Research on Engineering Structures & Materials
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Research Article

Mechanical properties of eco-friendly self-compacting concrete made from partially replaced single-use waste plastic and complete recycled coarse aggregate using RSM and ANN methods

Suvidha[1,a], Sumesh Jain[1,b], C. Arvind Kumar[*,2,c]

[1]*Department of Civil Engineering, Om Sterling global University, Hisar, Haryana, India*
[2]*Department of Civil Engineering, Matrusri Engineering College, Hyderabad, Telangana, India*

Article Info

Article history:

Received 07 May 2024
Accepted 21 Aug 2024

Keywords:

Recycled aggregate; Plastic waste; High-density polyethylene; Polypropylene; Response surface Method; Artificial neural network

Abstract

The paper aims to use most of the recycled material from the waste and develop a sustainable Eco-Friendly Self-Compacting Concrete (EF-SCC). Two different plastic wastes, High-Density Polyethylene (HDPE) and Polypropylene (PP), were collected from the dumping yard, thoroughly cleaned, and shredded into the desired shape and size. The plastic was substituted with fine aggregate (FA) in amounts ranging from 5% to 20%, with a 5% rise in each mix. The recycled coarse aggregate was obtained by breaking the concrete cubes, beams, and cylinders available for testing at the concrete technology lab. Totally 4 mixes were prepared for M40 grade EF-SCC to determine the mechanical property at 4 different ages (7, 14, 28 and 56 days). The compressive strength results were then predicted using statistical tools such as RSM and ANN. It is observed that both HDPE and PP have workability in the range of 650mm to 800mm, which is acceptable according to EFNARC 2002. The RSM method yielded 99.69% for PP material, while HDPE had 98.17%. The optimum compressive strength values were achieved at 7.5% of HDPE and 5% of PP material at 28 days and 60 days of curing. The training, validation, Test, and All values of R for M40 grade concrete for HDPE and PP material were 0.9955, 0.9980, 0.9244, 0.9241, and 1, 0.972, 0.802, 0.972 respectively. The flexural strength of EF-SCC showed the best results at 15% replacement. The prediction of actual compressive strength with RSM was more accurate for HDPE material compared to ANN. Recycled aggregate showed positive signs in using waste material in construction industries.

1. Introduction

India is the only country after the USA and European Union to produce the world's largest polymers, and it even creates waste plastic, according to the National Circular Economy Roadmap (NCER). India alone produces 3,500,000 metric tons of waste plastic, out of which only 30% is recycled according to The Economics Times India 2023. Therefore, waste plastic generation in India can be utilized in preparation of concrete with partial replacement of Fine Aggregate (FA) [3, 9 and 42], Coarse Aggregate (CA) [36], or Cement (C) which protect from depleting natural resources and protect the environment.

Substantial work is carried out on ordinary concrete, with the replacement of plastic waste [8], HD- PE [9], PET [10-18], E-Plastic [26], PP [19-24], and PVC [25]. The waste plastic was also used as a replacement for cementitious materials [22], as FA [10-13, 15, 17, 18], and CA [14, 21, 23] as plastic fibres in concrete [24]. Most researchers have worked on partial

*Corresponding author: arvind.cholker@matrusri.edu.in
[a] orcid.org/0009-0009-5993-9948; [b]orcid.org/0009-0009-3818-3977; [c]orcid.org/0000-0003-3980-9088
DOI: http://dx.doi.org/10.17515/resm2024.271me0507rs

replacement of FA/CA from 0% to 100%. Among the waste plastic used worldwide, PP and PET are widely recommended to be used as CA in concrete. Most of the work is carried out on the fresh properties (workability), hardened properties (mechanical properties), durability properties (Acid attack, sulphate attack, RCPT), and thermal properties (temperature variation, thermal conductivity) of concrete. The slump value (workability) of concrete was increased by being replaced partially by PP and PET as plastic waste conventional concrete [10, 14, 21]. The FA, the PET material can improve the workability property, i.e., slump cone test in concrete; this is because the plastic material has low workability and is frictionless [10-11]. It was found that waste plastic (PET), which is round and smooth in shape when replaced with FA in concrete, helps to improve the workability property of ordinary concrete [14]. The partially replacing PP with brick and stone CA, they found that the slump value (workability) of concrete was increased with the percentage increase in PP content regardless of water/cement (W/C) ratios [21].

Nevertheless, an opposite study was observed when PET was partially replaced with concrete. Its workability decreased with PET material increase [13, 15, 18 and 28]. The same material (PET) was used when its rheology was changed; the workability was reduced [13]. When PET was replaced by 20% with FA, it was observed that its workability, slump value, was reduced by 25% [15]. The slump value (workability) of concrete with PET material in concrete was decreased because of its irregular shape and size. The use of PET material to replace FA in concrete and observed the same pattern of reduction in workability because of the surface area of PET material [18 and 28]. The plastics used to replace FA or CA has a more specific gravity (SG) when compared with virgin plastic. Nevertheless, the waste plastics SG is lower than the natural fine and coarse aggregates [14 and 21]. Consequently, plastic waste has negligible weight compared to conventional material and, when replaced with concrete, can reduce the weight on soil strata [14 and 21]. The replacement of PET FA with brick aggregate and found that 10% replacement reduced concrete density by 50%. The heat treatment to PET materials, and when replaced in concrete with FA, a linear reduction in the density was observed [14 and 29]. With a maximum percentage of 15%, the dead weight was reduced by 5.6%. It was also found a linear reduction in density when replaced with PP in concrete. The optimum reduction percentage of 7.4% and 8.4% was observed with a 30% replacement of PP waste plastic with brick and stone aggregate in concrete [21]. The waste plastic material was utilized to prepare self-compacting concrete to consider was light weight concrete [40-41]

Some of the researchers on replacement of Waste Foundry Sand (WFS) with fine aggregate showed interesting facts and figures for M60 grade SCC. The replacement can be till 30% without any changes in the virgin properties of SCC. The waste generated from the foundry is considered as one of the meaningful utilization techniques. It was even observed that treated WFS can reduce the density of concrete and make SCC as lightweight, sustainable and green material [43]. The utilization of waste PET plastic as fiber with replacement of fine aggregate showed that the entire replacements (0.25, 0.5, 0.75, 1.0, and 1.25) % showed decrease in compressive strength after 28 days of curing [44]. He also observed that the correlation coefficient between the porosity and compressive strength is inversely weak relation. The use of fly-ash with PET bottles to improve the flexural and compressive strength of SCC was studied by [6, 34, 35, and 45]. The test results showed that the addition of PET fibers decreased the flowability of SCC. It was observed that fly-ash with PET fiber reduced in its compressive strength but increased the flexural property.

