Research on Engineering Structures & Materials
journal homepage: http://www.jresm.org
Research Group

Technical Note

Experimental investigation of spalling effect of elevated temperature on concrete containing waste plastic aggregates

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Article Info

Article history:

Received 18 Mar 2022
Revised 29 May 2022
Accepted 14 Jul 2022

Keywords:

Spalling;
Pore pressure;
High temperature concrete;
Waste plastic aggregates;
Fire resistance;
Concrete beams

Abstract

Fire spalling significantly increases the overall heat deformation of a fire-damaged building, resulting in significantly greater repair costs and, in certain situations, jeopardizing structural stability owing to the loss of reinforcing protection and lowering of bearing cross-sections. Due to intrinsic material characteristics such as unstable fracture behavior and limited permeability, elevated concrete is particularly susceptible to shear. Hence in this paper to improve the thermal stability of structures, aggregate waste plastics are added to the concrete to reduce the pore pressure generated inside the concrete subjected to a thermal environment. Here plastics are added to the concrete mix in various weight proportions as 0%, 10%, 20%, 30% and 40% thereby fabricating three types of specimens as cube, cylinder and beam which are then checked for volumetric degradation stability subjected to various thermal gradients like normal temperature, 600°C and 800°C respectively. Finally, the spalling of concrete at various plastic proportions under varying environments are investigated and the best way to incorporate plastic waste aggregates into concrete is explored.

1. Introduction

Strength endurance of construction materials with increasing temperature exposure is critical for constructions. Reinforced concrete (RC) structures may sustain fire damage during their service life [1]. It is a universal fact that molecular structures are stable only up to a certain temperature. This constancy may be compromised as temperature conditions change as the temperature is the deep-seated characteristic influenced by exposure duration and heating rates to impact the molecular structure; thus, it is responsible for concrete deterioration [2]. Concrete's material properties and stiffness decline drastically as a result of physical and chemical changes, resulting in a loss of strength at extremely high temperatures. [3,4].

Reinforced concrete (RC) structures made of traditional concrete, unlike structures made of other construction materials such as steel, have good fire resistance, which can be attributed to low conductivity, greater temperature capacity, and slower degradation of tensile properties with temperature [5,6]. However, owing to changes in microstructure that occur during fire exposure, the newest concrete types, especially High-Strength Concrete (HSC) and Ultra High-Strength Concrete (UHPC), show quicker strength decline, culminating in concrete spalling [1,7].

Spalling of concrete as a result of fire exposure is a well-known phenomenon with consequences for fire safety, building integrity, and the cost of rehabilitation after a fire.

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DOI: http://dx.doi.org/10.17515/resm2022.422st0318tn

During rapid heating and unsuitable conditions, fragments of concrete can explode off the surface, and a whole cross-section heated from two sides can disintegrate completely by spalling [8]. The surface of a concrete structural part will come off when subjected to fast heating conditions, such as during a catastrophic fire. Spalling happens when a fire-exposed concrete section with limited permeability experiences high amounts of pore pressure generated by high temperature gradients [9]. The primary disadvantage of using HSC in reinforced concrete buildings is that it has a higher tendency for heat-induced concrete spalling when exposed to high temperatures, which is due to its thick matrix and refined pore structure [10]. Thermo-hydro-mechanically related heat-induced concrete spalling is affected by thermal dilation and pore pressure gradients [11]. The unlimited water inside the concrete condenses as vapor when exposed to high temperatures, resulting in vapour pressure bubbles and, as a result, tensile stresses that exceed those supported by the concrete. When these concerns are not addressed, the civil structure suffers massive harm [12].

To ensure the safety of reinforced concrete structures designed with HSC, several technological solutions have been implemented, which include limiting the use of HSC to low exposure to firerisk structural components, considering the use of external fire protection systems, and even reducing thermal effects on structural components through design options. [13,14]. Synthetic(polypropylene—PP) and natural (sisal, basalt) fibers distributed in the cement structure, on the other hand, have been effectively employed in concrete to change its microstructure and mitigate the effects on high - temperature cement structural damage [15].

Even though worldwide obligations to the manufacturing process of reusable, recyclable, or biodegradable manufacturing goods originate from greater public concern over inordinate waste production and ineffective disposal practices, waste plastic has also been probed for valuation application fields in concrete buildings, fibres concrete beams, and concrete walkways [16]. Many countries' municipal recycling systems collect but do not recycle plastic waste, resulting in tonnes of plastic being burned, transferred to landfills, or even dumped into the seas. Another source of worry is that dumping plastic waste in landfills pollutes and contaminates soil and water, potentially causing human health concerns due to high levels of lead and cadmium.[17,18]. Despite the fact that the use of High-Strength Concrete (HSC) is increasing dramatically around the world, the use of plastic waste in the manufacture of HSC has not been properly investigated. The paper's main contribution is as follows:

- Improve the stability of concrete in a thermal environment by adding plastic wastes with polycarboxylic-based superplasticizer as aggregates.
- Investigate the spalling behavior of concrete with and without plastic wastes under various environmental conditions and compositions.

Aggregates and plastics increase the thermal stability of concrete to reduce the pore pressure generated inside the concrete when exposed to a heated environment. The structure of the paper has been developed as follows out of which section 1 is the introduction; Section 2 presents the recent works of literature; section 3 depicts the detailed description of the materials and processing methods involved; section 4 deliberates the experimental results and finally, section 5 discusses the conclusion.

2. Literature Survey

Camilo et al [19] in their work, investigated the impacts of high temperature on the residual qualities of concrete, as well as the physical, chemical, and mechanical properties of concrete comprising rejected recyclable plastic waste (RRPW), were explored. After 2 hours of exposure to 200°C, 400°C, and 600°C, concrete compressive and tensile strengths, Young's modulus, crack width, mass loss, water absorption by capillarity, chemical composition, and evidence of heat-induced concrete spalling were measured in concrete samples made with RRPW particles and compared to those made with commercial polypropylene (PP) fibres. Workability and durability difficulties connected to the use of RRPW in high-strength concrete should be investigated.

Hager et al [20] in their work evaluated the effect of high temperatures (up to 1000 degrees Celsius) on the microstructure and mechanical characteristics of geopolymer mortars With fly ash as the major precursor and four degrees of slag substitution (0, 10, 30, and 50 wt of %), four blends were examined. Ultrasonic pulse velocity, scanning electron microscope, mercury intrusion porosimetry, thermal stresses measurements, differential thermal analysis, and thermogravimetry were used to analyze damage evolution and identification tests. The goal of the study was to create a mortar that is thermally stable at high temperatures. However, further work on green materials is required to advance the technology of building structures in a sustainable manner and to minimise gas emissions.

Mohammad hosseini et al [21] in their work studied the impact of waste metalized plastic (WMP) fibres and palm oil fuel ash (POFA) on concrete performance at high temperatures of 200, 400, 600, and 800 degrees Celsius Four concrete mixes were cast, with 0 and 0.5 percent WMP fibres and 0 and 20% POFA content. The characteristics evaluated include mass loss, compressive strength, and ultrasonic pulse velocity. When compared to ordinary concrete mixes, adding WMP fibre to concrete mixes improves concrete performance at elevated temperatures by reducing the rate of strength loss and eliminating explosive spalling behaviour. Spalling analysis for varied structures, on the other hand, has not been concentrated.

Rohden et al [10] in their research studied the possible use of difficult-to-recycle plastic waste as a polymeric addition in elevated concrete, with a focus on the capacity to reduce thermal concrete spalling and its impact on mechanical properties The garbage correlates to soft and hard plastic, particularly domestic polymers, which are typically disposed of in landfills, while being theoretically recyclable. Mechanical and physical properties, cracking, mass loss, and the incidence of spalling in high strength concrete specimen constructed with either plastic waste or polypropylene fibres were tested after a 2-hour exposure to 600 C. Moreover, the spalling effect of the plastic aggregate induced concrete for beam structures and other structural members has to be analysed.

