 600 °C and 800 °C in an electric furnace for a duration of 1 hour after the attainment of peak temperature. After providing the exposure, the samples were cured by air cooling or water-cooling and were tested for visual observation, residual compressive strength and ultrasonic pulse velocity. It has been observed that thermal performance of CPA blended concrete was better than that of control mix sample. Also, out of the two different cooling regimes adopted, air cooling method showed better performance that water cooling.

Keywords: Concrete, coir pith ash, elevated temperature, cooling regime, residual strength

1.0 INTRODUCTION

The use of sustainable materials in concrete has been growing recently and it is showing great impact on the decline of non-renewable natural resources usage. The sustainable materials in concrete can be in the form of aggregates and admixtures. Replacing concrete constituents brings environmental protection as well as economy in concrete production. Cement can be considered the binding material in concrete and its consumption exceeds 4.1 million globally [1]. Several Supplementary cementitious materials (SCM) have been developed and most of them are industrial and agricultural byproducts. Fly ash, Silica fume, Rice husk ash and sugarcane bagasse ash are some of the popular SCMs used. Many researches have been carried out on the impact of SCMs on various mechanical and durability parameters of concrete. Coir Pith Ash (CPA) is comparatively new SCM derived from coir pith which is a by-product of coir industry. Coir pith (Figure 1) is a spongy material and is produced abundantly in all the coir producing countries like Brazil, Indonesia and India. In India, the coir industry in flourished mainly in the southern states of Kerala, Tamil Nadu, Andra Pradesh and Karnataka. These states account for 89 % of the total coconut production of the country [2]. Major chemical components of coir pith include lignin (30.7 %), cellulose (35.6 %) and hemicellulose (33.7%) [3]. The decomposition of coir pith is very slow due to the presence of lignin. Also, coir pith contains phenolic compounds which when comes in contact with running water cause water pollution. Thus, it is very essential to utilize the dumped coir pith in an ecofriendly manner. The calorific value of coir pith is 3975 kcal per kg which is close to 4200 kcal per kg of coal which makes it a good fuel briquette. [4].

The research on behavior of concrete exposed to elevated temperature is getting importance with increase in building activities. Even though, the concrete does not burn and emits no smoke, the impact of fire on concrete can be dangerous. Under special conditions like fire accidents, nuclear power plants, reactor vessels and tunnels, the temperatures can go beyond 1350 °C. Sometimes, the combined action of fire and other forces can cause concrete failure at a much lower temperature thereby reducing the efficiency of the structural members. [5]. When a concrete member is exposed to fire, the initial impact of heat will be on the surface and due to low thermal conductivity of concrete the transfer of heat to the interior portions occurs very slow. Thus, there forms a thermal gradient across the member which can create additional stresses. Elevated temperature also produces changes in the physical and chemical structure of concrete. Calcium Silicate hydrate present in the concrete expels chemically bound water when the temperature exceeds 110 °C. After 300 °C, the micro cracks start to pierce through the concrete mass due to the intense dehydration and internal stress caused by the thermal expansion of aggregate. [6] Beyond 530 °C, $Ca(OH)_2$ present in concrete dissociates thereby causing shrinkage. [7, 8]. Elevated temperature also changes the physical characteristics of concrete like colour, texture, strength, volume and elastic properties [9–11]. Therefore, the influence of elevated temperature on strength and durability of concrete is very high and it is very important to improve the thermal resistance of concrete. This study was carried out to check the performance of CPA blended cement concrete at elevated temperatures. The impact of CPA addition to concrete on various parameters such as Visual observation characteristics, compressive strength, and ultrasonic pulse velocity (UPV) values were evaluated

2.0 METHODOLOGY

2.1 Test Materials

The main test materials used in the study includes concrete components and CPA. Cement is the binding material in concrete. 53 grade Ordinary Portland cement satisfying the requirements as per IS 12269: 2013 and manufactured by Ultratech cements was taken for the study [12]. The various cement parameters like normal consistency, initial and final setting times, specific gravity and fineness were found out. The cement characteristics summary is shown in Table 1