When replaced with FA or CA in concrete, the above waste plastic materials have many advantages and must be cross verified using statistical tools. The Response Surface Methodology (RSM) is a specific approach within the broader Design of Experiments (DOE) framework, used to model and analyze the effects of multiple factors on responses with fewer experiments. This method is usually applied in concrete technology (CT) to predict the mix proportions and the strength properties of various grades of concrete [2, 27-29]. With the increasing demand in infrastructure and construction industries and models with solid/perfect performance, ANN [32-33] and RSM increasingly handle various civil engineering projects, primarily in material science engineering. ANN has been widely used in many engineering disciplines to counter the drawbacks of empirical formulas and approaches to assess or predict the model with non-linear multivariate interrelationships between concrete's mechanical properties [30].

Table 1. M40 grade eco-friendly self-compacting (EF-SCC) concrete mix proportion

Nomenclature	W/C=0.40					
	Cement (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	100% RA (Kg)	HDPE	PP
HDPE5	273.5	776.52	60.52	776.52	3.21	-
HDPE10			54.10		6.42	-
HDPE15			44.47		9.63	-
HDPE20			31.63		12.84	-
PP5			60.52			3.21
PP10			54.10			6.42
PP15			44.47			9.63
PP20			31.63			12.84

The present study aims to evaluate the mechanical properties of EF-SCC with partial (5%, 10%, 15% and 20%) replacement of HDPE and PP material and complete replacement of recycled coarse aggregate (RCA). The compressive strength achieved experimentally is cross verified with the Statistical tools such as RSM and ANN methods. We must train a neural network with the Levenberg-Marquadt algorithm (LMA) in MATLAB for the ANN model, a fast method to assess the variables. The Mean squared error (MSE) is the mean squared difference between the outputs and responses, and the regression R-value (R) is the correlation between the output and responses, depicting that both the technique, RSM and ANN, are effective in predicting mechanical properties of concrete. Moreover, both RSM and ANN gave nearly the same values as experimental values, but the RSM model is much more accurate than ANN.

2. Materials

Ordinary Portland cement (OPC) of 43 grade affirming to IS: 8112-1989 was used. All the physical properties of cement were tested according to IS 4031-1988. Locally available river sand (Fine Aggregate -FA) passing through 4.75mm confirming to IS 2386 (part-1)-1963 with a specific gravity of 2.61, Fineness modulus as 2.45%, and dry density as 2400-2900 kg/m3. The Coarse Aggregate (CA) was collected by breaking the available failed concrete cubes, beams, and cylinders at the concrete technology lab. Table: 1 M40 grade eco-friendly self-compacting (EF-SCC) concrete mix proportion. The CA was then cleaned with water and dried in the sun for 24 hours. SG was 2.45, Fineness modulus was 8.35, and dry density was 1750 kg/m3. Waste plastic such as HDPE and PP has achieved a specific gravity of 0.38 and 0.27, nearly 8-10 times less than conventional aggregates. The polycarboxylic ether is a superplasticizer for high performance and long workability retention, eliminating vibration and freeing it from chlorides and alkalis.

3. Methodology

To evaluate the mechanical properties of EF-SC M40 grade, trial mixes were prepared, cast, and the final blend was achieved. The final mix was prepared by Water/Cement (W/C) ratio as 0.40, and the mix proportion is given in Table 1. The slump cone test was performed to check the workability of EF-SCC. The test results achieved experimentally (Mechanical property) were cross verified using statistical toll using the Response Surface Method (RSM) in Minitab and Artificial Neural Network (ANN) in MATLAB.

3.1 Mathematical Model

3.1.1 Response Surface Method (RSM)

The response Surface Method (RSM) gives the relation between the variables, and it uses different outputs to analyze the variables and then design the experiments (DoE). The DoE is used to select the other variables to evaluate and choose the most suitable data with which it can predict the response surface in an examined manner. In the same way, the RSM is used to optimize and adjust all the experimental circumstances, which can yield the best results/responses [33]. The RSM is a mathematical model/technique widely used in research and industries to optimize, refine, and grow any product/variable. It is the best technique to determine the effect of various variables with non-dependent variables and their fundamental interactions. The below Eq (1) gives y responses with £ responses for the above method (RSM).

$$y = f \neg (£1, £2, £3 \ldots £k) \ + \ £ \tag{1}$$

The parameters to input are £1, £2, £3, and £k, and the result is y. Similarly, f represents the response function with a mathematical error. Instead of employing a linear polynomial, the model validated the input variable data with a second polynomial order, as stated in Eq (2).

$$y = \beta_0 + \sum_{i=k}^{k} \beta_i \mathcal{L}_i + \sum_{i=k}^{k} \beta_{ii} \mathcal{L}_{ii}^2 + \sum_{i=1}^{k} \sum_{j=1.j\neq 1}^{k} \beta_{ij} \mathcal{L}_i \mathcal{L}_j + \in \tag{2}$$

y = response, β = coefficient, £ = factor, and ε = error. βo, βi, βii, and βij are regression coefficients for intercept, linear, quadratic, and interaction terms, respectively. £i and £j are input variables.

3.1.2 Artificial Neural Network (ANN) – MATLAB

ANN is a statistical model used to assess concrete's mechanical properties, consisting of input, hidden, and output layers. This method was a valuable tool in predicting the correct output variables. The ANN model's primary advantage is finding the exact model for nonlinear equations with different inputs. Moreover, the ANN method is widely used because it addresses discrepant and undependable data [37, 38]. In the ANN application, there are a lot of basic units to handle, which are bugged together in a complicated network. These units have many interconnections known as neurons. The interconnection between neurons is communicated with other neurons. These multiple neurons are multiplied with different weights, added together to make a single output, and then applied to the activation function using Eq (3). Table 2 lists the various % substitute levels for HDPE and PP material in the EF-SCC.

$$z = \mathrm{f}(\sum i = 0 - n \; wixi) + d \tag{3}$$

Table 2. Different levels of variables

Variables	Min (%)	Max (%)
HDPE	0	20
PP	0	20

3.1.3. Comparison Parameters

Using different statistical models like R, R^2, RMSE, MAE and MAPE, which are implemented in RSM and ANN models [39]. The error that occurs in RSM and ANN calculations will be performed by below Eqs (4)–(6).

$$RSME = \sqrt{\frac{\sum_i^n (y-x)^2}{n}} \tag{4}$$

$$MAE = \frac{1}{n}\sum_i^n [y-x] \tag{5}$$

$$MAPE = \sum_i^n [y-x]^* 100 \tag{6}$$

Here, x=accurate data, y=forecast data, and n=number of samples. The above equations are taken from [39]. R-squared (R^2, Eq. 7) measures how well an independent variable or variables in a statistical model explain for fluctuations in the dependent variable. It has a value from 0 to 1, with 1 indicating a perfect fit between the model and the data. R^2 is a statistical metric that measures how well an independent variable in a regression model explains the variation in a dependent variable. When it comes to investing, R^2 is typically defined as the percentage of a fund's or security's price swings that can be explained by changes in a benchmark index. When a security's movements (or any other dependent variable) are completely explained by changes in the index or any other relevant independent variable, the R^2 value is 100%.

$$R2 = 1 - \frac{unexplained\ Variation}{Total\ Variation} \tag{7}$$

4. Results and Discussion

The current article focuses on the use of recycled coarse aggregate and waste plastic in the construction sector to improve the mechanical characteristics of EF-SCC. The greatest amount of plastic trash should be used in the development of various infrastructure projects to reduce the increase of plastic garbage at dumping yards, therefore protecting the environment. Similarly, recycled aggregate from building and demolition debris will be considered best practice in the construction business.