Umasabor et al [22] in their work experimentally investigated the PET pulverized mix with the concrete. Crushed PET was used in concrete at weight percentages of 5%, 10%, and 15% of conventional fine aggregate. There were four distinct types of concrete specimens made, including a control. The concrete specimens' flexural and compressive strengths were assessed after 3 days, 7 days, 14 days, and 28 days of curing, respectively. The concrete specimen containing 5% by weight PET had a better compressive strength than the other specimens, according to the findings. However, spalling effect for samples due to increased thermal gradients were not investigated in the work.

Oluwarotimi et al [23] in their study examines the effect of elevated temperature on the strength of concrete containing glass powder (GWP) as Ordinary Portland cement replacement. They partially replaced by 0, 15, 18, 21, 24, 27 and 30 % of cement with GWP. The cube samples are curing in water for 90 days were exposed to 60, 150, 300 and 500°C temperatures increased at a heating rate of 10°C/min. They measured a compressive strength values of unheated samples and after air-cooling period of the heated samples by scanning electron microscope to examine alterations in the matrix and interface. The compressive strength of the concrete matrix should be concentrated for higher temperature.

From the survey, for [19] issues with workability and durability when using RRPW in high-strength concrete, for [20] more development on green materials is required for a sustainable environment and to minimize gas emissions, for [21] analysis of spalling for various structures has not concentrated, for [10] the spalling effect of the plastic aggregate induced concrete for beam structures and other structural members has to be analyzed and for [22] spalling effect of the specimens due to increased thermal gradients. Hence as a result to overcome the issues in spalling effect of reinforced plastic wastes has to be experimentally investigated.

3. Experimental Program

3.1. Materials and Methods

In this investigation, the binder was composed of Portland cement (CEM II 52.5 R) and plastic wastes. The sand-to-binder ratio of 0.4 was employed. Silica sand with a mesh size of 106 to 120 lm (120 to 150 mesh) was included in the mix. A polycarboxylic-based superplasticizer was present in all of the combinations (30 percent solid content). To explore the influence of plastics on the spalling resistance of concrete with appropriate workability of the new mixture and aggregate plastic dispersion, the concrete was prepared with 0 to 40% plastic wastes in the size up to 20 mm to get adequate ductility. The post consumed waste plastic is collected, after grinding and melting it, again cut in to small pieces. The same pieces after cooling are used as coarse aggregate for the concrete.

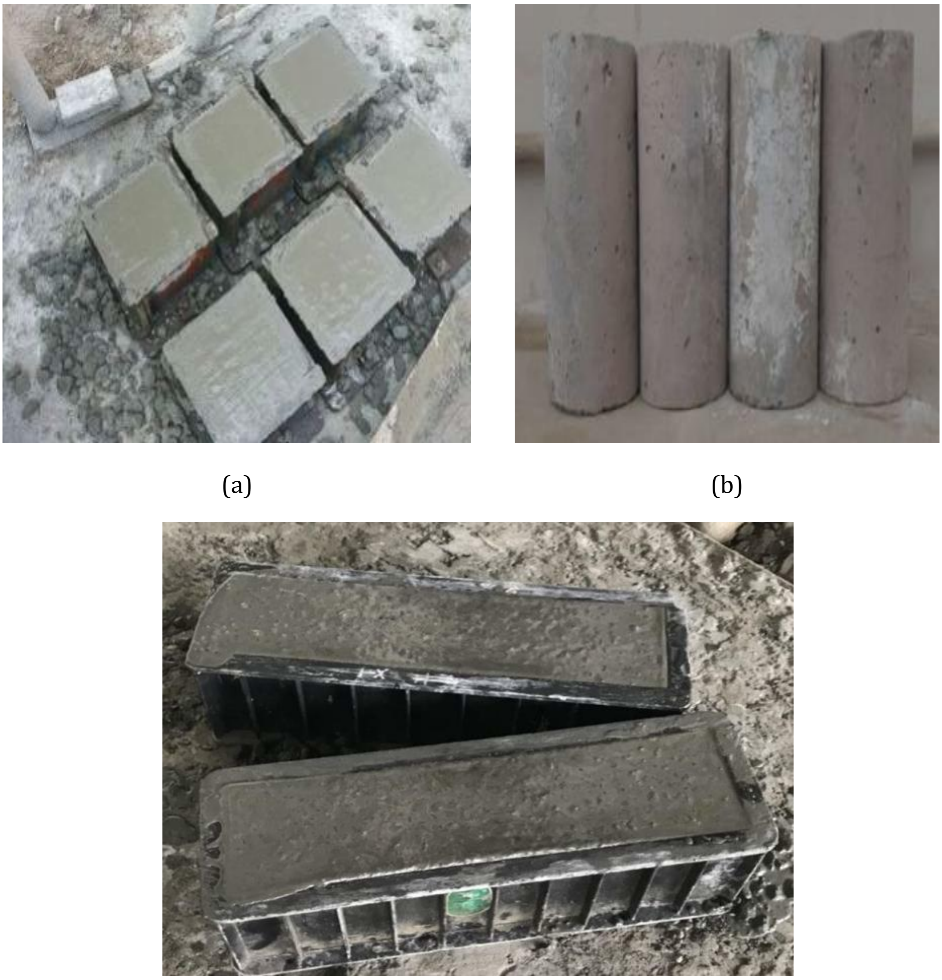
Fig. 1 Plastic waste aggregate

3.2. Mix Proportions and Batching

To make the specimens five different proportions of plastic wastes are added to the concrete which are 0%, 10%, 20%, 30% and 40% respectively. The 0% indicates the pure concrete specimens without the addition of plastic wastes. The specimens are prepared and tested in such a way to investigate the addition of plastic wastes to the conventional concrete. Three types of specimens are prepared with the above mentioned proportions which are a cube, cylinder and beam specimen. The cube is prepared with dimensions 150x150x150 cm3 so that the surface area of the cube is 22500 cm2. The cylindrical specimen is made with dimension having diameter as 150 cm and height of 300 cm with a surface area of 176625 cm2 and the rectangular beam is made with dimensions 150x150x500 cm3.The numbers of samples prepared for each of variation are 6. Mix design proportions were shown in Table 1.

Table 1. Mix design proportions

Plastic waste		Specimens		
(%)	(size)	Cube	Cylindrical	Rectangular beam
0 to 40%	20 mm	150x150x150 cm^3	150×300 cm^3	150x150x500 cm^3



(a) (b)

(c)

Fig. 2 Fabricated specimens

3.3. Testing Methods

BS EN 12390-2, 3:2009 was used to create the concrete cube samples. The concrete cubes were dismantled after 24 hours and submerged under water for 90 days. The cubes were then taken from the water tank and left to dry at room temperature, with the mass of the specimens being monitored until they reached a constant weight. Before the heat exposure test, the starting mass of all concrete specimens was recorded, and the specimens were then examined for a non-destructive UPV test in line with ASTM C597-09 requirements. This test is carried out by sending an ultrasonic pulse into the concrete being tested and measuring the time it takes for the pulse to pass through the construction. Slower velocities suggest concrete with many fractures or voids, whereas higher velocities indicate good quality and continuity of the material. The concrete cubes were then placed inside a furnace that was gradually heated from ambient temperature to 600 and 800 degrees [26]Celsius at a pace of 10 degrees Celsius per minute. The furnaces used for higher temperature have temperature control arrangements, with the help of that temperature inside furnace were kept constant. To establish thermal equilibrium inside the concrete cubes, the peak temperature [26]was kept for 1 hour for each temperature range[25].

