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Effect of Polystyrene Waste on Concrete at Elevated Temperature

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Abstract

Objectives: The purpose of the present study is to examine the thermal and impact behaviour of the concrete containing polystyrene waste as aggregates. **Methods**: The concrete specimens were cast and cured in a conventional way to examine the mechanical behaviour of the concrete. A separate equipment was prepared to determine the impact strength of the concrete as per ASTM D5420-21. The thermal behaviour of the concrete with plastic aggregates were also examined with reference to IS 7861-1 (1975). Artificial Neural Network was also used to predict and compare the properties between both the conventional and plastic concrete. **Findings**: The mechanical behaviour of the concrete behaves well at Mix 2 when compared to other mixes. The impact strength of the concrete was found to be 98.375 J at Mix3 which was 20.69% higher than the Mix2. At Mix2 the 7 days compression strength in elevated temperature is 16.79 N/mm^2 which was 4.8% higher than the Mix 1 and 31.74% higher than the Mix 3. At 28 days, the compressive strength of concrete containing 50% replacement of aggregate exposed to temperature 50^{o}c for 24 hours is 26.84 N/mm^2 which shows a better result and resistance in the thermal condition than the other mixes. ANN also gives reliable predicted values which exhibits a clear relation with the inclusion of the plastic aggregate and concrete matrix with some minimum errors. **Novelty**: From the experimental investigation it was observed that the plastic concrete fails in the transition zone of concrete due to the weaker bonding between the plastic aggregate and cement matrix. The plastic aggregate has not undergone any crushing failure in the concrete specimens when compared to the conventional aggregate. Thus, this solid polystyrene waste can be used as an alternative material for coarse aggregate in concrete.

Keywords: Waste plastic; Modified concrete; Mechanical properties; Impact Strength; Thermal behaviour

1 Introduction

Among all the waste which has been generated on this universe the dumping of plastic waste reminds more when compared to the any other waste in the solid waste[1]. The generation of waste material produced nowadays is inversely proportional to the rate of energy conversion[2]. If we take globally among 79% of total plastic waste were produced and only 9% of the waste is recycled[3]. Among these plastic wastes the Polystyrene occupies 30 percent of the space in landfills. The plastic waste remains high in the municipal solid waste quantity, even though there are different ways of disposing of plastic[4]. This substantial growth in the plastic waste leads to the way of reusing and recycling. In the current scenario, usage of waste materials has become popular in the construction industry[5].

On the other hand, nearly 13.12 billion natural aggregates are required for the production of concrete in every year[6]. Using of plastic in concrete is not a new topic for the science, but the usage of which type of plastic under suitable conditions in concrete holds the difference. In concrete the failure of the structure will be initiated with the failure of the aggregate[7]. The natural failure pattern of concrete is brittle in nature and also it has the tendency to carry the entire compressive load which is similar for the coarse aggregate[8]. The usage of plastic aggregates in concrete leads to reduce the brittle nature in concrete which will help to increase the sustainability of load carrying capacity of the structures[9]. Usage of this plastic waste will help to reduce the usage of natural aggregates and also leads to the decrease in the usage of natural resources[10].

The existing works states that several investigations were made by incorporating plastic waste in the form of shredded pieces or in small shapes into the concrete[11]. The previous studies were made with the incorporation of polypropylene (PP), polyethylene terephthalate (PET) and high-density polyethylene (HDPE) in concrete to examine its fresh and hardened properties[12]. All researches shows that there will be a decrease in the density of concrete with the increase in the replacement level of plastic aggregate[13–15]. The mechanical properties of the concrete decreased further more with inclusion of plastic as aggregate and the workability of the concrete also varied with respect to the type of the plastic used in the concrete[16]. The weaker in bond between the plastic and the cement paste leads to the decrease in the strength of the concrete[17]. The split tensile strength has been affected significantly when the replacement level of the plastic when it crosses below 5%[18]. Many of the research work also stated that the minimum replacement level of the plastic does not contributes towards the development of strength in concrete.