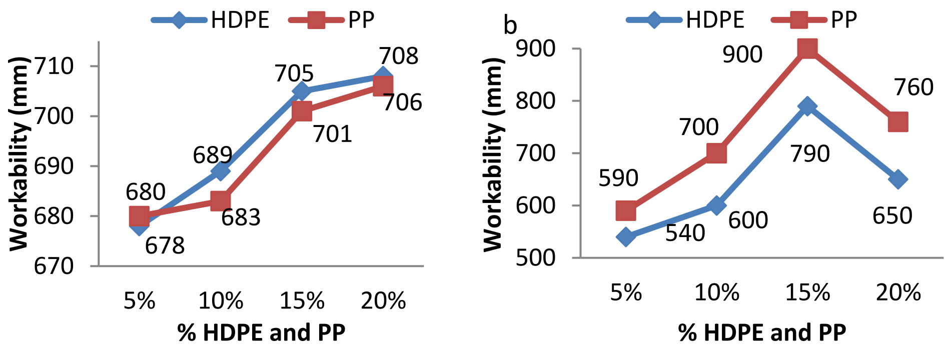
4.1 Workability

The workability test was performed on freshly mixed concrete of various compositions to know the flowability of the concrete (EFNARC) 2002). The findings show whether concrete workable is as it’s a self-compacting concrete compacted with the help of its self-weight. The below results are taken when 100% replacement of RCA was used instead of natural coarse aggregate with various percentage replacement of HDPE and PP.

4.1.1 Slump Flow Test

The 5% HDPE and PP flowability are 678mm and 680mm, respectively, which is suitable according to EFNARC 2002. It is observed from Fig. 1a that if the % of HDPE and PP material increased from 5% to 20%, its flowability also increased in the flow table test. The pattern was slightly changed when the NA was replaced entirely with RA. It was observed that till 15%, the spread of concrete was increased in both HDPE and PP material, but for 20%, there was a forceful decrease in the flow of concrete [Fig. 1b].

The optimum percentage of 15% was recommended in both natural and recycled aggregate. The slump value of concrete was reduced with the % increase of PP in concrete [16]. The same pattern was observed in natural aggregate after 15% replacement, but the trend was linearly increasing in recycled aggregate. The post-consumer plastic in concrete as a replacement with CA, and they found a zero (0) slump for concrete with plastic when compared with conventional concrete (CC) [1 and 5]. The portion of the FA with PET waste plastic, they saw that the drop in the concrete rose by 22 cm when 75% of the PET material was replaced [4 and 7].



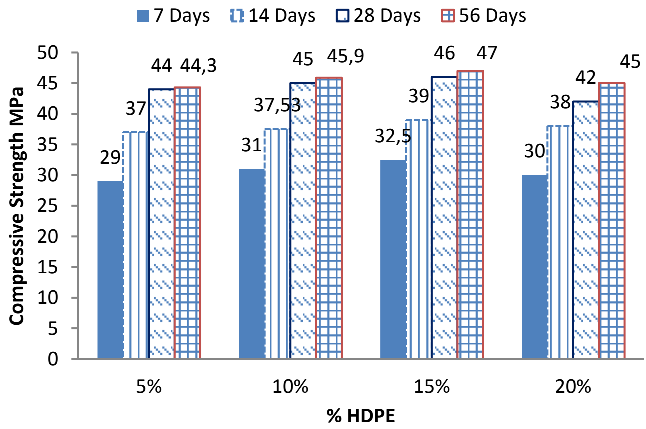
(a) (b)

Fig. 1. J-ring Test a) 100% RA b) 100% NA

When FA was substituted for PET waste aggregate in concrete, the slump value rose by 16 cm. According to the current J-ring test findings, recycled coarse aggregate performed better than NA [14]. Given that the curve from Fig. 1a depicts a linear rise in slump value, the percentage of waste plastic made of HDPE and PP may be raised beyond 20%. However, as seen in Fig. 1b, the pattern for natural coarse aggregate has reached an ideal proportion of 15% for both the materials of HDPE and PP.

4.2 Compressive Strength (CS)

The compressive strength (CS) of EF-SCC was cast with distinct percentages of HDPE, and the PP material was partially substituted with FA. All the EF-SCC specimens were tested at 4 different ages, i.e., 7, 14, 28 and 56 days. It was found that there was a linear enhance in CS for all the percentage replacements for both recycled CA and Natural CA. For 7 and 14 days, the results are satisfactory when utilizing recycled aggregate. However, as Fig. 2 illustrates, after 28 and 56 days, the strength of the PP material increased when compared with HDPE. Maximum CS for HDPE at 15% FA replacement is 32.2 MPa, while for PP material at 5% partial FA replacement after 7 days, it is 33 MPa. With a 15% substitution, the HDPE material's strength was almost identical to that of CC, but its CS was lower. The highest CS of 39 MPa and 39.58 MPa for HDPE and PP was noted when the curing period was extended to 14 days respectively. After 28 days, the recycled aggregate (RA) replaced the coarse aggregate (CA) to determine the CS. Fig. 2 shows that RA may provide strengths of 40 MPa to 45 MPa when combined with 10% HDPE and 15% PP, respectively. Compared to PP, HDPE material displayed 4.5% more, but 4% less than PP. The utmost CS of concrete is 48 MPa when PP is replaced with 15% and 46 MPa when HDPE is replaced with 15%.



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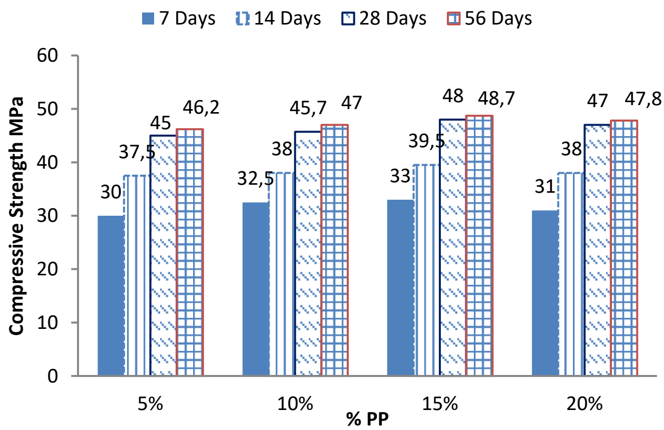


(b)