The modest temperature increase was intended to avoid substantial temperature gradients in the specimen and, as a result, severe micro cracking, which would have changed the experimental results. The samples were tested to ensure that the pre-heating temperature was reached throughout the specimen. The exposure temperature was kept constant for one hour (1h), and cooling to room temperature was accomplished in the closed and disconnected furnace (about -0.3°C/min). In the oven chamber, the controlled temperature is measured (i.e. not in samples).To investigate the influence of qualities of reinforced plastic wastes, the samples at thermal gradient are compared to the specimen sample at room temperature. Low temperature gradients are used in this procedure and the majority of mortar damage is physicochemical in nature. the samples are prepared in such a way that they represent specimens with and without addition of plastic wastes.

3.4. Effect of Temperature on Conventional Concrete

Even if the temperature is only somewhat raised, the concrete built with portland cement is subjected to heat, which causes a variety of transformations and reactions. Because aggregate materials account for 65 to 75 % of the volume of concrete, the aggregate type has a significant impact on the behavior of the concrete at increased temperatures. Thermal stability of commonly used aggregate materials ranges from 300°C to 350°C. Physical qualities (e.g., thermal conductivity and thermal expansion), chemical properties (e.g., chemical stability at temperature), and thermal stability/integrity are all important aggregate features for concrete behavior at high temperatures. Crystal transitions in aggregate materials result in considerable volume increases [e.g., crystalline transformation of -quartz (trigonal) to -quartz (hexagonal) between 500 and 650 C with a 5.7 percent increase in volume]. With rising temperature, some siliceous or calcareous aggregates with some water of composition display considerable dehydration, which is accompanied by shrinkage (e.g., opal at 373 C shrinks by 13% by volume). Most non-siliceous aggregates may withstand temperatures of up to600°C.Results show that when the temperature is raised above 600 degrees Celsius, the weight loss of specimens gets increases. Aggregates such as Calcareous aggregates (Calcite – $CaCO_3$), magnesite ($MgCO_3$), and dolomite ($MgCO_3/CaCO_3$) were breakdown into oxides and carbonites CO_2 ($CaO + CO_2$) at higher temperatures [25]. Calcium carbonate is a white colored powdered compound which on strong heating (calcination) produces calcium oxide along with a release of carbon dioxide. Magnesium carbonate is also a colorless powdered compound which on thermal decomposition produces magnesium oxide and releases carbon dioxide gas.

A mixture of calcium carbonate and magnesium carbonate is heated strongly. The reaction that takes place is as follows:

$$CaCO_3(s)+MgCO_3(s)\xrightarrow{\Delta}CaO(s)+MgO(s)+2CO_2(g)$$

Evaporable water occupies between 30 and 60 percent of the volume of saturated cement paste and 2 to 10% of the volume of saturated structural concrete at room temperature. Evaporable water is pushed out as the temperature of the cement paste rises, until at a temperature of around 105°C, all evaporable water is lost after a sufficient exposure duration. The firmly absorbed and chemically combined water (i.e., water of hydration) is gradually lost from the cement paste hydrates at temperatures over 105°C, with dehydration virtually complete at 850°C. Calcium hydroxide dehydration is nearly negligible up to around 400°C, accelerates quickly around 535°C, and is complete at about 600°C.Hence at these elevated temperatures, the concrete undergoes complete dehydration and the bond strength decreases, thereby the concrete materials at the face of the structures loses its adhesive property and tends to de-bond thereby creating a failure of the structures which is termed as spalling.

3.5. Effect of Temperature on Plastic Reinforced Concrete

The concrete specimen which is raw without any plastic mix deteriorates much faster at a lower temperature and hence to improve its stability, plastic wastes are added to it. The specimens are made and are tested for its stability in the furnace over a while. The samples are exposed to temperature range of normal temperature, 600 and 800 degrees Celsius in the furnace. The cube specimens have a maximum spalling effect which is denoted by the breakage of the mold specimens under thermal loading. At normal temperature, cube specimen, cylindrical specimen and rectangular beam specimen of concrete samples remains in the same weight. When the weight is increased to 600 to 800 degree Celsius, there is a significant effect on temperature is observed at the specimens with more weight loss. Moreover, the specimens are also observed to undergo a variation of weight due to elevated thermal gradients. the results of the observed investigation are discussed in the following section.

4. Results and Discussion

The section elaborates the results obtained from the fabricated specimens which are subjected to different temperature zones.

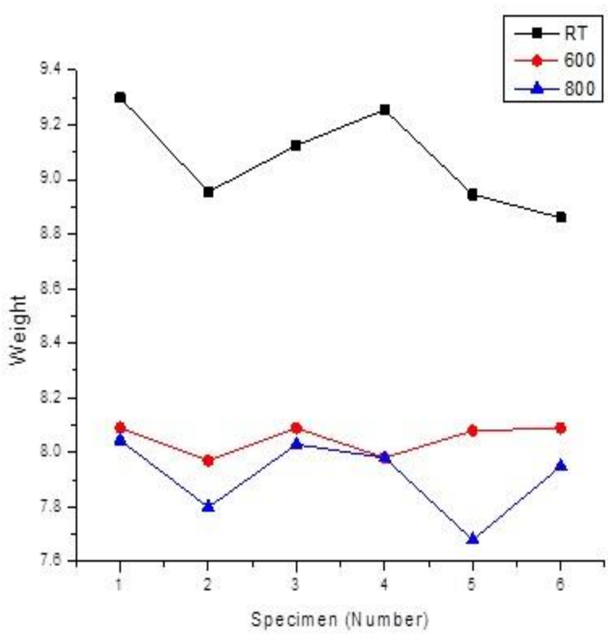
4.1. Weight Loss

In all cases, the spalling process began with a violent event affecting the entire heated region. The spalled layer appeared rather homogeneous after cooling, corroborating the idea that spalling is not strictly related to local mechanisms involving aggregate-to-cement paste interaction under substantially uniform heating and loading conditions, and that a more general explanation based on temperature, pressure, and stress fields can be provided. The evolution of the thermal field was rather constant across genera. This result implies that moisture transport mechanisms play a little impact in concrete thermal behavior. The weight loss at the end of the test for the mortars is nearly identical. The weight loss for the cube specimens are identified and are represented in the graphs. From Fig 3a to 3e, 4a to 4e, 5a to 5e X-axis is showing the specimen's number.

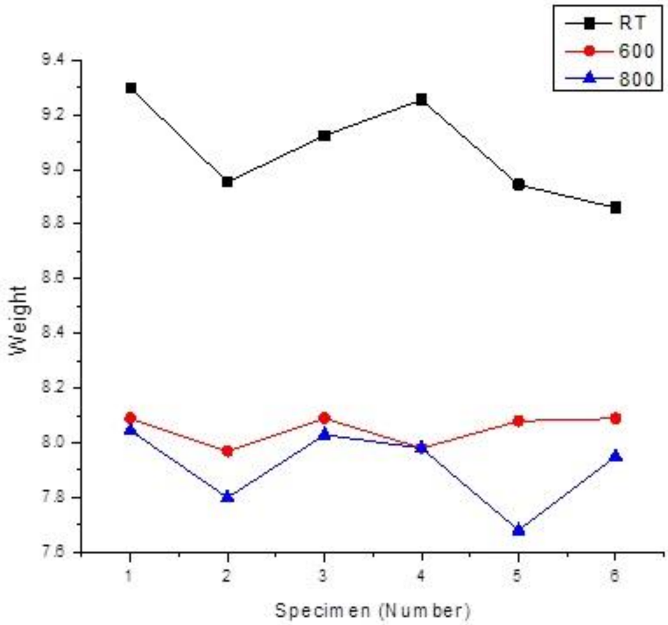
The graphs plotted in fig 3 represents the weight loss of the cube specimens at room temperature, 600 and 800 degrees Celsius for 0%, 10%, 20%, 30% and 40 % plastic addition. From the graph it is clear that the specimens at room temperature has a maximum weight of 9.3 kg at 0% plastic addition. When the specimen is subjected to 600o C the weight loss obtained for the specimen is 8.09 kg which indicates a 13% weight reduction. the minimum weight of specimen obtained is 7.970 kg. When subjected to 800oC the weight reduced for the specimen is 8.045 indicating a 13.5% weight reduction. Moreover, the minimum weight of the specimen is 7.680 kg.