Few more researchers were also examined about the impact strength and energy absorption of the concrete with the addition of plastic waste and stated that the impact resistance and energy absorption have increased due to the ductile behaviour of plastic[18]. The thermal behaviour of the plastic with concrete were also studied to determine the critical condition of when the concrete was exposed to heat. And it was observed that a white smoke along with foul smell was occurred in the PET concrete which shows the poor fire- resistant behaviour. They found that, when the concrete is coated with some insulated materials the fire resisting behaviour can be enhanced[19]. Some studies also shows that the addition of the mineral admixture as silica fume in the plastic concrete enhances its thermal performance[20,21]. This study focuses on the partial replacement of coarse aggregate by polystyrene waste in M20 grade of concrete at elevated temperature. Since, both the materials are different in their thermal behaviour and also it is very important to identify the behaviour under different thermal conditions with their performances.

To reduce the manpower, materials and experimental operations in the making of concrete and also to get the reliable results the Artificial Neural Network (ANN) technique was adopted for the last two decades. As like your human brains the ANN is interconnected by the neurons through which the information processing technique will happen. Nowadays this ANN technique was used predominantly in the many fields to predict, analyse, optimization and to create the models from the data[22,23].

In ANN, all the neurons will have the dense parallel interconnections which will possess many information processing units through a single or multiple layers. The initial part of the process starts from entering the values of input and output data from two different ways. One is all the data are extracted from the excel sheet, another one is we can enter the values manually. However, the data are extracted from the sheet for the precise feeding. The role of neurons plays a vital role in the data acquisition which actually connects between the input and output data. The neurons will communicate the weights received from the inputs to the output with the help of an activation function in the hidden layers. Usually, all the ANN models can be efficiently analysed with one hidden layer itself, but in some cases the number of hidden layers can be increased to 2 for more efficiency. The next part is sum function, in which the effect of inputs and weights are calculated to process the element to next cell. The last part is the output, where we can have the predicted or analysed data with the relative regression plot[24,25].

Various attempts were also made with the use of different plastic components as a replacement material for concrete, only few studies have been made with solid polystyrene waste in concrete. So far in the literature no work was carried on the polystyrene waste which is generated in the production of many plastic products electrical appliances (i.e. switches, plug points, circuit boards, etc.,) manufactured by electrical industries. The plastic waste collected here is HIPS (High Impact Polystyrene) polystyrene which belong to the type of thermoset plastic. This waste is generated during the manufacturing process of coil sheets. This research extensively investigates the applications of using the plastic aggregate in concrete to examine its fresh and hardened properties. The failure of concrete starts with the crushing failure of the coarse aggregate which can get influenced under varying thermal condition. Hence this present study focuses on the impact resistance and the thermal behaviour of the Polystyrene Aggregate (PSA) concrete under elevated temperature. Artificial Neural Network technique was also adopted for predicting the different mechanical properties of the concrete under different conditions. Furthermore, this investigation can provide the feasibility of using polystyrene plastic waste as coarse aggregate in concrete.

2 Methods

Materials and Characteristics

The materials used for concrete are cement, fine aggregate, coarse aggregate, Plastic aggregate and water were tested for their properties to decide about their suitability for using them in concrete.

2.1.1 Cement

Ordinary Portland Cement (OPC) is used as the main binder with other ingredients. The physical properties of cement used in this study evaluated with Indian standards conforming to IS 8112- 1989. The standard consistency of the cement is 33% with an initial stetting time of 40minutes and final setting time of 272 minutes and having a specific gravity of 3.10.

2.1.2 Fine Aggregate

Conventional standard river sand is used in this investigation which is free from all the impurities. The physical properties of the Fine Aggregate were evaluated by IS 650-1966 and IS 2386-1968. With the help of sieve analysis, the fineness modulus of the fine aggregate was found to be 2.55 which fall under the zone III. The fine aggregate having the water absorption capacity of 1.05% and specific gravity value of 2.65

2.1.3 Coarse Aggregate

The physical properties of Coarse Aggregate evaluated by standard tests as per IS 2386-1968. Fineness modulus of the coarse aggregate was found to be 6.7 by sieve analysis method. The specific gravity of the coarse aggregate and its water absorption capacity is found to be 2.74 and 0.6% respectively.