Table 1 Cement Characteristics

Sl No	Cement Parameters	Value
1	Grade of Cement	53
2	Fineness (%)	8%
3	Specific Gravity	3.15
4	Normal Consistency (%)	36.75 %
5	Initial Setting Time	77 Minutes
6	Final Setting Time	320 Minutes

Locally available saturated surface dry river sand having fineness modulus 3.53 and specific gravity 2.67, passing through 4.75 mm IS sieve were used as fine aggregate. Regarding coarse aggregates, aggregates having fineness modulus 7.22 and specific gravity 2.70, passing through 20 mm and retained on 10 mm were used. The water absorption values of fine aggregate and coarse aggregate were found to be 1.39 % and 0.81 % respectively. Coir Pith ash (CPA) (Figure 2) used for the research was produced from coir pith obtained from Chingoli, a village in Kerala, India. Coir pith was subjected to 24 hours drying in sunlight before heating in a metallic vessel to get coir pith ash. The duration of heating was 4 hours and the temperature were maintained at 400 °C using non-contact thermometer. The ash obtained was sieved through 200 microns sieve and was stored in air tight containers. The chemical characteristics values are shown in Table 2

Figure 1 Coir Pith

Figure 2 CPA

2.2 Concrete Mix Proportion and Manufacture

M25 grade concrete was used for the research and the mix design was done as per 10262:2009 [14]. The mix proportion of 1:1.5:2.58 and a water cement ratio of 0.49 was taken. The details of the mix proportion are shown in Table 3. Five different CPA blended mixes were taken into consideration. The cement replacement percentage varied from 0% to 20 %.

The mix proportions are denoted by the following representations

1. CM - Control Mix
2. P5 - 5 % Cement replaced by CPA
3. P10 - 10 % Cement replaced by CPA
4. P10 - 10 % Cement replaced by CPA
5. P20 - 20 % Cement replaced by CPA

A total of 120 cubes of size 100 mm were cast to check the thermal performance of CPA bended concrete by various tests like compressive strength, UPV and weight loss. After casting, the specimens were kept in moulds in 24 hours. The specimens were then demoulded, and allowed for water curing until testing.

Table 2 Chemical Composition of CPA [13]

Sl.No	Composition	CPA (%)
1	CaO	16.14
2	SiO_2	34.50
3	Al_2O_3	01.35
4	Fe_2O_3	02.22
5	MgO	02.07
6	SO_3	-
7	KCl	26.48
8	LOI	09.43

2.3 Heating of Concrete Specimens

The study is intended to check the efficiency of CPA blended concrete at elevated temperature. The experiment was carried out using a box type electric furnace. The samples are subjected to temperatures of 27 °C, 200 °C, 400 °C, 600 °C and 800 °C for 1 hours after reaching the peak temperature to attain steady state condition. The average rate of heating was 10 °C/min [15, 16]. The furnace was turned off after the heating process and the specimens were allowed to come back to its initial room temperature of 27 °C. In order to study the diverse post fire curing conditions, the thermally treated specimens were allowed to cool in two different ways i.e., air cooling and water cooling. In air cooling method, the specimens were allowed to cool normally in air to reach the initial room temperature. But in case of water-cooling method, water sprays were applied to the specimens to replicate fire combating situations. The tests for various parameters like residual strength and ultrasonic pulse velocity were carried out.

2.4 Tests for Compressive Strength and UPV

The impact of temperature on the strength of concrete specimens were assessed by compression strength test on cubes exposed to various temperatures using a compression testing machine with a maximum capacity of 2000 KN. The test was conducted on cube specimens of size 100 x 100 x 100 mm, prepared as per IS 516: 1959 [17]. Nondestructive testing method using UPV was applied to understand the uniformity and relative quality of concrete specimens subjected to different temperatures to obtain residual UPV values. The comparison of various parameters obtained for cubes tested at 27 °C with those exposed to elevated temperature gave a clear picture on the efficiency of CPA blended concrete to high temperatures. The test was carried out as per IS 13311 (Part 1): 1992 [18]. The residual compressive strength (RCS) was calculated to assess the thermal performance of various specimens. RCS (%) was calculated using the formula

$$RCS\ (\%) = (\sigma_t / \sigma_{27}) \times 100$$

Where σ_t is the compressive strength (MPa) of specimens exposed to elevated temperatures and σ_{27} is the compressive strength (MPa) of concrete specimens at ambient room temperature of 27 °C

3.0 RESULTS AND DISCUSSIONS

3.1 Effect of Elevated Temperature on Physical Characteristics of Concrete

The summary of physical observation made on the concrete specimens is presented in Table 5. Notable changes were observed at elevated temperatures especially at 800 °C. At 800 °C, all the specimens were observed to develop hairy cracks with brownish grey colour.