Similarly, for 10 % addition the maximum weight is 8.97 kg for room temperature and when subjected to 600o C the weight for the specimen is reduced to 6.99 kg and for 800o C the weight loss is observed to be 6.60 kg which indicate a weight loss of 22.1% and 26.4 % when increasing temperatures respectively. For 20 % the maximum weight corresponds to 8.32 kg and the weight loss percentage during elevated temperatures corresponds to 17.7% and 28.1% respectively at 600o C and 800o C. The values of maximum weight loss at the corresponding temperatures are 6.95 kg and 6.580 kg.

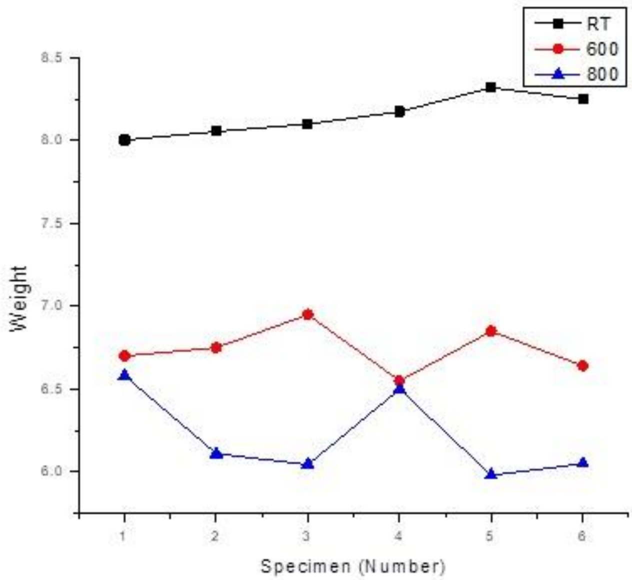
The weight loss percentage for the 30% addition is 17.3 % and 28.2% for 600o C and 800o C respectively as the maximum weight losses denoted the value of 8.05 kg at room temperature to the increased temperature are 6.66 and 5.78 kg respectively. For maximum 40% weight addition the specimen at room temperature is 7.87 kg and weight loss in maximum for 800-degree and 600-degree temperature which is 29.6% and 25.2 % respectively while the maximum weight corresponds to 5.89 and 5.54 kg respectively. From figure 3, it is clear that when temperature raises from 600 to 800, there is a weight loss of concrete samples. Hence, in this research, plastic wastes were added to concrete samples to reduce weight loss by reducing the pore pressure generated inside the concrete subjected. When the addition of plastic waste is increased from 0 % to 40%, the weight loss decreases since plastic waste in concrete reduces the direct effect of high temperature on concrete surface.