Fig. 2. Compressive strength for M40 grade SCC with complete recycled Aggregate

a) HDPE b) PP

The maximum compressive test for the M40 grade is 40.10 MPa; nevertheless, the final CS test is raised. The initial CS test is not increased by 5% in three days by replacing PP with fine aggregate. Fine aggregate is substituted for PP material in amounts of 5%, 10%, 15%, and 20%, and the CS test is conducted for three, seven, fourteen, and twenty-eight days. For three, seven, and fourteen days, 15% of the PP was substituted with fine aggregate, and the highest CS test result remained at 40 MPa. With the substitution of 20% PP with fine aggregate, the CS test is enhanced in 3 days, 7 days, 14 days, and 28 days. The maximum CS test is 47 MPa in 28 days. The results from a few researchers showed that replacing FA with plastic waste can reduce the mechanical properties of concrete. It was observed that several researchers have conducted the same experiments and stated that the axial CS decreased with the incorporation of such polymeric waste material in concrete

[11, 37, 39-45]. It is advised that in RA and NA concrete, the CS of both HDPE and PP materials increased by up to 15%, after which the strength decreased. Using RA in concrete that contains HDPE and PP is sustainable because none of the ingredients have a negative environmental impact. The use of the RA, HDPE, and PP in the IS code is encouraged to regulate the usage of Plastic Waste (PW) and Construction and Demolition (C & D) trash in landfills.

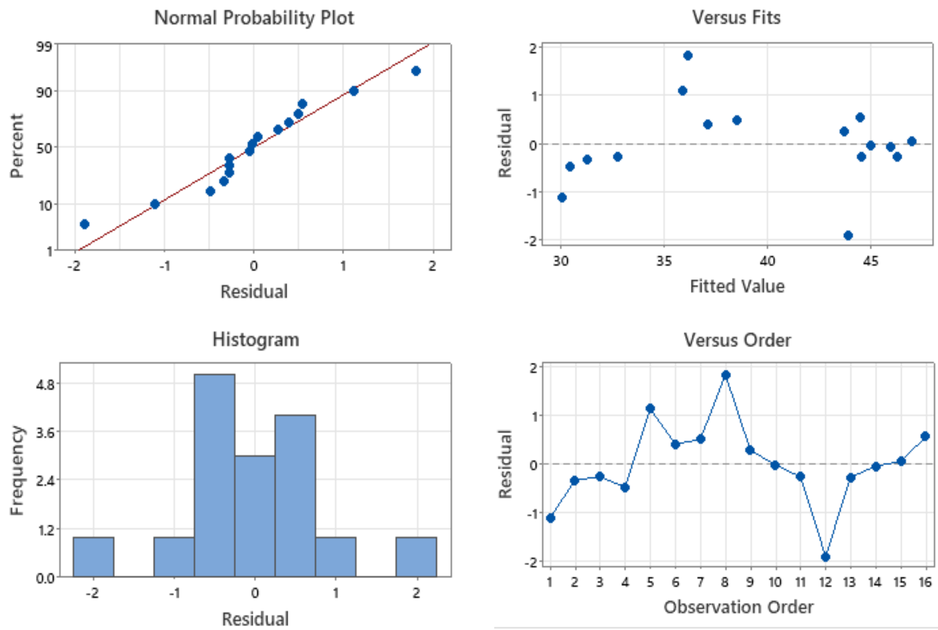
4.2.1 Response Surface Method (RSM)

The RSM method was used to analyze the influence of different variables, such as HDPE and PP material, to predict the CS of EF-SCC M40 grade concrete. The CS equation for HDPE (Ƒcs28 of HDPE) was generated and given in Eq (8) for PP material in Eq (9). The residual plots of CS for both HDPE and PP material are shown in Fig. 3.

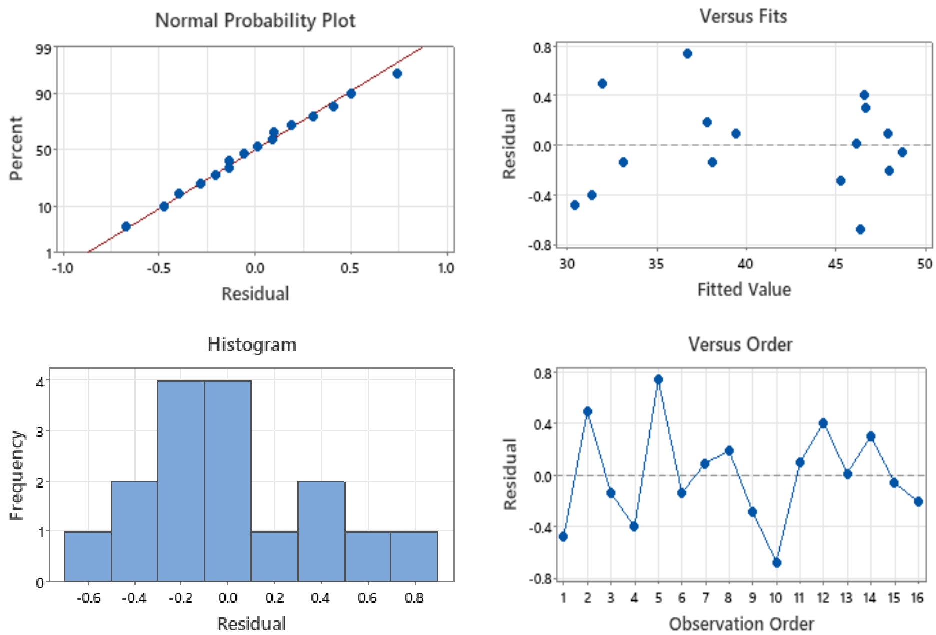
$$\mathcal{F}cs28\ of\ PP = 361 + 8.2X1 + 193X2 - 1.48X3 + 0.89X4 - 0.0137X1 * X1 + 0.30X1 * X2 - 0.0256X1 * X3 - 0.0004X1 * X4 \quad (8)$$

$$\mathcal{F}cs28\ of\ PP = 361 + 8.2\ X1 + 193.0X2 - 1.48X3 + 0.898X4 - 0.013732X1 * X1 + 0.30\ X1 * X2 - 0.0256X1 * X3 - 0.0004X1 * X4 \quad (9)$$

X1= Days; X2= Percentage of HDPE; X3=Cement; X4= Fine Aggregate



(a)



(b)

Fig. 3. Residual Plots of Compressive strength for a) HDPE and b) PP using RSM

Table 3. Summary of RSM for EF-SCC M40 grade

Material	S	R-sq	R-sq(adj)	R-sq(pred)
HDPE	1.23466	98.17%	96.08%	86.84%
PP	0.550001	99.69%	99.33%	96.54%

The Table 3 provided is a summary of the Response Surface Methodology (RSM) analysis for EF-SCC of M40 grade, considering two different materials: HDPE and PP. The standard deviation (S), R-Square (R-sq), R-Square (Adjusted) (R-sq(adj)) and R-- Square (Prepaid) (R-sq(pred)) is given in Table 3. The regression analysis using the RSM method for PP material gave 99.69%, whereas 98.17% was for HDPE materials. The deviation value for HDPE material is >1, and for PP material is <1.