3.2 Effect of Elevated Temperature on Residual Compressive Strength (RCS)

The study investigated the impact of elevated temperature on compressive strength of CPA blended concrete. The effect of CPA content on the thermal performance is shown in Figure 4 & Figure 5.

The RCS of CPA blended concrete decreased significantly with increase in temperature. The increase in level of damage of the samples with increase in temperature can be attributed to the following reasons (1) evaporation of free, adsorbed and chemically attached water content in the hydrated cement paste matrix of CPA concrete leading to increase in the vapour pressure. (2) the C-S-H gel present in the cement paste matrix of the CPA concrete gets degraded. (3) decomposition of calcium hydroxides above 450 °C. All these factors can eventually lead to weakening of cement paste.

However, the thermal performance of CPA blended concrete was observed to be better than that of control mix sample. The thermal performance of both air-cooled and water-cooled CPA concrete increased with increase in the percentage of CPA content from 0% to 20 %. At 200 °C, for air cooled specimens, the RCS was found to increase from 89 % to 94.98 % and for water cooled specimens, RCS increased from 86% to 89 %. RCS of air-cooled specimens subjected to 400 °C increased from 66% to 84%. Similarly, RCS of water-cooled specimens subjected to 400 °C increased from 60% to 74 %. At 600 °C, RCS of air-cooled specimens increased from 55% to 73% and RCS of water-cooled specimen increased from 50% to 62%. Finally, at 800 °C, RCS increased from 31% to 51% for air cooled specimens and 28% to 49% for water cooled specimens.

Figure 3 Concrete Specimen in electric furnace

Table 3 Mix proportions of various mixes

Mixture No	CPA %	CPA (Kg)	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Ltr)
CM	0 %	0	438.13	655.72	1130.29	215.49
P05	5 %	21.92	416.23	655.72	1130.29	215.49
P10	10 %	43.81	394.32	655.72	1130.29	215.49
P15	15 %	65.72	372.41	655.72	1130.29	215.49
P20	20 %	87.63	350.51	655.72	1130.29	215.49

Table 4 Grading of Concrete based on UPV [18]

Pulse Velocity	Concrete Quality Grading
Above 4.5 Km/S	Excellent
3.5- 4.5 Km/S	Good
3.0 – 3.5 Km/S	Medium
Below 3.0 Km/S	Doubtful