2.1.4 Plastic aggregates

When we use the plastic waste in construction activities, it will lead to the reduction of waste in the environment and also contributes to save the natural resources in which the raw materials can be obtained. The polystyrene waste material was collected from the M/S Random Fibres Pvt Ltd., located in Pondicherry, India. After the collection of the waste, it was then cut into pieces with the help of grinding machine in the size of 10mm to 20mm which was shown in the Figure 1. Then these materials were used as an artificial coarse aggregate and the test for the aggregate was carried out as per the codal provisions shown in the Figure 2. The replacement level of this polystyrene waste as aggregates in concrete (artificial aggregates) is 0%, 50% and 100%. In most of the works the replacement level of the plastic waste has the range between 0% to 50% in concrete. No works were carried out in the remaining replacement level and also this study is mainly focused to determine the behaviour of the concrete when it is partially and fully replaced with the polystyrene plastic waste.

Fig 1. Plastic aggregate from waste

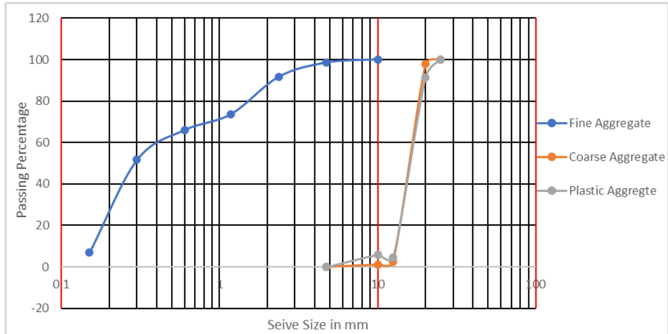

Fig 2. Particle Size distribution of Aggregates

To examine the thermal behaviour of the concrete under compression the test specimens were casted in 100mm cube and then cured for 28 days. After 28 days of curing the specimens were kept in the oven for 24 hours and then the specimens were tested under the compression testing machine to know its ability to resist the compression load when it is exposed to an elevated temperature of 50°C. The polystyrene plastic is prone to weak in thermal condition and also the world's peak temperature is 50°C which prompted this study to test the specimens under these conditions**.**

3 Experimental Investigation

The experimental program comprises of five stages viz., collection and preparation of materials, design of mixes, preparation of specimens, curing of specimens and testing of specimens. The concrete has to be designed in such way that it should need to satisfy the safety, serviceability, durability and economic conditions. The concrete mixes designed as per IS 10262:2009 based on the characteristics of ingredients. The solid polystyrene plastic waste is collected from the industrial zones and then it is processed to become an artificial coarse aggregate with appropriate shape and size. This plastic aggregate was then used in the concrete as a replacement of coarse aggregate to examine its mechanical behaviour. As per the Indian code of practice, the concrete was casted in the form of cubes, cylinders and prism to determine the compressive, split tensile and flexural strength respectively.

According to the designed proportions, the quantity of each ingredient was calculated and the materials were mixed with necessary quantity of water and placed in moulds and compacted well. The numbers of specimens cast are 36 numbers of l0cmxl0cmxl0cm cubes, 36 numbers of 50cmxl0cmxl0cm beams, 36 numbers of 10cmx20cm cylinders, 18 numbers of 10cmx5cm discs in all three mixes. The de-moulded specimens were kept inside the curing tank which was filled with water to keep the specimens under submerged conditions for of period 7days and 28 days. The specimens were tested after 7days and 28 days of curing to determine for their mechanical properties. To know the thermal behaviour of the concrete, the concrete cubes has been kept at temperature of 50°c for 24 hours and then it was tested to determine the compressive and split tensile strength respectively. The impact strength of the concrete was also studied to know the energy absorption of the PSA present in concrete. All the tests were carried out according to the Indian code of practices and the results are discussed below.

Feed forward back propagation algorithm technique was adopted in this study to predict the mechanical properties of both plastic and normal concrete. Among the different algorithms of multilayer perceptron available in the MATLAB, the back propagation algorithm will gives the reliable result with minimized cumulative error. In training and testing of ANN model cement, coarse aggregate, plastic aggregate, fine aggregate and water contents were kept as input data while the respective mechanical property was kept as output. The input and target data were imported to the workspace from the source file. All the input and target variables were named as input and target data. In addition to that the sample variables were also added as an input data which will actually help in interpreting the values in regression analysis. After creating the modules in the name of input, target and sample data, the variables were cross verified with the source data.

