Research Article

Response Surfaces for Fresh and Hardened Properties of Concrete with E-Waste (HIPS)

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The fresh and hardened properties of concrete with E-waste plastic, that is, high impact polystyrene (HIPS), as a partial replacement for coarse aggregate were analyzed using response surface methodology (RSM). Face-centred central composite response surface design was used in this study. The statistical models were developed between the factors (HIPS and water cement ratio) and their response variables (slump, fresh density, dry density, compressive strength, split tensile strength, and flexural strength). The Design-Expert 9.0.3 software package was used to analyze the experimental values. The relationships were established and final mathematical models in terms of coded factors from predicted responses were developed. The effects of factors on properties for all variables were seen visually from the response surface and contour plot. Validation of experiments has shown that the experimental value closely agreed with the predicted value, which validates the calculated response surface models with desirability =1. The HIPS replacement influenced all the properties of concrete than water cement ratio. Even though all properties show the decline trend, the experimented values and predicted values give a hope that the E-waste plastic (HIPS) can be used as coarse aggregate up to certain percentage of replacement in concrete which successively reduces the hazardous solid waste problem and conserves the natural resources from exhaustion.

1. Introduction

Generation of solid waste and its safe disposal have become a challenging task for developing and developed countries. Among the solid waste, electronic waste (E-waste) shows an alarming growth. For the past few decades, the developed and developing countries totally ignored this waste. The major reasons are complexity of waste, lack of recycling infrastructure, recycling in informal sector, lack of awareness among people, and so forth. Now, the E-waste generation receives the attention of the developed countries but their way of recycling the E-waste is different; that is, they have started exporting this harm to developing countries as shown in Figure 1 [1, 2]. E-waste comprises many toxic substances like mercury, lead, cadmium, brominated flame-retardants, beryllium, polyvinyl chloride, printed circuit boards, plastic casings, cathode ray tubes, batteries, and cable sheathing, and so forth, which are harmful to human health and environment if not handled

properly [3–5]. In developing countries, after recovering the precious metals and useful materials from the E-waste in informal manner, the waste is being disposed in land, water body, or in open incineration. Most of the developing nations have framed the laws to restrict the import of E-waste and recycling in informal manner but the rules are in print without spirit.

E-waste disposals impact human health in two ways which include (a) food chain issues: contamination by toxic substances from disposal and primitive recycling processes that result in byproducts entering the food chain and thus transferring to humans and (b) direct impact on workers who labour in primitive recycling areas from their occupational exposure to toxic substances [6, 7]. A joint study on electronic waste generation was carried out by the Manufacturer's Association of Information Technology (MAIT) of India and Gesellschaft für Technische Zusammenarbeit (GTZ) of Germany in India during 2007. The estimated generation of

FIGURE 1: Asian E-waste traffic [1, 2].

electronic waste was approximately 400,000 tonnes of waste annually (from computers, mobile phones, and television sets only), which is expected to grow at a rate of 10–15% per year. The study also reveals that only about 19,000 tons of E-waste is recycled and large amounts of E-waste are refurbished and sold in the secondary market [8, 9].

Throughout the world, there has been a rapid increase in the utilization of concrete today, which results in increased consumption of natural aggregate. The developing countries are consuming more concrete to develop their infrastructure; this leads to the depletion of natural aggregates sources. In order to conserve the natural aggregate resources and to avoid environmental pollution, researchers have considered the different types of waste materials generated from different sources [10, 11] and adopted them to fine aggregate and coarse aggregate such as recycled aggregate [11–13], post-consumer plastics [14–16], and scrap tyres [17, 18]. Recently, researchers have started to minimize the E-waste impact on the environment by preserving the natural aggregate resource and by utilizing the E-waste as construction material as an alternative to natural aggregate.

In E-waste, researchers focused only on the usage of plastic and glass waste from electrical and electronic equipment to use as an aggregate in cement and concrete composites [9, 19–30].

2. Materials and Methods

In this experimental investigation, the recycled computer plastic waste from E-waste has been used as a partial substitute for coarse aggregate in concrete; that is, high impact polystyrene (HIPS) plastic from computers and its accessories are used in the concrete as a partial substitute for coarse aggregate in various volume percentages such as 10%, 20%, 30%, 40%, and 50%. Ordinary Portland cement (OPC 53 Grade) with specific gravity of 3.13 was used in all concrete mixtures meeting the specifications of IS 12269-1987 [31]. The broken granite with a maximum size of 12.5 mm, specific gravity of 2.79, and density of 1624.22 kg/m³ has been taken as a coarse aggregate. River sand with a maximum size of 4.75 mm, specific gravity of 2.65, and density of 1656.09 kg/m³ has been taken as fine aggregate. HIPS aggregate with a size varying from 6 to 12 mm, specific gravity of 1.29, and density of 595.30 kg/m³ has been used to meet the specifications of IS 2386-1963 (Parts I–IV) [32]. The HIPS aggregate has flaky shape, smooth texture, and uniform black colour as shown in Figure 2. The concrete mix of three different grades of concrete (M20, M25, and M30) with three different water cement ratios (0.45, 0.49, and 0.53) was designed on the basis of IS 10262-2009 as shown in Table 1 [33]. Potable water available in college campus was used in all

TABLE 1: Concrete mix proportions (IS 10262:2009).