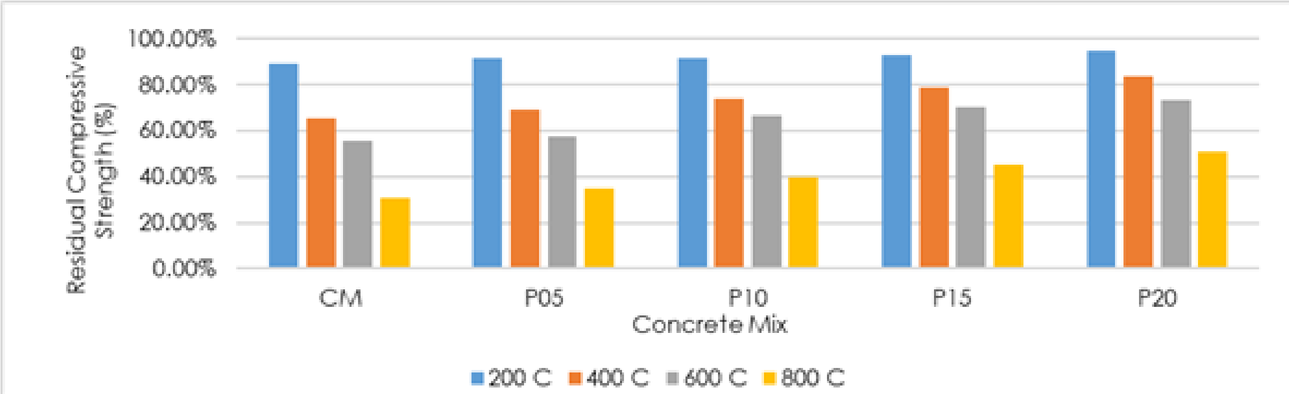

Figure 4 Effect of CPA content on the residual compressive strength of air-cooled CPA blended concrete exposed to elevated temperatures

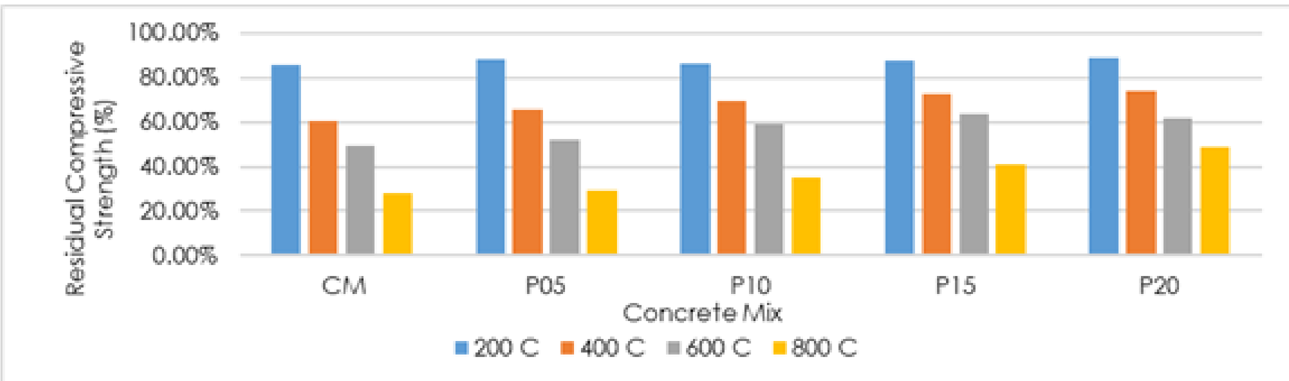

Figure 5 Effect of CPA content on the residual compressive strength of water-cooled CPA blended concrete exposed to elevated temperatures

3.3 Effect of Cooling Regime on Residual Compressive Strength (RCS)

The effect of cooling regime on residual compressive strength of CPA concrete are shown in Figure 6 to Figure 10. The relative performance of air-cooling and water-cooling system on the compressive strength of specimens are shown. The RCS is significantly influenced by the cooling regime adopted. Although, there was a notable strength loss with increase in temperature, the air-cooling method showed better performance in sustaining residual properties than water-cooling method. However, the difference was not significant. In air cooling and water-cooling systems, the specimens were subjected to gradual and sudden cooling respectively. Quenching of specimens during water cooling can cause thermo shock. As per the findings of Tanaçan *et al*. [19], extensive inner cracking of compacted concrete can be due to evaporation of physically and chemically bound water. In addition to that, in water cooled specimen subjected to quenching, there occurs sudden changes in temperature which in turn leads to the development of stress concentrations at various locations inside the specimen. Thus, the thermal performance of water-cooled specimens becomes lesser when compared to air-cooled specimens.

3.4 Effect of Elevated Temperature on Ultrasonic Pulse Velocity (UPV)

The impact of elevated temperatures on ultrasonic pulse velocity method is shown in Table 6. In general, at 28 days of curing, the following observations were found. (1) UPV values decreased with increase in replacement levels (2) UPV values decreased with increase in exposed temperature (3).