In the command window type 'nntool' which initiates to open the neural network / data manager window. Import the entire variable such as input, target and sample from matlab workspace to network / data manager. Assign the network name, network type, input data, target data, training function, adaption learning function, performance function, number of layers, number of neurons and transfer function of the network. The custom neural network model has been created and stored in the neural network / data manager window. Open the network to view and to check the input, output, hidden layer and output layer. Assign the training info and parameters and then train the network. After the network was trained view the regression plotting and maximum epoch reached. In the regression plotting, the data line should match up with the fit line with the coefficient of determination equals or near to one. If not, train the network until the network will get fulfilled by the above condition. After getting the precise network model, the network will be stimulated to get the expected or targeted values with errors. These values can be imported directly to the workspace in the network manager and then stored in the source file.

The values of parameters used in this research are as follows:

- Number of input layer units = 8
- Number of hidden layers = 2
- Number of first hidden layer units = 8
- Number of second hidden layer units = 8
- Number of output layer units = 2
- Momentum rate = 0.9
- Learning rate = 0.85
- Error after learning = 0.000515
- Larning cycle = 30.000.

4 Results and Discussion

In order to assess mechanical properties of concrete using plastic aggregate, the specimens were cast in the appropriate shape and size and compared with conventional concrete. The specimens were kept cured in the ordinary Portland water for a period of 7 days and 28 days. Then the specimens are tested at the relative ages of the concrete as per the guidelines of I.S 516-1959. The tested values were noted from the well calibrated Compression Testing Machine which was used to find the failure loads.

4.1 Density

Before subjecting the specimens for crushing test, they were weighed for density calculations. The average density of concrete with fully replaced plastic aggregates at Mix 3 was found to be 1736.4 kg/m^{3}which was 31.44% lesser than the conventional concrete. As per ASTM C576 the concrete is said to be structural concrete when its density is between 1440kg/m^3 to 1750kg/m^3. Thus, the plastic concrete falls under the light weight concrete which can significantly contribute for the reduction of the dead load of the structures. Due to the reduction in the dead load of the concrete which often leads to the better economical construction practice.

4.2 Compressive Strength

Predominantly the failure of structures depends with the crushing of coarse aggregate in concrete. By increasing the crushing strength of the aggregate, the failure of the concrete will be reduced. In this study the coarse aggregate was replaced with the plastic aggregate to know its behaviour in mechanical properties. The compressive strength of the concrete containing the plastic aggregates has been found out at the ages 7 and 28 days after the curing period. The concrete cubes were kept in such a way that the application of the load will acts perpendicular to the concrete specimens. With the help of Compression testing machine, the relative values were found as per the IS 516: 1959. The Artificial Neural Network (ANN) model was also developed for predicting the compressive strength values were compared with experimental values which were given in the Table 1.

Table 1. Compressive strength of the conventional and plastic concrete

Sl. No.	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Plastic aggregate (kg/m^3)	Compressive strength (N/mm^2) at			
						7th day		28th day	
						Exp	Pre	Exp	Pre
Mix 1	320	724	1274.79	175	0	16.80	12.89	26.76	26.78
Mix 2	320	724	637.395	175	637.395	12.23	12.32	28.69	28.64
Mix 3	320	724	0	175	1274.79	12.67	12.40	23.84	24.34

The findings of the compressive strength of concrete containing conventional and plastic aggregate shows that there will be a decrease in compressive strength with the increase in the plastic aggregate at early days of concrete strength. But at 28 days of compressive strength there will be increase in the compressive strength with 50% replacement of conventional aggregate with plastic aggregate (Mix 2) is 28.69 N/mm^2 which was 7.21% higher than the conventional concrete. At Mix3 with 100% of replacement of coarse aggregate with plastic aggregate, the compressive strength is decreased slightly and the value is lesser than the other two mixes. From these test reports, it has been found that the combination of conventional aggregate and plastic aggregate at Mix2 behaves better in holding the compressive stress than the other two mixes. The synergy effect of both conventional and plastic aggregate plays a major role in the enhancement of the strength at Mix2. Even though the compressive strength is less at Mix 3, it can be used as structural concrete since the compressive value is 23.84 N/mm^2 which is higher than the 20 N/mm^2 which will be the minimum characteristic strength of M20 grade of concrete at 28 days.

The analytical models were created and validated in the artificial neural network to predict the compression strength values. The values from the regression analysis shows that the predicted valued were very closer to the experimental values with least errors. The regression equation was also determined in the ANN model which can be used in future to determine the compressive strength of the concrete without casting the cubes. The regression equation for predicting the compressive strength is Output = 1.1*Target + 1.8.