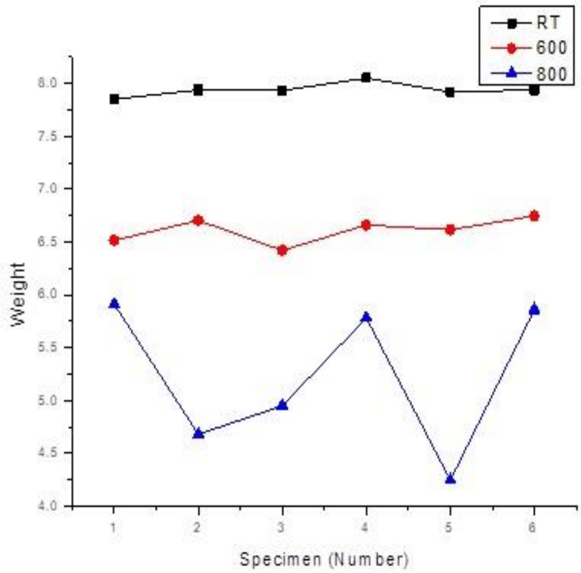
(a) 0% plastic waste



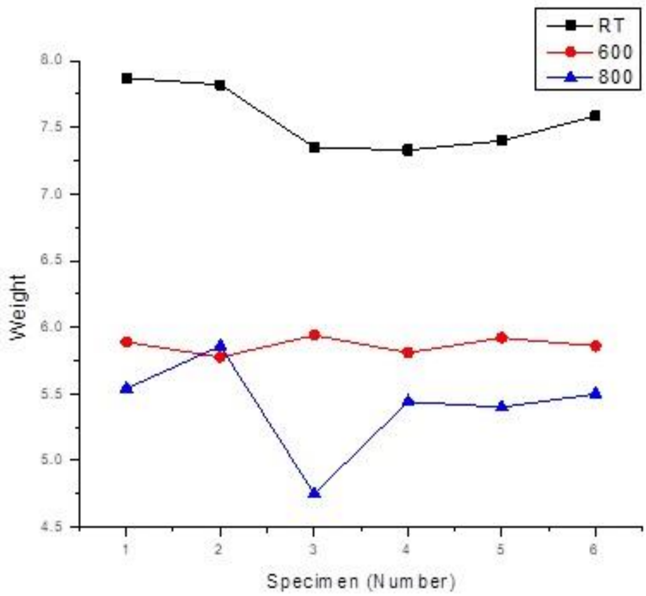
(b) 10% plastic waste



(c) 20% plastic waste

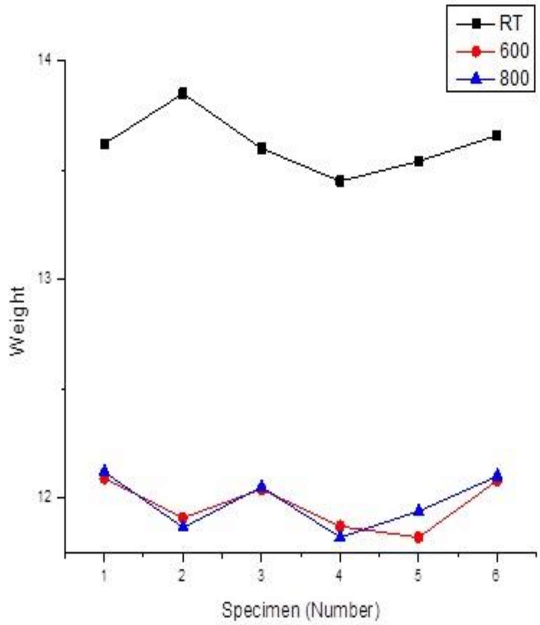


(d) 30% plastic waste

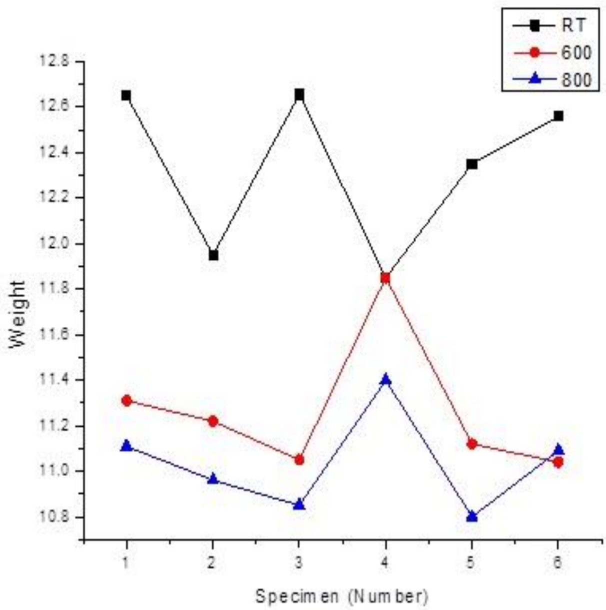


(e) 40% plastic waste

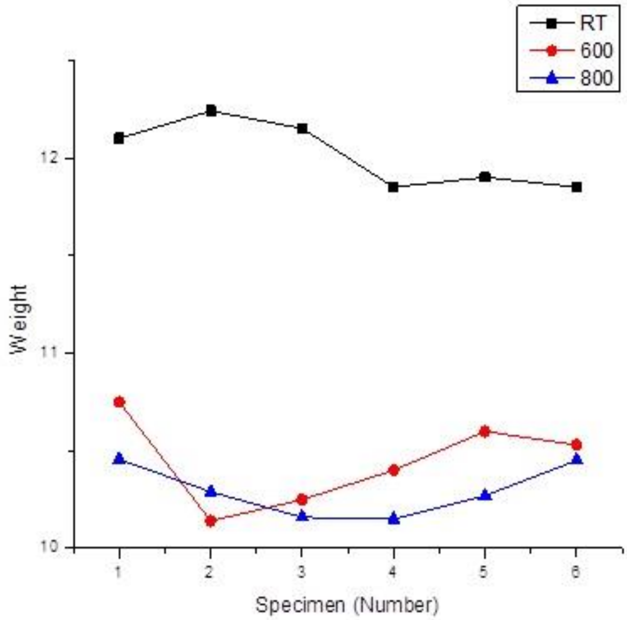
Fig. 3 Weight loss in cube specimens



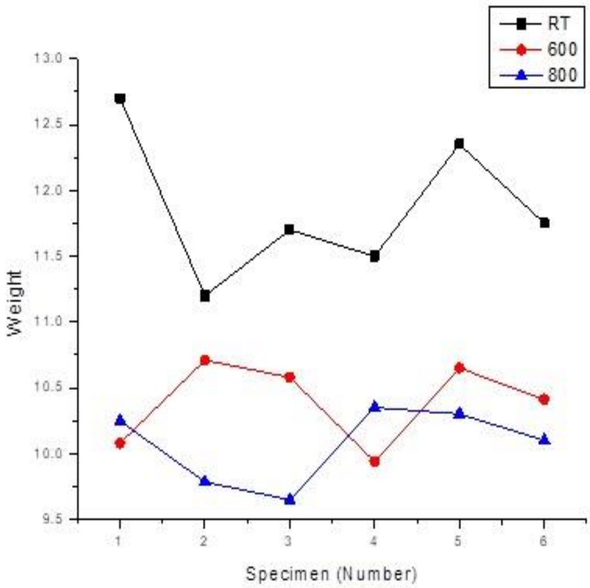
(a) 0% plastic waste



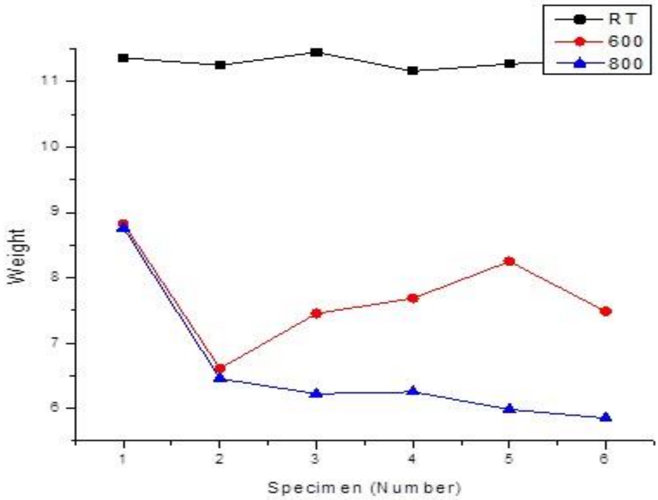
(b) 10% plastic waste



(c) 20% plastic waste



(d) 30% plastic waste



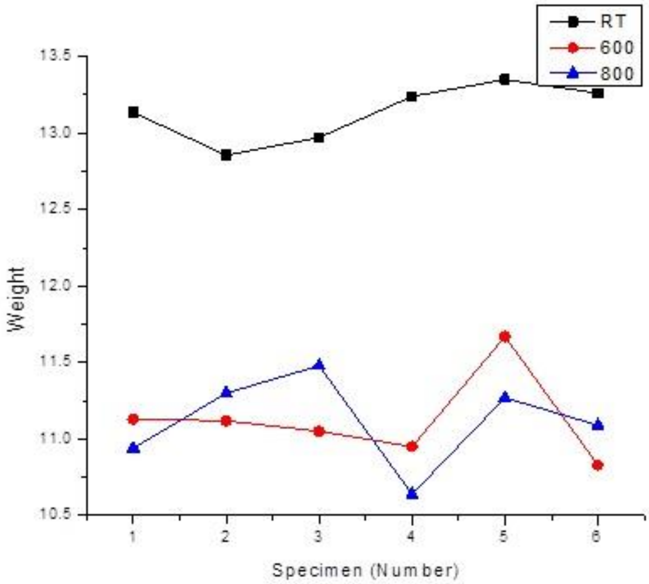
(e) 40% plastic waste

Fig. 4 Weight loss in cylindrical specimens

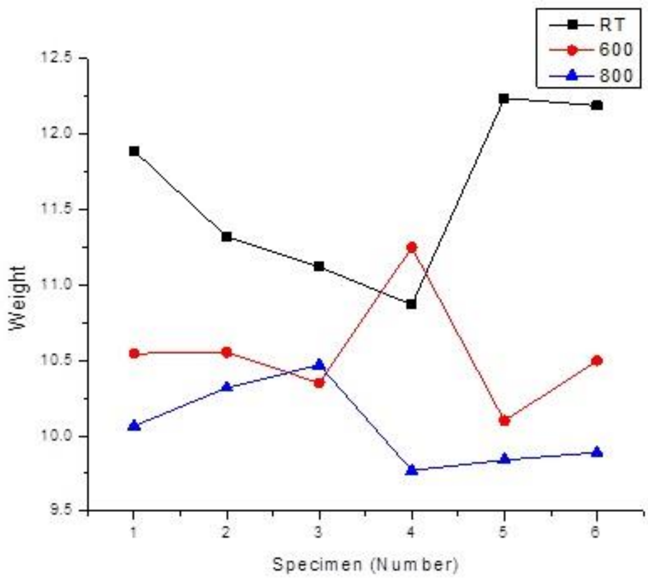
The graphs plotted in fig 4 represents the weight loss of the cube specimens at room temperature, 600 and 800 degrees Celsius for 0%, 10%, 20%, 30% and 40 % plastic addition. From the graph it is clear that the specimens at room temperature has a maximum weight of 13.85 kg at 0% plastic addition. When the specimen is subjected to 600o C the weight loss obtained for the specimen is 12.09 kg which indicates a 11% weight reduction. the minimum weight of specimen obtained is 11.87 kg. When subjected to 800oC the weight reduced for the specimen is 12.12indicating a 11.12% weight reduction. Moreover, the minimum weight of the specimen is 11.82kg.

Similarly, for 10 % addition the maximum weight is 12.655 kg for room temperature and when subjected to 600o C the weight for the specimen is reduced to 11.31 kg and for 800o C the weight loss is observed to be 11.11 kg which indicate a weight loss of 10% and 12 % when increasing temperatures respectively. For 20 % the maximum weight corresponds to 12.24 kg and the weight loss percentage during elevated temperatures corresponds to 17.2% and 15.9% respectively at 600o C and 800o C. The values of maximum weight loss at the corresponding temperatures are 10.14 kg and 10.29 kg respectively.