For all the mixes air cooled specimens exposed to an elevated temperature showed better UPV than water cooled specimens exposed to similar temperatures. The reduction in the UPV can be attributed to the modification of the microstructure of concrete. At temperatures above 450°C, degradation of C-S-H gel takes place leading to increases in the percentage of air voids within the concrete mass which in turn decreases the velocity of ultrasonic waves through concrete specimen. [20]

The specimens at lower temperature showed excellent UPV values irrespective of the mix. However, the values decreased as the temperature elevated. At initial temperature of 27 °C, the UPV values of all the mixes ranged between 4742 m/s – 5027 m/s which can be considered excellent in terms of concrete quality. At 200 °C, CM and P05 showed excellent quality. For P10, P15 and P20, UPV values were in between 4046 m/s to 4909 m/s which verified good quality of concrete. Similarly, at 400 °C, all the mixes showed good quality and the UPV values were in the range of 3531 m/s – 4258 m/s. At 600 °C, the UPV values ranged between 2724 m/s - 3571 m/s. Air cooled CM specimens at 600 °C showed good quality. All the other specimens showed medium and doubtful quality. Exposing the specimens to 800 °C resulted in huge decline in the UPV values. The values were in the range of 2136 m/s – 1347 m/s which can be classified as doubtful quality (Table 4).