The plastic aggregate concrete has absorbed more strain energy at Mix2 when compared to the other two mixes. The compressive strength of the concrete increases with increase in the plastic aggregate content. After reaching the optimum replacement level of plastic aggregate in concrete the compression strength tends to fall. It is majorly due to the low compressive resistance of plastic aggregate when compared to the conventional aggregate. This behaviour has been predominantly noted in all the tested specimens in where the conventional coarse aggregate has failed through crushing. The compression failure of the alternative material to the conventional aggregate is similar in most of the existing works which will cause the distress more in the concrete. This distress in concrete will be decreased with the inclusion of the plastic aggregate which will leads to an enhanced sustainability load carrying capacity.

4.3 Split Tensile Strength

The indirect way of measuring the tensile strength of concrete is to determine the split tensile strength of cylindrical specimens which may fails along in its diameter. A total of 36 cylindrical specimens were casted to determine the split tensile strength of concrete for all the mixes. The casted specimens were undergone curing for 7 days and 28 days and tested in Compression testing machineIS 5816-J 999. According to the codal provisions the testing was performed and the results were tabulated. With the help of the experimental and other input data the analytical model was created in the ANN for predicting the experimental values.

From the test results it has been found that the inclusion of the plastic aggregate in the concrete decreases the split tensile of the concrete at both ages. At 28 days the split tensile strength of Mix 2 is 2.995 N/mm^2 which is less 4.61% than the Mix 1 but when compared with the Mix 3 it is 17.86% higher than the concrete containing plastic aggregates alone. This condition also replicates at the early day strength of concrete in all the mixes. The failure of the specimen shows that the efficiency of the plastic aggregate is more when it is performing along with the conventional aggregate than the separate line of attack. This combined effect of the conventional aggregate and plastic aggregate once again leads to the path of synergy. Overall, there will be slight decrease in the split tensile of the concrete with the inclusion of the plastic aggregate. The analytical model was also created to predict the split tensile strength of the concrete using ANN. The predicted values are nearer to the experimental values and the regression equation was also plotted with the help of all the dependent and independent values. While predicting the experimental values the ANN shows least error with great accuracy. The regression equation for predicting the split tensile strength of the concrete with given dependent and independent value is Output = 1.2*Target + 0.57.

Addition of plastic waste as in the coarse aggregate form has not contributed the tensile strength of the concrete due to its geometrical profile. During the application of tensile load, the propagation of the crack will be arrested by the inclusion of fibre in the concrete. Due to the specific geometrical profile of the fibre, the crack propagation was arrested[21,22]. The shape and size of the plastic waste used was angular and 20mm which was not supposed to act as bridge during the crack propagation. This condition made the plastic concrete to have a less tensile strength than the conventional aggregate. Existing works also stated that there will be increase in the tensile strength of the concrete when the additives are used with an optimum aspect ratio without exceeding the limit (aspect ratio).

4.4 Flexural Strength

Before a material yields, it will undergo in maximum bending stress that can be applied to that material which can be termed as the flexural strength of the material. In this study the prism specimens have been used to determine the flexural strength of concrete containing plastic and conventional aggregates. A total of 36 prism specimens was casted and tested according to the IS 516:1959. Single point loading setup has been adopted to determine the pure flexure of the prism specimen. Regression equation was also developed for predicted the flexural strength of the concrete using ANN model.

From the noted observations it has been found that the inclusion of plastic aggregates in the concrete leads to the increase in the flexural strength at both the ages. At Mix3 the flexural strength of concrete is 4.79 N/mm^2 which is 36.5% and 46.5% greater than the Mix2 and Mix1 respectively. At Mix2, the flexural strength of the concrete is greater than Mix 1 concrete at both the ages. At 28days flexural strength the Mix3 is 37% and 44.8% higher than the Mix2 and Mix1. When compared between the other two properties of this mix 3, it behaves well in the flexural strength than the compressive and in split tensile. Overall there will be a decrease in flexural strength with the addition of plastic aggregates. This is mainly due to the adhesion property and weaker transition zone which has been created between the cement mortar particles and with the coarse aggregate. Similarly with the help of all the experimental data, the regression analysis has been done with the help of artificial neural network in Matlab. The ANN model shows a good prediction of the flexural strength of the concrete with least error and great accuracy.