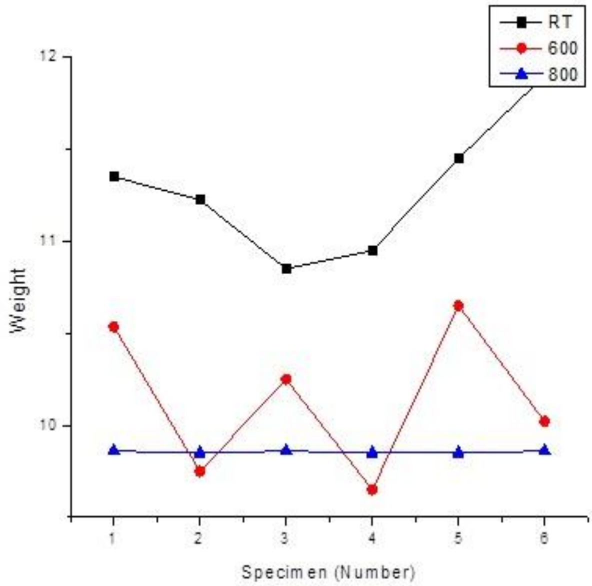
The weight loss percentage for the 30% addition is 20.1 % and 19.3% for 600o C and 800o C respectively as the maximum weight losses denoted the value of 12.700 kg at room temperature to the increased temperature are 10.08 and 10.25 kg respectively. For maximum 40% weight addition the specimen at room temperature is 11.45 kg and weight loss in maximum for 800-degree and 600-degree temperature which is 34.9 % and 45.6 % respectively while the maximum weight corresponds to 7.45 and 6.22 kg respectively. It is observed that the maximum amount of weight loss is observed at the 40% plastic addition which indicates that as the amount of plastics increase, they get converted into ash upon elevated temperature which indicates the maximum weight loss. From figure 4, it is observed that for cylindrical specimen, the weight loss is increased with addition of plastics and increase in temperature. Hence, for this type of specimen, the additions of plastics reduce the effect of high temperature on concrete but conversion of plastic into ash cause maximum weight loss.



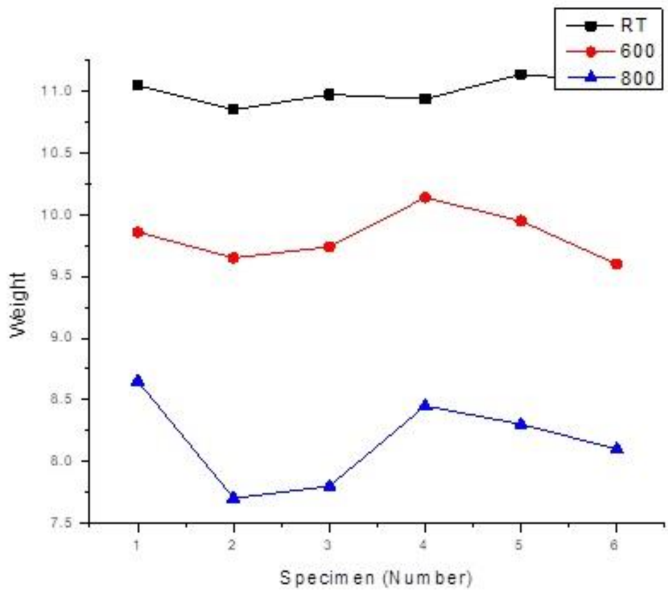
(a) 0% plastic waste



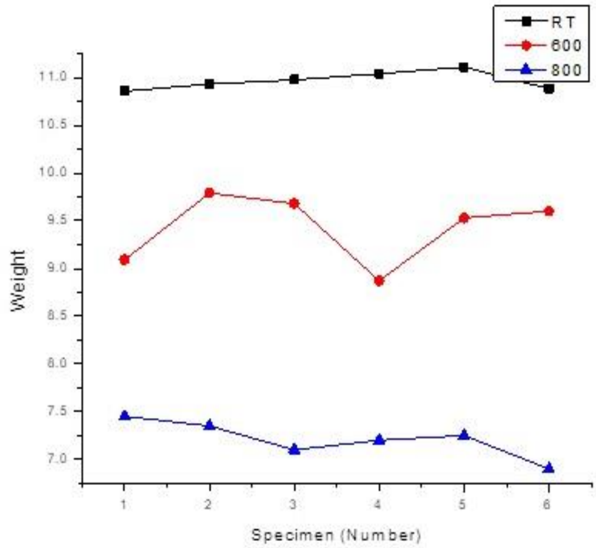
(b) 10% plastic waste



(c) 20% plastic waste



(d) 30% plastic waste



(e) 40% plastic waste

Fig. 5 Weight loss in beam specimens

The plots in fig 5 depict the weight loss of the beam specimens at room temperature, 600 and 800 degrees Celsius for 0 percent, 10%, 20%, 30%, and 40% plastic addition. The graph clearly shows that the specimens at room temperature have a maximum weight of 13.35 kg with0% plastic addition. When the specimen is exposed to 600o C, the weight loss obtained is 11.67kg, indicating a 12 percent weight drop. The minimum specimen weight obtained is 10.83 kg. When exposed to 800oC, the weight of the specimen is reduced by 11.27, suggesting a 15% weight reduction.

Similarly, for 10% addition, the maximum weight is 12.24 kg at room temperature, and when subjected to 600o C, the weight for the specimen is reduced to 10.1 kg, and when subjected to 800o C, the weight loss is observed to be 9.8 kg, indicating a weight loss of 17.1% and 19.4% when increasing temperatures, respectively. The maximum weight for 20% amounts to 11.90 kg, and the weight loss percentage with elevated temperatures relates to 15% and an average of 14 percent at 600o C and 800o C, respectively. Maximum weight loss values at the corresponding temperatures are 10.02 kg and 9.850 kg, respectively.

The weight loss percentage for the 30% addition is 10 % and 25.5% for 600o C and 800o C respectively as the maximum weight losses denoted the value of 11.14 kg at room temperature to the increased temperature are 9.9 and 8.3 kg respectively. For maximum 40% weight addition the specimen at room temperature is 11.11 kg and weight loss in maximum for 800-degree and 600-degree temperature which is 14.2% and 34.7 % respectively while the maximum weight corresponds to 9.5 and 7.25 kg respectively. It is obvious from the preceding results that as the temperature rises, the weight loss of the beam specimen decreases due to the addition of plastic wastes. This is because when plastic waste deteriorates at high temperatures, it turns into ash, which has a lower density than plastic and hence causes low weight loss in concrete specimens.

4.2. Edge Spall

All of the data on spalling are reported below after the edge effects have been neutralized, as seen in Figure. These effects are mostly caused by stress patterns along the edges, which is frequently referred to as the "corner effect." The results in Table[2] indicate the corner effect and the deterioration of the molded sample which provide a valuable assessment of the phenomenon's variability. The depth of the damaged concrete ranges from 4 to 15 cm, with a considerable degree of variability. Spalling frequently reaches or even through the reinforcing mesh. Figures show the quantitative influence of the edge effect on the test results.

From the graph the edge spalling of the cube specimen is described for room temperature, 600 degrees and 800 degrees Celsius for various specimens with 0 %, 10%, 20%, 30% and 40% addition of plastic aggregates. All the edge spalling for room temperatures are zero as it does not show any deviation of specimens. Hence the specimen is considered to be zero at room temperature. At 600 degrees the cube specimen has deteriorated to an edge effect of 11 cm and for 800 degrees it is indicated to be 15 cm for 0% plastic addition. For 10% addition the value is found to be maximum at 12 cm for both temperatures. for 20% addition of plastics the edges of the cubes deteriorated to 15 cm and 11.5 cm respectively for the 600 degrees and 800-degreeCelsius elevation of temperature. The edge was found to remove from the mold for a measurement of 11 cm and 12.5 cm in the 30% addition and as the temperature increases the 40percent addition showed an edge effect of 11.6 and 12 cm respectively. From the graphs it is clear that the addition of plastic wastes reduces the edge spalling till 20% and beyond that the spalling increases at elevated temperatures and hence the 20% plastic addition is depicted to the optimum value of spalling.