4.2.2 Lack of Fit (p-value) and Pareto Analysis

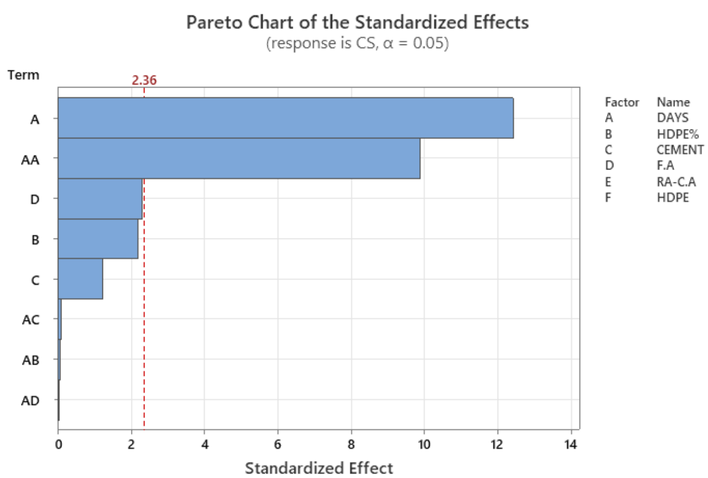
The importance of doing progression is assisted by the p-value. The values given in the F-value test should be minimum, which is the p-value of the given model. If the variable of the progression "P" lies in the range of $0.00<P<0.005$, then it is treated as considerable, and if it lies > 0.005, then it is insignificant. According to Table 4, the values of X1=0.000, X2, X3, and X4 are more significant than 0.005 for HDPE material, and the values of X1=0.000, X2= 0.004, X3, and X4 are more substantial than 0.005 for PP material which clearly indicates that the curing days plays an essential role in achieving the strength.

Table 4. Analysis of variance of RSM model for M40 grade concrete

Source	Compressive Strength					
	HDPE			PP		
	DF	F-value	p-value	DF	F-value	p-value
Model	8	47.00	0.000	8	280.67	0.000
Linear	4	46.09	0.000	4	283.16	0.000
X1	1	154.10	0.000	1	1002.55	0.000
X2	1	4.80	0.065	1	17.00	0.004
X3	1	1.53	0.257	1	7.20	0.031
X4	1	5.31	0.055	1	16.53	0.005
Square	1	97.45	0.000	1	580.94	0.000
X1* X1	1	97.45	0.000	1	580.94	0.000
2-Way Interaction	3	0.03	0.992	3	1.18	0.383
X1* X2	1	0.01	0.940	1	0.01	0.908
X1* X3	1	0.01	0.915	1	0.34	0.576
X1* X4	1	0.00	0.957	1	0.00	0.973

X1= Days; X2= Percentage of HDPE; X3=Cement; X4= Fine Aggregate

The Pareto chart from Fig. 4 indicates that the days of curing (A) the concrete is the most critical parameter, followed by the percentage of HDPE and PP percentage replacement in EF-SCC. The cement(C), which acts as a binding agent to FA and CA, has been proven to achieve the CS of concrete for both HDPE and PP materials. The Pareto chart of HDPE material for EF-SC M40 grade concrete showed that the standard effect for HDPE material is 13 and for PP material is 32. The statistical tool from Mintab (RSM) and Matlab (ANN) methods calculated the CS of EF-SC M40 grade concrete, as shown in Table 4. The below predicted RSM values gave much more accurate HDPE material values for all the percentages when compared with ANN. The values of experimented CS for 15% replacement of HDPE gave -0.82%, 1.26%, -0.58% and 0.09% for 7, 14, 28 and 56 days of curing respectively.



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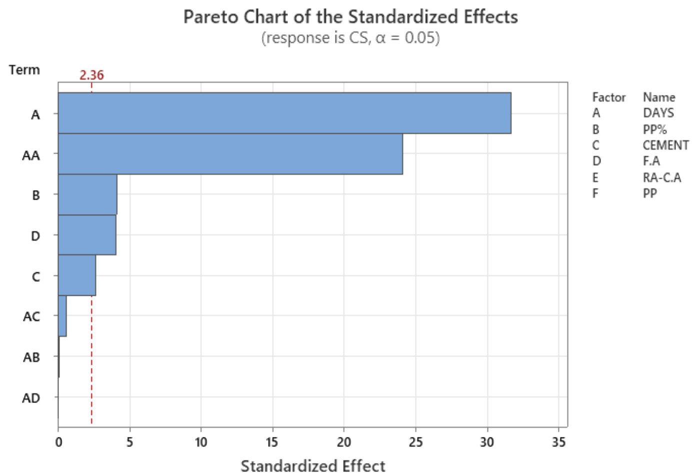


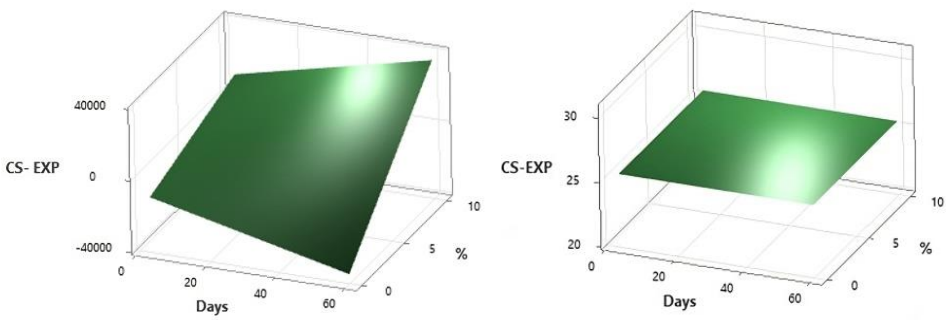
(b)

Fig. 4. Pareto Chart of a) HDPE b) PP

The only predicted value of ANN for 15% at 28 days was -0.82%, nearly tending to zero, but other values are also.The values of RSM and ANN for PP material showed nearly zero value for 11 activities out of 16 activities. When the RSM was evaluated for 7 days at 15%, the value was -0.41% when compared with conventional concrete; at 14 days for 10%, 15%, and 20%, replacement with FA gave -0.35 %, 0.24%, and 0.50%, respectively, at 28 days only 10% replacement showed -1.46% but remaining percentages of PP gave nearly zero percentage deviation. As the days of curing increased to 56 days, all the percentages of PP showed zero percentage deviation. For the ANN method, the pattern, when compared with RSM, was different; initially, for 7 days of curing, the percentage deviation was nearly zero, but as the age increased to 56 days, the percentage deviation was 4.78% when compared with conventional concrete.