The presence of plastic aggregate does not enhance the flexural strength of the concrete due to the poor bonding between the plastic aggregate with the cement matrix. If the plastic aggregate was undergone any special treatment to enhancing the bonding property, then the plastic aggregate may impart better resistance against the tensile and flexural loads. The previous research work also stated that the plastic aggregate will give better moment carrying capacity when it was treated with relative conditions.

4.5 Temperature Effect on Compressive Strength

When the concrete is exposed to heat, it undergoes several changes along with its physical and mechanical properties. These concrete properties can be majorly influenced by the heating rate and peak temperature. The changes in mechanical properties at high temperatures are related to the evaporation of moisture in concrete was given in Table 2. This study was carried out at the temperature of 50^{o}c. The highest peak temperature observed was 43^{o}c with the reference to that the elevated temperature was chosen as 50^{o}c.

Table 2. Temperature effect on compressive strength

Sl. No.	Average loss of weight on cube kept on oven for 24 hrs at 50^{o}c (kg)	Compressive strength (N/mm^2) at 50^o C				Split Tensile strength (N/mm^2) at 50^o C			
		7th day		28th day		7th day		28th day	
		Exp	Pre	Exp	Pre	Exp	Pre	Exp	Pre
Mix 1	0.0335	15.97	17.57	25.91	27.05	2.29	2.15	2.60	2.58
Mix 2	0.0355	16.79	18.84	27.05	27.24	1.88	1.73	2.09	2.10
Mix 3	0.0375	11.46	11.37	18.24	20.14	1.73	1.70	1.92	1.73

A total of 36 cube specimens were casted to determine the compressive strength at the elevated temperature of 50^{o}c. From the test results it has a clear view that the single effect of plastic aggregate and conventional coarse aggregate having less compression strength compared to the combined effect at Mix2 for both ages of concrete. The expansion of volume in the concrete specimens was also observed in all the mixes in which at Mix 2 specimens are having less volume expansion compare to other mixes during its peak temperature.

At Mix2 the 7 days compression strength is 16.79 N/mm^2 which was 4.8% higher than the Mix 1 one and 31.74% higher than the mix 3. Similarly at 28 days strength of compression at mix 2 has a higher intensity compared to the other two mixes. The 28 days compressive strength for Mix2is 27.05 N/mm^{2}which was 4.21% higher than the Mix 1 and 32.56%higher than the Mix 3. This relation once again shows the synergy effect of the conventional and plastic aggregates in concrete which can leads to increase in strength at Mix2. It was also observed that the heat was more absorbed in Mix 1 and in Mix 3 than the Mix 2. This shows the replacement of plastic aggregates behaves better with the presence of conventional aggregate in peak temperature.

The weight loss was also noted to determine the change in density of concrete with respect to the elevated temperature. The weight loss is more in the Mix 3, since this mix only contains the plastic aggregate alone which shows a greater influence with temperature condition. The average weight loss for Mix 3 was 0.0375 kg at 50^{o}c which was 10.6% and 5.3% higher than the Mix1 and Mix 2 respectively. Also, the regression equation has been plotted with the help of artificial neural network which shows the good relation between the experimental data and predicted values with the least error and reliable predicted results with a regression equation of 0.69*Target + 9.4.

Increase in the exposed temperature of the concrete leads to the decrease in the compression strength of the concrete. The coefficient of thermal expansion is higher in the plastic aggregate when compared to the conventional aggregate which caused the volume expansion of the concrete often leads to the debonding effect between the plastic aggregate and matrix. At Mix2 the thermal behavior of the concrete is good when compared to the other two mixes which shows the feasibility of using plastic aggregate with conventional aggregate along with the concrete matrix. Due to the variability in coefficient of thermal expansion and the synergy effect of the plastic and conventional aggregate the better strength was obtained at Mix2.

4.6 Temperature Effect on Split Tensile Strength

To determine the split tensile strength of concrete at elevated temperature as 50°C, a total of 36 cylindrical specimens were casted and tested at 7days and 28 days. Each specimen at different mixes was kept in the oven for 24 hours at 50°C to examine its thermal behavior. Since the plastics are generally influenced with thermal conductivity, the inclusion of plastic aggregates in concrete leads to the decrease in the tensile strength. The artificial neural network model was also created to predict the split tensile strength of the concrete at elevated temperature as 50°C .