Figure 7 depicts the edge spalling of the cylindrical specimen at room temperature, 600 degrees and 800 degrees Celsius for various specimens with 0 percent, 10%, 20%, 30%, and 40% addition of plastic aggregates. All of the edge spalling for room temperatures is 0 because there is no specimen variance. As a result, the specimen is found to be zero at room temperature. The cube specimen has degraded to an edge effect of 3 cm at 600 degrees and 8 cm at 800 degrees with 0% plastic addition. The value for 10% addition is determined to be greatest at 5.5 and 7 cm for both temperatures. The edges of the cubes degraded to 4 cm and 5 cm for the 600degrees and 800-degree Celsius temperature elevations, respectively, with a 20% increase of plastics. The edge was found to remove from the mold for measurements of 8 cm and 7 cm in the30% addition, and as the temperature increased, the edge effect was 7 and 8 cm in the 40% addition. From the results the addition of 20% plastic addition depicts the optimal addition of reinforcement in the concrete.

The values for spalling depths in these figures were calculated on a series of six specimens built with five concretes of proportions and values are calculated from the only measured depth within the center zone. When the edge effect is considered, the deviation decreases slightly, the distance between maximum and minimum values decreases slightly, but average spalling increases. This is supported by the observation of the exposed specimens which shows that the edges are less influenced with addition of plastic wastes.

From the results obtained, the addition of plastic waste (0% to 40%) in three specimens, namely cube specimen, cylindrical specimen and rectangular beam specimen of concrete samples, can tolerate the effect of high temperature on concrete surface up to 800 degrees Celsius. However, Calcium carbonate break down when the temperature exceeds 700o C. At higher temperatures that is more than 600 degree celsius, aggregates such as calcite ($CaCO3$), magnesite ($MgCO3$), and dolomite ($MgCO3/CaCO3$) were broken down into oxides and carbonites $CO2$ ($CaO + CO2$) [25].

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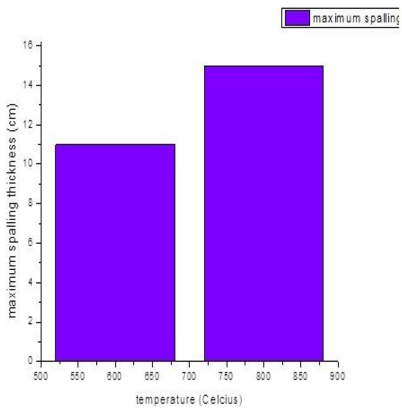
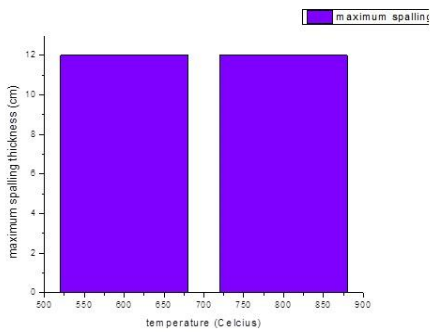
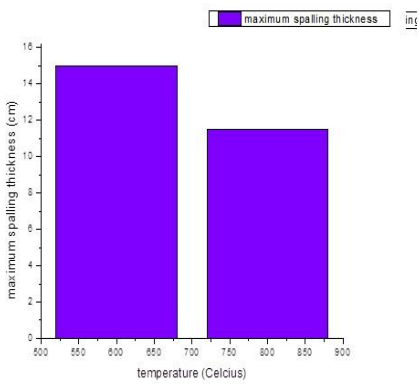


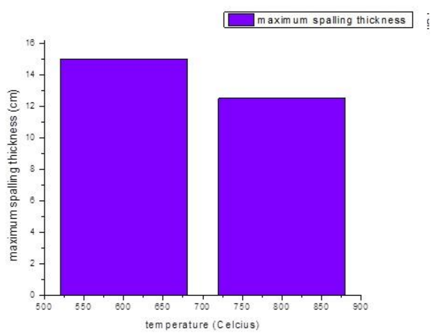
(a) 0% plastic waste



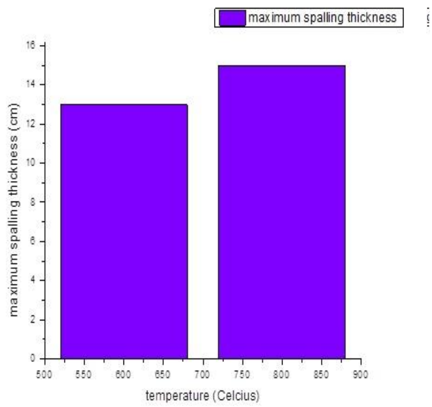
(b) 10% plastic waste



(c) 20% plastic waste

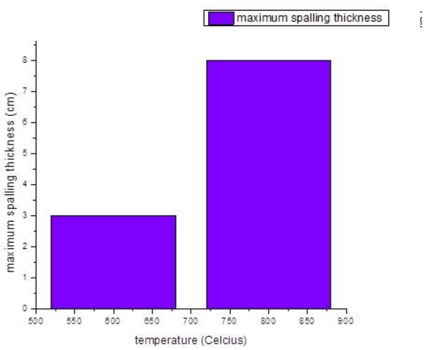


(d) 30% plastic waste

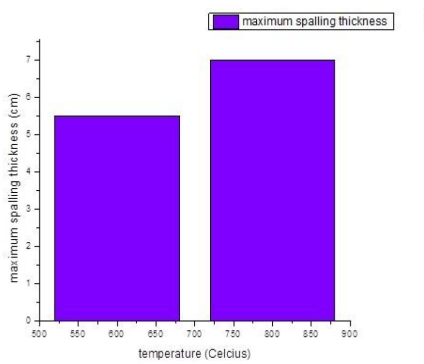


(e) 40% plastic waste

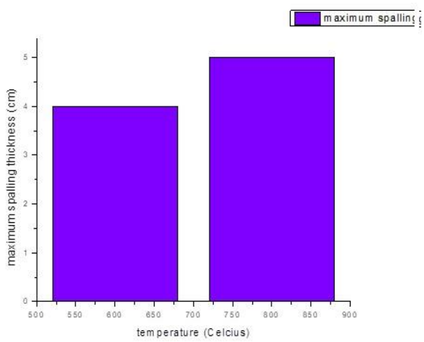
Fig. 6 Edge spalling of cube specimens



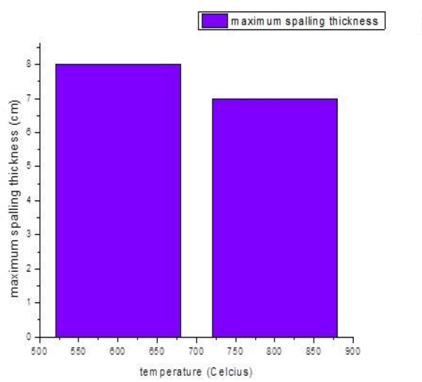
(a) 0% plastic waste



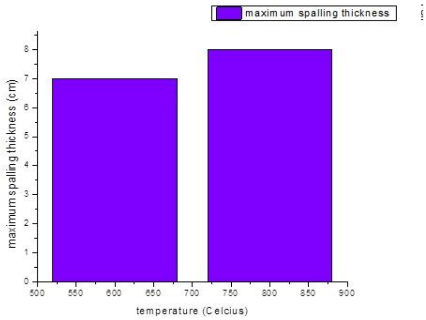
(b) 10% plastic waste



(c) 20% plastic waste



(d) 30% plastic waste



(e)

Fig. 7 Edge spalling of cylindrical specimens

Figure 7 depicts the edge spalling of the cylindrical specimen at room temperature, 600 degrees and 800 degrees Celsius for various specimens with 0 percent, 10%, 20%, 30%, and 40% addition of plastic aggregates. All of the edge spalling for room temperatures is 0 because there is no specimen variance. As a result, the specimen is found to be zero at room temperature. The cube specimen has degraded to an edge effect of 3 cm at 600 degrees and 8 cm at 800 degrees with 0% plastic addition. The value for 10% addition is determined to be greatest at 5.5 and 7 cm for both temperatures. The edges of the cubes degraded to 4 cm and 5 cm for the 600degrees and 800-degree Celsius temperature elevations, respectively, with a 20% increase of plastics. The edge was found to remove from the mold for measurements of 8 cm and 7 cm in the30% addition, and as the temperature increased, the edge effect was 7 and 8 cm in the 40% addition. From the results the addition of 20% plastic addition depicts the optimal addition of reinforcement in the concrete.