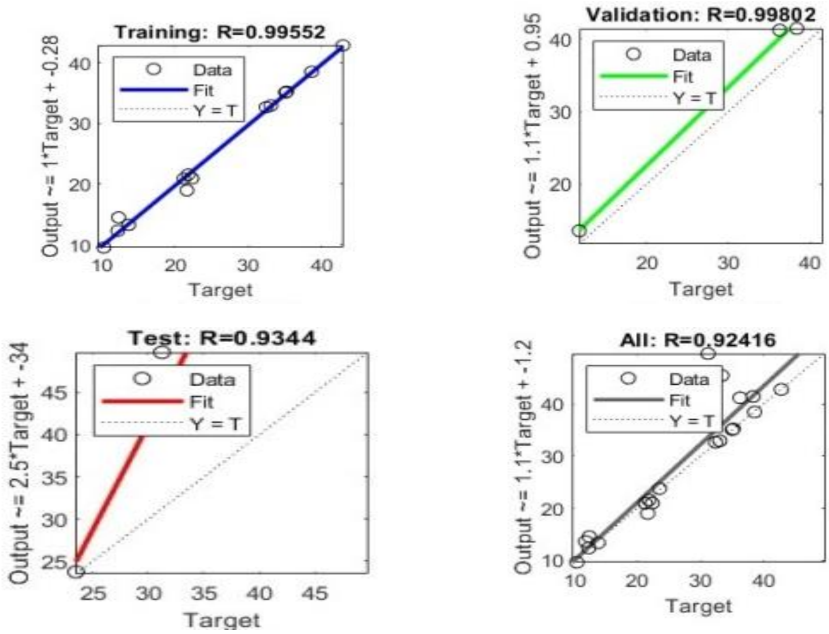
4.2.3 Surface Plot Analysis and Optimization of Progression Variables

The influence of HDPE and PP materials on the CS of M40-grade concrete is depicted in 3D surface plots in Fig. 5. It shows that the material with 7.5% HDPE and 5% PP had reached the ideal CS values after 28 days, and the same pattern was still visible after 60 days of curing.



(a) (b)

Fig. 5. 3D Surface plot of a) HDPE b) PP



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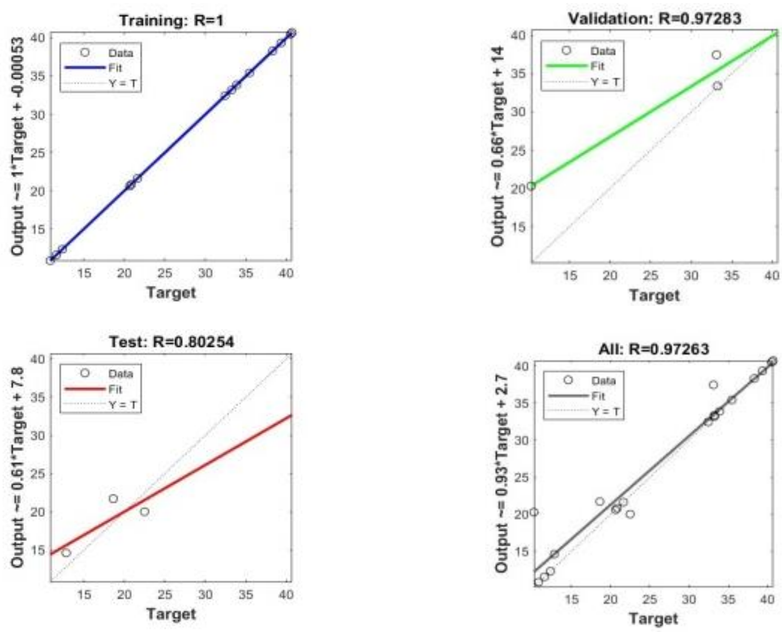


(b)

Fig. 6a. Determination of training, validation, Test, and all values of R for a) HDPE b) PP material in M40 concrete

When HDPE and PP increased from 7.5% to 5%, the CS was reduced. It was observed that PP material gave more strength than HDPE, and the same was even observed in the 3D surface plot graph. These could be the future fine aggregate materials in construction industries to reduce the usage of natural river sand. Some of the research findings of SCC materials are eggshells [23; 24-26], Flyash [27-28], GGBS [24, 29] and Pumice [30] has replaced plastic waste with cement and validated with RSM and ANN. It was discovered that poor bonds have formed in concrete, resulting in low strength and damaging the surface e texture by [31].

4.2.4 ANN Model

To predict the CS of M40-grade concrete, we must train a neural network using the Levenberg-Marquadt algorithm (LMA), which is a fast method for assessing variables. The Mean squared error (MSE) is the mean squared difference between the outputs and responses, and the regression R-value (R) is the correlation between the output and responses, depicting that both the technique, RSM and ANN, are effective in predicting mechanical properties of concrete. For every day that concrete would cure—that is, for 3, 7, 28, and 60 —the ANN technique made predictions. 30%of the model, which was trained to predict the CS of the samples, is reserved for testing and validation. The HDPE and PP waste plastic were considered as the parameters, CS is the output layer, with 2 hidden layers as 10 neurons were picked out to make the ANN model as shown in Fig. 6b. The effects of training and validation, Test, and All are presented in Fig. 6a. The training, validation, Test, and All values of R for M40 grade concrete for HDPE and PP material are 0.9955, 0.9980, 0.9244, 0.9241 and 1, 0.972, 0.802, 0.972 respectively, where R represents linear correlation coefficient. The above results of the R-value show that the trained ANN model is in good relationship with the experimental values.

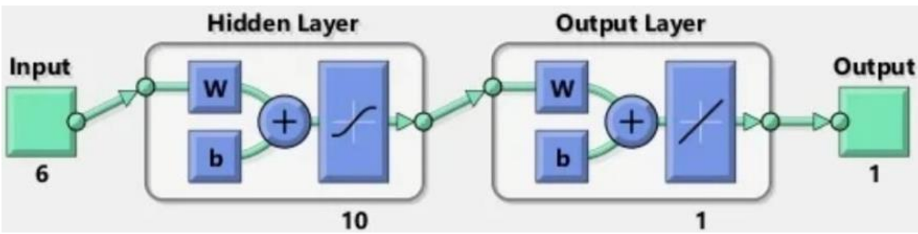


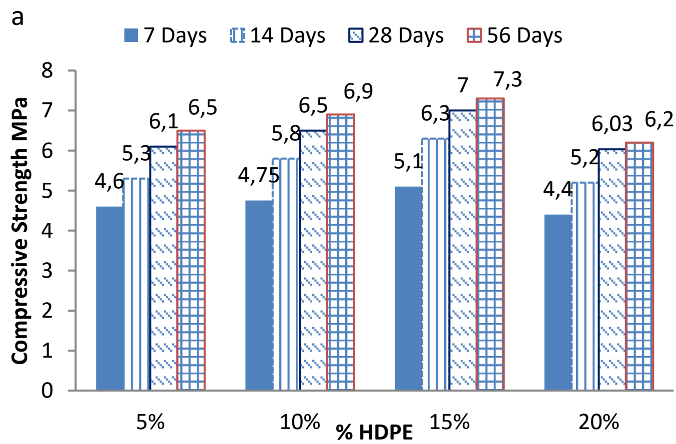
Fig. 6b. The schematic layout of ANN model developed in Matlab