The test results shows that the thermal behavior of a concrete which containing plastic aggregates does not perform well when compared to the ordinary conventional aggregate concrete. The weight loss shows the similar values for both the compressive and split tensile strength of the concrete. The increase in the plastic aggregates in concrete leads to the reduction in the split tensile strength of the concrete. The 7 days strength at Mix1 is 2.2 N/mm^{2}which is 17.9% higher than the Mix 2 and 24.4 % higher than the Mix 3. For 28 days split tensile strength of the concrete shows the similarity of readings at Mix1 is 2.60 N/mm^2 which is 19.57 % higher than the mix 2 and 26.15 % higher than the Mix 3. The thermal conductivity of conventional aggregate having a major influence in the strength of the concrete while comparing it to the plastic aggregates.

The failure is generally initiated with the bulging of volume and with the expansion of plastic aggregates inside the concrete specimen which tends to expand its volume when it is exposed to the 50°C but in case of natural coarse aggregate there won't be any volume expansion at 50°C was observed. From the artificial neural network model the regression equation has also developed and the values were also predicted. The predicted value shows there is a very minor error with the experimental values and the regression equation can also be used in a future to predict this potential strength of this concrete at elevated temperature.

The variability in coefficient of thermal expansion and synergy effect have not contributed significantly in the tensile strength of the concrete when compared to the compression behavior. The volume expansion of the concrete specimens is noted with increase in the temperature. During the failure of the concrete specimen, the plastic aggregate was broken into small pieces which shows that the plastic aggregate is less in resisting the tensile load when the temperature increases. This often leads to decrease in strength of concrete with plastic aggregates.

The structural components are designed to take unexpected load when it is exposed to the worst condition like earthquake, blast forces and some nuclear exposures. During these conditions the structure can go long term deformation and expected to sustain the loads. The Indian code of practice was not having a separate test to determine the impact strength of the concrete. The impact resistance of the concrete can be determined according to the ASTM procedure where the sudden impact load is applied on the structural element. In this method, a free fall from a standard height and weight is dropped on the concrete until it fails and split into three equal halves. The number of blows required to break the concrete specimen is noted to calculate the impact energy absorbed in the concrete. To determine the impact test, the specimens were casted with 100mm diameter and 50mm length. These disc specimens were then kept in the test set up as shown in the Figure 3 which was locally fabricated as per the ASTM D 1557 standard and the test was conducted.

Fig 3. Impact test on concrete

As per the code of ASTM D 1557, a total of 18 cylindrical specimens of 100mm diameter and 50mm height of size were casted and cured for 28 days. The impact specimens are tested after the curing of 28 days in ordinary Portland water. The testing equipment and set up was also prepared according to the code of ASTM D 1557. The dropping hammer has been prepared with a weight of 4.54kg and with a free fall height of 457mm. A steel ball having 20mm diameter was placed on the top of the concrete disc specimens. Then the hammer is allowed to fall freely on the top of the steel ball to generate the sudden impact load on the specimen. The number of blows on the specimens are noted on two occasions first when the initial crack forms and next at the specimens were separated into three different halves. Based on the number of blows, the total impact energy of the concrete specimens was calculated using the flowing equation

Impact Energy absorbed = n*m*g*h

Where, n=Number of blows at last crack

m=Mass of the drop weight

g=Acceleration due to gravity

h=Height of the fall

Table 3. Impact strength of concrete

Mix	No. of blows at first crack	No. of blows at Last crack	Energy absorbed in joules (j)
Mix 1	2	4	80.17
Mix 2	3	5	100.21
Mix 3	3	6	120.25

The results which were given in the Table 3 shows that there is a decrease in the impact strength of the concrete with the inclusion of Plastic aggregate. At Mix1 the coarse aggregate crushing failure has been absorbed but at Mix 2 and 3 the plastic aggregate has not undergone any crushing failure in concrete. The failure of the specimens in Mix 2 and Mix 3 fails in the transition zone of concrete, the weaker bonding between the plastic aggregate and cement matrix may leads to the failure. The conventional aggregate has crushed more than the plastic aggregate which shows the failure was only due to the bonding between the aggregates and the cement matrix.