The values for spalling depths in these figures were calculated on a series of six specimens built with five concretes of proportions and values are calculated from the only measured depth within the center zone. When the edge effect is considered, the deviation decreases slightly, the distance between maximum and minimum values decreases slightly, but average spalling increases. This is supported by the observation of the exposed specimens which shows that the edges are less influenced with addition of plastic wastes.

From the results obtained, the addition of plastic waste (0% to 40%) in three specimens, namely cube specimen, cylindrical specimen and rectangular beam specimen of concrete samples, can tolerate the effect of high temperature on concrete surface up to 800 degrees Celsius. However, Calcium carbonate break down when the temperature exceeds 700o C. At higher temperatures that is more than 600 degree celsius, aggregates such as calcite (CaCO3), magnesite (MgCO3), and dolomite (MgCO3/CaCO3) were broken down into oxides and carbonites CO2 (CaO + CO2) [25].

4.3. Aggregate Variation Effect

The results enable the examination of the impact of aggregate nature of the added plastic wastes at varying proportions. Part of the variation in recorded spalling depths for the of aggregates is very definitely due to material loss during the cooling phase. It should be noted that, as stated, spalling depths were assessed following the test. Materials may fall off the tested elements during the cooling phase. The thickness reduction measured after the test includes every phenomenon that resulted in material loss, whether it occurred during the heating or cooling phases. Material loss might be seen during the cooling period. Calcium carbonate breakdown occurs when the temperature exceeds 700° C. This is followed by re-hydration and carbonation during the cooling phase, which causes material separation resulting in spalling. Which identified by a phenolphthalein solution to determine the carbonation depth in concrete as an indicator.

Table 2. Corner effects of cubes

% Plastic addition	Cube (normal temperature)	Cube at 600°C	Cube at 800°C
	Spalling corners brokes	Spalling corners brokes (cm x cm x cm)	Spalling corners brokes (cm x cm x cm)
0	No change	2.5x6.5x9	corner broken
	No change	5.5x7.5x1	3x15x4.5
	No change	2x6x10	3x14x4.6
	No change	5.5x7.5x2	3x12x4.7
	No change	2.5x6.5x11	3x15x5
	No change	5.5x7.5x3	3x13x4
10	No change	2.5x12x1.5	3.5x11x2.5
	No change	9.5x11.5x5.5	8.5x11.5x6.5
	No change	cracks and plastic burns	3.5x11x2.6
	No change	2.5x11x2	8.5x12x6.6
	No change	9x11x5	3.5x11x2.7
	No change	2x10x1	8.5x11.5x6.7
20	No change	7.5x15x10	8.5x11x7.5
	No change	small corner broken	9.5x11.5x7.5
	No change	9x10x6.5	8.5x11x7.6
	No change	9x9x7	9.5x11.5x7.6
	No change	8x8x11	8.5x11x7.7
	No change	7x10x10	9.5x11.5x7.7
30	No change	15x10x11	15x11x11
	No change	4x11x7	6x11x7
	No change	5x6x10	5x10x11.5
	No change	7x6x11	6x11x8
	No change	8x9x11	6x12x10
	No change	10x8x7	10x10x12.5
40	No change	13x10x11.5	15x10x11
	No change	5.5x11x7	4x11x7.5
	No change	5x8x10	5.5x8.5x10
	No change	13x10.5x11.6	15x10x12
	No change	5.5x11.5x8	4x12x7.6
	No change	5x8.5x11	5x8x11

The specimens' sections were identical, but their thickness varied. The position of the plastic in the concreate identified by passing ultrasonic wave through the specimens. Plastic on the surface which is exposed to high temperature melts early as compare to the plastic which in not exposed to high temperature. At room temperature as the slabs are not loaded, thickness may have an effect on stress distribution due to thermal non-linear gradients. On the other hand, it can contribute to water migration. Because the reinforcement is so dispersed, there is no clear trend toward thicker specimens. This discovery is almost definitely owing to the fact that numerous phenomena, such as mechanical strength and thermal gradients, are fighting for attention.

Table 3. Corner effects of cylindrical specimens

% Plastic addition	Cylinder (normal temperature)	Cylinder (600˚C)	Cylinder (600˚C)
	Spalling corners brokes	Spalling corners brokes	Spalling corners brokes
0	No change	2x2	6x7
	No change	corners broken	6.5x8
	No change	1.5x2	7x6.5
	No change	2.5x2	7x5
	No change	2x3	6x6.5
	No change	3x1.5	7x7
10	No change	3x5.5	5x3
	No change	cracks	4x5.5
	No change	4x4	5x4
	No change	3.5x4.5	4x6
	No change	5x4	5x5
	No change	5.5x3.5	4x7
20	No change	small croner	5x4.5
	No change	3x4	3.5x4.5
	No change	2x3	5x4.6
	No change	2.5x3.5	3.5x4.6
	No change	3x2	5x4.7
	No change	2.5x2.5	3.5x4.7
30	No change	8x2.5	5.5x6
	No change	4x6.5	6.5x5
	No change	corner broken	5x6
	No change	3x7	4x7
	No change	2x6	6.5x7
	No change	3.5x7.5	5.5x6.5
40	No change	5.5x6.5	6.5x6.5
	No change	6x6.5	7x6.5
	No change	5.8x6.6	6.5x6
	No change	6.5x6	7x6
	No change	6x7	6.5x8
	No change	6x6	6.5x7.5

5. Conclusion

Cracking and spalling can occur as a result of sudden temperature fluctuations, and aggregate expansion can cause friction in the concrete. Concrete's compressive strength is also affected by high temperatures due to inherent material features such as unstable fracture behavior and limited permeability. Hence experimental investigation of spalling effect of elevated temperature on concrete containing waste plastic aggregates utilized the addition of aggregate waste plastics to concrete in order to minimize the pore pressure formed inside the concrete when it is exposed to a thermal environment, thereby boosting building thermal stability. Plastics are added to the concrete mix in various weight proportions, such as 0%, 10%, 20%, 30%, and 40%, resulting in three types of specimens: cubes, cylinders, and rectangular beams which are then tested for volumetric degradation stability under various thermal gradients including room temperature, 600°C, and 800°C. The spalling of the edges in the specimens were identified and concluded based on the findings. For 600°C and 800°C temperature elevations, the margins of the cubes deteriorated to 15 cm and 11.5 cm respectively with a 20 percent plastic addition, and therefore the 20 percent plastic addition is depicted to the optimal value of spalling for cubes and cylindrical specimens. A 40 percent plastic addition results in the largest weight reduction because as the number of plastics grows, they are turned into ash at high temperatures, resulting in the greatest weight loss. Plastic position in the specimens is also essential; when exposed to higher temperatures, it degrades more quickly than specimens with plastic that has not been exposed to higher temperatures. In the future, researchers should concentrate on different types of aggregates and plastic wastes to be added to the concrete surface in appropriate size and concentration to tolerate high temperatures of more than 800 degrees Celsius thereby analyze the spalling as well as cracking effect on concrete.

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