By utilizing Matlab to compare the actual experimental data with the anticipated data, the competence results obtained from the ANN model were ascertained by coefficient determination. A well-fitting model could be shown in the expected CS values of M40-grade concrete containing HDPE and PP. An R-value greater than 0.9 demonstrated a positive connection between the projected and actual CS values. Furthermore, when trained with an ANN model, the tested CS value produced projected results that were quite close to the measured values. The actual, ANN, and RSM projected strengths are shown in Table 5. The present research has several practical applications in civil and infrastructure engineering. To design the mix proportion and any model, such preliminary designs are required to make a product performance based on the optimum percentage replacement of any such materials with cement or FA [32]. To protect the environment from CO_2 emission while cement manufacturing can be reduced by partially replacing waste plastic by regulating the minimum mechanical performance of SCC. For such a study, statistical tools to predict the mechanical properties are helpful and much required. Such tools are useful in civil engineering projects to regulate psychoanalysis's budget and financial feasibility. There are many statistical tools to predict the CS of concrete, but the ANN model is much faster, and it is less expensive when compared with the theoretical experimentation [33]

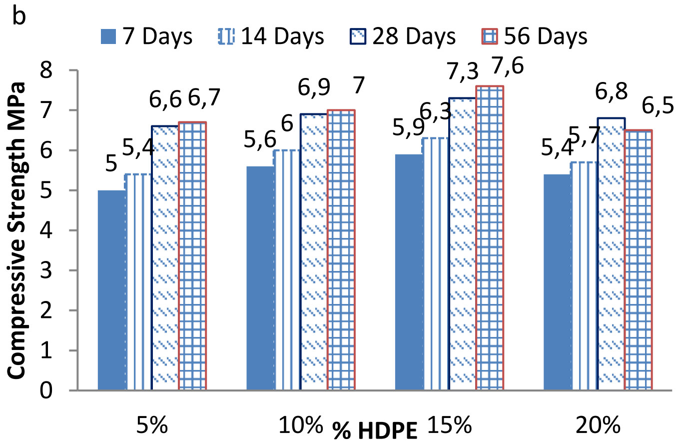
4.3 Flexural Strength

Following IS 516-1959, the flexural strength of EF-SCC concrete was tested. Fig. 7 shows the 100x100x500mm beams tested on several days and with varying amounts of HDPE and PP. At 15% replacement of HDPE in concrete, the maximum flexural strength of 5.1 MPa was recorded, which is 0.8 MPa stronger than PP after 7 days. The flexural strength of the remaining HDPE replacement 5%, 10%, and 20% was inferior to that of PP. In concrete, the HDPE material demonstrated 4.6 MPa and 4.75 MPa at 5% and 10% replacement, or 0.15 MPa and 0.18 MPa after seven days. A few researchers used plastic aggregates to perform and publish their findings on Flexural strength [34–38]. The flexural strength increased when PET waste plastic was included at low partial replacement levels; the pattern changed when PET material was added in high doses [34]. As seen in Fig. 7, the flexural strength was almost identical after 28 and 56 days. It has been shown that the flexural strength of PP material rose by 1.4 MPa and 1.7 MPa for 28 and 56 days, respectively, as the curing period increased. The flexural strength of concrete was lowered by 0.5 MPa when 20% of PP material was added, but it increased to 1.4 MPa when 15% of PP material was substituted in the concrete. Fig. 7 illustrates how the RA concrete graph steadily climbed as the number of days it took to cure, in contrast to the inconsistent NA concrete graph.

The flexural strength test increases the % of HDPE and the number of days. For the 7 days, the flexural strength test is increased by replacing 20% HDPE. For the 28 days replaced HDPE with 20%, the maximum flexural strength test is 6.50 MPa. The flexural strength of concrete with PP is partially replacement with fine aggregate. In replacement of 20% PP, the flexural strength is increased by 0.10 MPa in 3 days, and for 7 days, with replacement of 20%, the flexural strength is decreased by 0.90 MPa. It was observed in Fig. 7 the flexural strength test is increased by 20%, and replacement for 28 days is increased, compared to 10%, and PP is increased by 0.20 MPa. It is observed from Fig. 7 that 100% of the RA used to prepare concrete with 15% HDPE and 15% PP material for flexural strength achieved more strength than the NA concrete mix. According to [35] showed the same pattern as in our study, but the concrete has improved by 10% replacement with plastic waste.



(a)



(b)

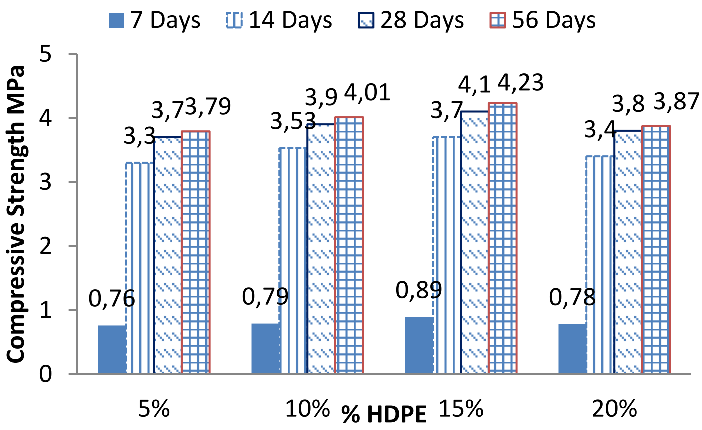
Fig. 7. Flexural strength of M40 grade concrete with a) HDPE and b) PP material

According to the [39] experiment, the high PP material dosage showed a drastic reduction in flexural strength. A similar study conducted by [36] partially replaced with e-plastic showed that the flexural strength was below the value of conventional concrete. When 20% of plastic waste was replaced with FA, the maximum reduction was achieved after 28 days of curing. According to [40] has concluded that the waste plastic showed an increase in flexural strength of SCC up to 1.75% replacement by volume.