The energy absorbed by the plastic aggregate concrete is more when compared to the combined effect of conventional aggregate with plastic aggregate. This behavior exhibits the strain hardening property of the concrete with the inclusion of plastic aggregate. From the tested specimens it was also noted that the plastic aggregate does not breaks into separate pieces and stick with the cement matrix itself during its failure. And the conventional aggregates have broken down into fine small pieces when the impact load was applied. This shows that the impact failure of the plastic aggregate concrete is majorly due to the improper bonding between the surface of the plastic aggregate and the concrete matrix. If the bonding property of the plastic aggregate and the matrix is increased, then there might be a possibility of achieving higher impact strength in the plastic concrete.

5 Conclusions

Increase in plastic aggregate content leads to the decrease in the density of the concrete and the average density of concrete with fully replaced plastic aggregates at Mix 3 was found to be 1736.4 kg/m^3 which was 31.44% lesser than the conventional concrete. This Plastic concrete can be used as light weight concrete in structural elements which can be cost effective with acceptable strength.

The 28 days compressive strength with 50% replacement of conventional aggregate with plastic aggregate (Mix 2) is 28.69 N/mm^2 which was 7.21% higher than the conventional concrete. The Mix 2 behaves better than the other two mixes in resisting compression strength. The combined effect of the conventional aggregate and plastic aggregate once again leads to the path of synergy which can cause the increase in compression at Mix2. The stress developed initially at the compression state will be carried by the rigid conventional aggregate and the stress created in the posttensioning stage will be carried by the strain hardening plastic aggregate. This combined effect of carrying the stresses often will contributes to achieve the maximum compressive strength at Mix2. This shows that the plastic aggregate can able to withstand a higher compressive load when it acts together with conventional aggregate. The plastic aggregates contributed majorly to the compressive strength of the concrete when compared to the tensile and flexural strength. At 28 days the split tensile strength of Mix 2 is 2.995 N/mm^2 which is less 4.61% than the Mix 1 but when compared with the Mix 3 it is 17.86% higher than the concrete containing plastic aggregates alone. This is due to the improper bonding and the larger size of the plastic aggregate provided in the concrete matrix. During the tensile failure, propagation of the cracks is not bridged with the inclusion of the plastic aggregate which leads to the further reduction in tensile strength. Even though the plastic aggregate was not contributed to the tensile strength of the concrete, it has the acceptable strength at the Mix2 when the plastic aggregate is combined with the conventional aggregate. At Mix3 the flexural strength of concrete is 4.79 N/mm^2 which is 36.5% and 46.5% greater than the Mix2 and Mix1 respectively. At Mix3, the flexural strength of the concrete is greater than Mix 2 concrete at both the ages. Overall, there will be a decrease in flexural strength with the addition of plastic aggregates. The flexural strength of the concrete increases in increase with plastic aggregate content which eventually shows that the resistance against the flexure is more in the concrete which has more plastic aggregate content. This shows that the plastic aggregate has the tendency to absorb strain energy when it is under flexure. Poor adhesion property and weaker transition zone between the cement mortar and the plastic aggregate further leads to the failure of the specimen. At Mix2 the 7 days compression strength in elevated temperature is 16.79 N/mm^2 which was 4.8% higher than the Mix 1 and 31.74% higher than the Mix 3. This relation once again shows the synergy effect of the conventional and plastic aggregates in concrete which can leads to increase in strength at Mix2.

At elevated temperature, the failure is generally initiated with the bulging of volume and with the expansion of plastic aggregates inside the concrete specimen which tends to expand its volume when it is exposed to the 50°C but in case of natural coarse aggregate volume expansion was not observed at 50°C. It was observed that the plastic aggregates are less resistance to the thermal exposure, it is recommended to use the plastic aggregate for the external purpose. The impact energy absorbed by the plastic aggregate concrete is higher than the combined effect of the conventional and plastic aggregate. This relation once again shows that the plastic aggregate has the capability to resist sudden impact load which can be occurred in any unexpected condition. The analytical model was created and regression equations were found for all the relative properties in the Artificial Neural Network using Matlab. The predicted ANN values were closer to the experimental values with minimal error and higher accuracy. These regression equations can be used to predict the mechanical and all relative properties without experimental work. Solid polystyrene waste aggregate is still not used in practice, this investigation will provide the feasibility of using the waste as aggregate in the construction industry. Furthermore, the surface treatment of the plastic aggregates can be done to improve the bonding between the aggregates and cement matrix which can improve the bonding between the plastic aggregate and cement matrix.

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