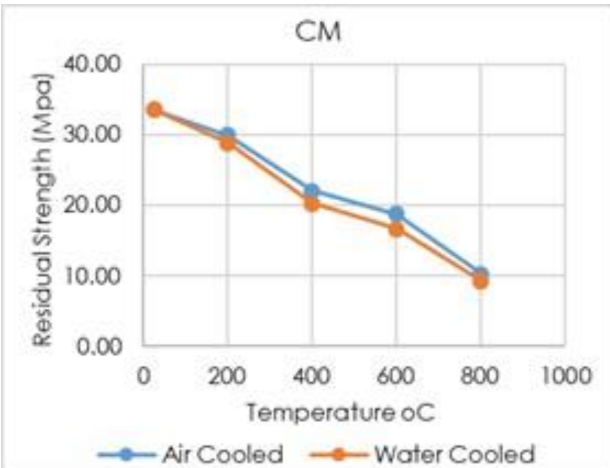

Figure 6 Effect of cooling regime on residual compressive strength – CM

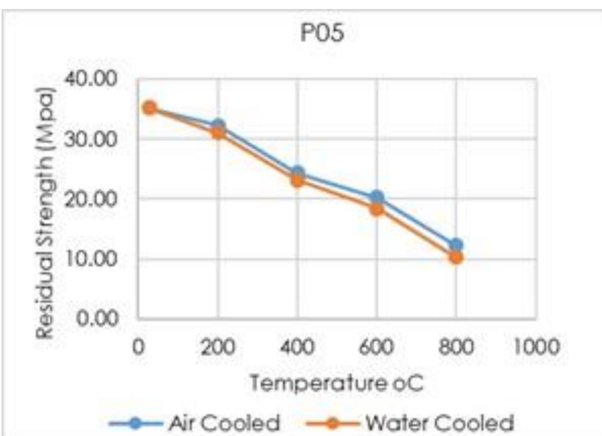

Figure 7 Effect of cooling regime on residual compressive strength - P05

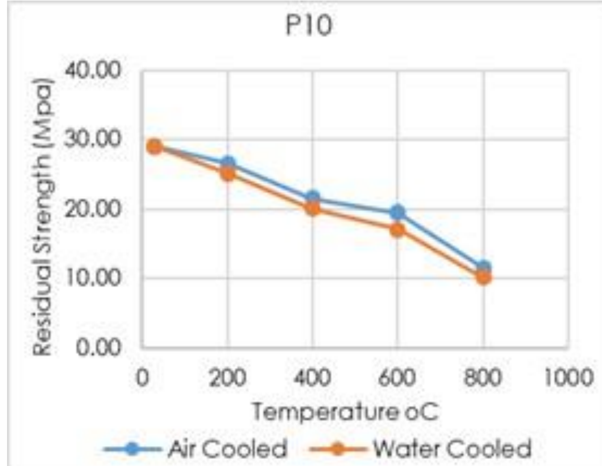

Figure 8 Effect of cooling regime on residual compressive strength - P10

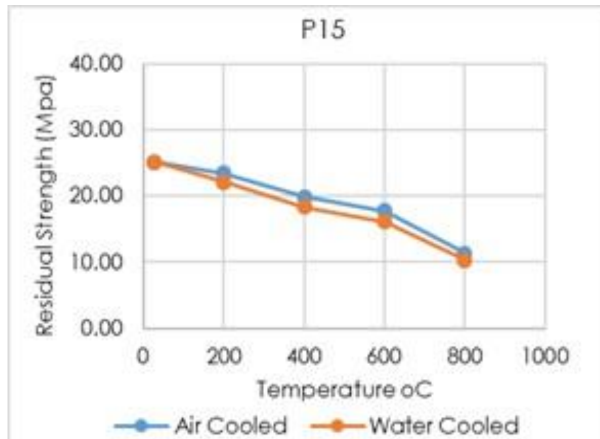

Figure 9 Effect of cooling regime on residual compressive strength - P15

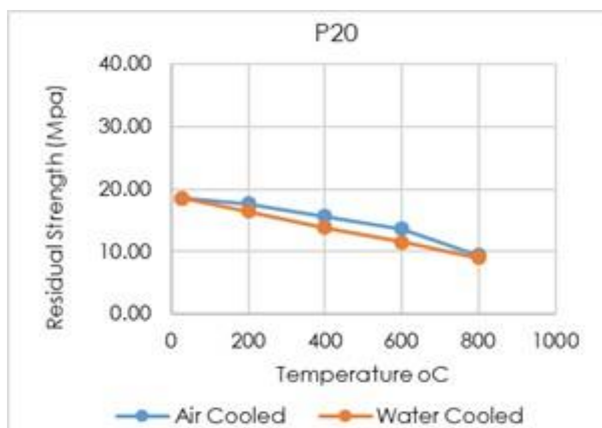

Figure 10 Effect of cooling regime on residual compressive strength - P20

Table 5 Surface characteristics of concrete at various temperatures

Sl No	Temperature	Specimen	Texture
1	27°C	CM	Smooth
		P05	Smooth
		P10	Smooth
		P15	Smooth
		P20	Smooth
2	200°C	CM	Smooth
		P05	Smooth
		P10	Smooth
		P15	Smooth
		P20	Smooth
3	400°C	CM	Smooth
		P05	Smooth
		P10	Smooth
		P15	Smooth
		P20	Smooth
4	600°C	CM	Small cracks & Rough
		P05	Rough
		P10	Rough
		P15	Rough
		P20	Rough
5	800°C	CM	Cracks & Fragmentation
		P05	Cracks & Fragmentation
		P10	Cracks & Fragmentation
		P15	Cracks & Fragmentation
		P20	Cracks & Fragmentation

Table 6 Change in ultrasonic pulse velocity of concrete exposed to high temperatures

Ultrasonic pulse velocity (m/s) in air-cooled (A/C) and water- cooled (W/C) specimens											
SL NO	Temperature(°C)	CM		P05		P10		P15		P20	
		A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C
1	27	5027	5027	4990	4990	4885	4885	4810	4810	4742	4742
2	200	4909	4849	4762	4698	4431	4258	4314	4220	4167	4046
3	400	4258	4117	4134	3921	4001	3934	3852	3695	3725	3531
4	600	3571	3312	3492	3431	3304	3047	3108	2882	2987	2724
5	800	2136	1934	2058	1785	1973	1678	1749	1508	1457	1347

4.0 CONCLUSION

The paper explores the performance of coir pith ash blended concrete exposed to elevated temperature. From the observations and experimental results, it was noted that, at all levels of CPA replacement, the compressive strength decreased with increase in temperature. The thermal performance of both air-cooled and water-cooled CPA concrete increased with increase in the percentage of CPA content from 0% to 20 %. The experiments carried out revealed that cooling regime significantly influences residual properties. Under identical temperature conditions, air-cooling method showed better performance in sustaining residual properties than water-cooling method. UPV values decreased with increase in replacement levels and exposed temperatures. For all the mixes, air cooled specimens exposed to an elevated temperature showed better UPV than water cooled specimens exposed to similar temperatures. Thus, it can be inferred that, in concrete structures exposed to elevated temperatures, implementing air cooling method will be more effective and efficient in recovering structural properties than conventional water-cooling methods

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