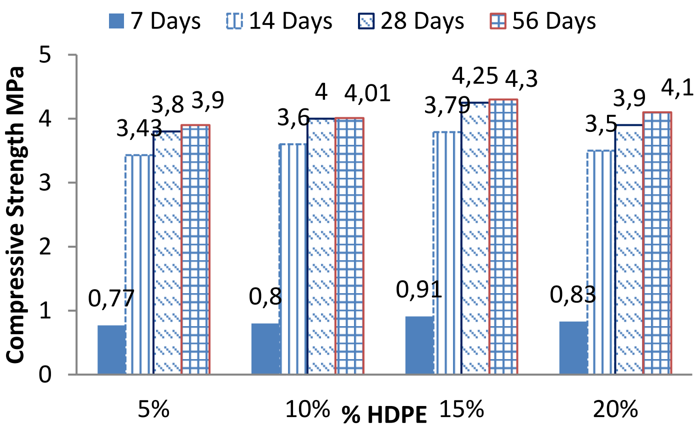
4.4 Split Tensile Strength

Fig. 8 displays the split tensile strength pattern for 7, 14, 28, and 56 days [34, 36, 41]. According to a related study, the split tensile strength may increase up to a specific optimal proportion of plastic waste, but the strength sharply decreases [34, 36]. At 15% replacement of HDPE in concrete, the maximum flexural strength of 0.91 MPa was recorded, 0.02 MPa less than PP after 7 days. The flexural strength of the remaining HDPE replacement 5%, 10%, and 20% was inferior to that of PP. In concrete, the HDPE material demonstrated 0.76 MPa and 0.79 MPa at 5% and 10% replacement, or 0.25 MPa and 0.22 MPa after 7 days. As seen in Fig. 8, the tensile strength for 28 and 56 days was almost identical. The maximum strength for 15% PP material is 3.35 MPa for 28 days and 3.4 MPa for 56 days, respectively. The tensile strength of concrete was lowered by 0.35 MPa when 20% of PP material was added, but it increased to 0.35 MPa when 15% of PP material was substituted in the concrete. According to [9], PET material's substantial tensile properties can improve the tensile property by up to 10% in replacement of waste plastic compared to other concrete materials.

Compared to 100% RA, the 100% NA concrete has good results even with fewer days of curing. It is observed that the maximum strength for 15% HDPE and PP material is 4.23MPa and 4.3MPa for 28 days, respectively, more than RA concrete at 28 days. It is observed from Fig. 8 that 100% of the RA used to prepare concrete with 15% HDPE and 15% PP material for tensile strength achieved more strength than other mixes. According to [36], after 28 days of curing for 20% partial replacement of waste plastic has received maximum tensile strength. When the partial replacement was increased to 30%, it showed a drastic reduction. According to [42], the strength was reduced by 1.5% and 11% for 10% and 20% partial replacement of high-impact polystyrene (HIPS).



(a)



(b)

Fig. 8. Split tensile strength test a) HDPE and b) PP

4.5 Prediction of RSM and ANN with actual Experimental for Compressive Strength

The experimentally tested values of EF-SCC cubes for CS, when predicted with RSM and ANN methods, are given in Table 5. When expected with ANN and RSM, the CS experimental (CS-EXP) for HDPE showed that the RSM method gave much more accurate results than ANN. The maximum percentage variation in prediction for RSM was positive 4.7% at 20% for 14 days of curing; similarly, the negative maximum percentage variation was 4.49 for 20% replacement but at 28 days. When ANN was analyzed, it showed a maximum percentage variation of -23.65% at 20% of HDPE at 7 days, similarly +14.64% for 5% replacement at 28 days of curing.

Table 5. Actual and predicted compressive strength of M40 grade SCC using RSM and ANN method

Days (X1)	% (X2)	F.A. (X4)	HDPE/PP (Kg/m³)	CS- EXP (HDPE)	ANN	RSM	CS-Exp (PP)	ANN	RSM
7	5%	60.52	3.21	29	28.16	30.10	30	29.92	30.47
7	10%	54.1	6.42	31	30.27	31.33	32.5	32.12	31.99
7	15%	44.47	9.63	32.5	31.38	32.76	33	32.98	33.13
7	20%	31.63	12.84	30	37.09	30.47	31	31.28	31.39
14	5%	60.52	3.21	37	30.24	35.88	37.5	34.20	36.75
14	10%	54.1	6.42	37.53	33.72	37.13	38	37.77	38.13
14	15%	44.47	9.63	39	38.09	38.50	39.5	39.42	39.40
14	20%	31.63	12.84	38	39.8	36.18	38	37.18	37.80
28	5%	60.52	3.21	44	37.55	43.73	45	44.55	45.28
28	10%	54.1	6.42	45	43.73	45.01	45.7	45.63	46.37
28	15%	44.47	9.63	46	46.38	46.27	48	48.02	47.90
28	20%	31.63	12.84	42	44.76	43.88	47	46.83	46.58
56	5%	60.52	3.21	44.3	44.77	44.57	46.2	46.12	46.18
56	10%	54.1	6.42	45.9	44.65	45.94	47	44.75	46.69
56	15%	44.47	9.63	47	49.38	46.95	48.7	48.87	48.75
56	20%	31.63	12.84	45	48.01	44.44	47.8	48.82	48.00

CS-EXP (HDPE) = Compressive strength –Experimented for HDPE material; CS-EXP (PP)= Compressive strength –Experimented for PP material; RSM= Response Surface Method; ANN= Artificial Neural Network.

The RSM and ANN method was even predicted for PP material with different percentages at different days of curing. Both methods showed the same results as those that were tested. After 28 days of curing, the maximum CS of 48MPa was achieved with 15% replacement, and when it was predicted with RSM, it showed 0.199% variation, and ANN showed - 0.05% variation, a negligible percentage error. The CS achieved suitable mechanical properties even after being partially replaced by 15% with FA in EF-SCC. The recycled aggregate also showed a positive sign in using such waste material in construction industries.

5. Conclusion

The present study ascertains the optimum percentage of HDPE and PP material in workability and mechanical properties of EF-SCC, which was experimentally and statistically evaluated.

- In the slump flow table test, it was found that waste plastic made of HDPE and PP with 20% replacement exhibited 708 mm and 702 mm, respectively. These results fall inside the permitted ranges specified by EFNARC (2002), which is 650 mm to 800 mm.
- The highest compressive strengths of 47 MPa and 48.7 MPa were attained by replacing 15% of the HDPE and PP in the EF-SCC.
- It is recommended that in RA and NA concrete, the compressive strength of both HDPE and PP materials should grow to 15% in replacement, after which the strength should decline.

- For PP materials, the RSM technique regression analysis yielded a result of 99.69%, whereas for HDPE materials, the result was 98.17%.
- With a few exceptions, the P-value from the Pareto analysis revealed values between 0 and 0.005.
- It is evident from Fig. 5 that the material at 7.5% HDPE and 5% PP reached the ideal compressive strength values after 28 days. Surface plot analysis revealed the similar pattern during 60 days of curing.
- For M40 grade concrete for HDPE and PP material, the training, validation, test, and all values of R are, respectively, 0.9955, 0.9980, 0.9244, 0.9241, and 1, 0.972, 0.802, 0.972. R stands for linear correlation coefficient.
- For both materials, the EF-SCC's flexural strength demonstrated the greatest results at 15% replacement.
- In the split tensile test, the NA performed better than the RA. In the split tensile test, a similar pattern to that of flexural strength was noted, with the greatest results for both materials coming at 15% replacement.
- The prediction values of the RSM and ANN techniques for PP material were considerably more accurate; 11 out of 16 values indicated the same projected value. • The prediction of real compressive strength using RSM offered correct results for HDPE material compared with ANN.
- The utilization of such waste material in the building industry appeared to be beneficial for recycled aggregate as well.

6. Further Studies

It is recommended that microstructural properties be conducted in different thermal properties and that different waste plastics are used in various types and other grades of concrete.

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