Concrete grade	W/C ratio	HIPS content (%)*	Mix proportions (kg/m ³)			HIPS aggregate
			Cement	Fine aggregate	Coarse aggregate	
M20	0.53	Control batch			1147.81	0.00
		10			1033.02	53.07
		20	340.00	799.23	919.04	106.14
		30			803.66	159.12
		40			688.28	212.46
		50			572.91	264.89
M25	0.49	Control batch			1133.32	0.00
		10			1019.98	52.40
		20	367.34	789.14	907.44	104.80
		30			793.52	157.11
		40			679.59	209.78
		50			565.67	261.55
M30	0.45	Control batch			1117.22	0.00
		10			1005.49	51.65
		20	400.00	777.93	894.55	103.31
		30			782.24	154.87
		40			669.94	206.80
		50			557.64	257.83

* Percentage replacement by volume.

FIGURE 2: E-waste plastic (HIPS as aggregate).

concrete mixes on the basis of IS 456-2000 [34]. The fresh and hardened properties of concrete tests were performed in accordance with the IS 516-1959 [35] and IS 1199-1959 [36].

3. Experimental Design

According to Montgomery, response surface methodology (RSM) is a collection of mathematical and statistical techniques used for modeling and analyzing of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [37]. In this study, the fresh and hardened properties of concrete were analyzed and relationships were developed based on RSM. The response surface design used in this study is face-centred central composite response surface design. A face-centred central composite response surface design with $\alpha = 1$ and full quadratic model for each response was used. The statistical

TABLE 2: Factors and factor levels adopted for RSM.

Factor	Code	Factor levels of code		
		Low level	Intermediate level	High level
		-1	0	1
HIPS (Vol %)	A	10	30	50
W/C ratio	B	0.45	0.49	0.53

software “Design-Expert version 9.0.3,” Stat-Ease, Inc., is used to analyze the experimental design. The volume percentage of HIPS (Vol%) is coded as A and water cement ratio (W/C ratio) is coded as B; both were selected as the factors and studied at different 3 levels. The factors and factor levels are shown in Table 2.

Table 3 presents the experimental runs, their factor combinations, the translation of the coded levels to the actual experimental units, and space types used in this study. Fresh properties such as slump, fresh density, and hardened properties such as dry density at 28 days and compressive strength, split tensile strength, and flexural strength at 7 and 28 days were taken as the response variables. Equation (1) shows the full quadratic model in terms of coded factors:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_{12} AB + \beta_{11} A^2 + \beta_{22} B^2, \quad (1)$$

where Y is predicted response; β_0 is intercept; β_1, β_2 are linear effect coefficients; β_{11}, β_{22} are quadratic effect coefficients; β_{12} is interaction effect coefficient.

4. Results and Discussion

Using Design-Expert software version 9.0.3, the experimentally obtained fresh and hardened properties of concrete

TABLE 3: Factor combinations as per the face-centred central composite response surface design.

Run	Coded factor levels		Actual factors		Space type
	A	B	HIPS (Vol %)	W/C ratio	
1	−1	−1	10	0.45	Factorial
2	−1	0	10	0.49	Axial
3	−1	1	10	0.53	Factorial
4	0	−1	30	0.45	Axial
5	0	0	30	0.49	Center
6	0	1	30	0.53	Axial
7	1	−1	50	0.45	Factorial
8	1	0	50	0.49	Axial
9	1	1	50	0.53	Factorial
10	0	0	30	0.49	Center
11	0	0	30	0.49	Center
12	0	0	30	0.49	Center
13	0	0	30	0.49	Center

TABLE 4: Actual and predicted values of slump (mm), fresh density (kg/m³), and dry density (kg/m³).

Run	A	B	Slump (mm)		Fresh density (kg/m ³)		Dry density (kg/m ³)	
	HIPS (Vol %)	W/C ratio	Actual value	Predicted value	Actual value	Predicted value	Actual value	Predicted value
1	−1	−1	24.00	23.07	2629.14	2638.64	2489.98	2484.52
2	−1	0	24.33	25.53	2598.52	2604.30	2467.85	2472.64
3	−1	1	25.67	25.40	2571.85	2556.58	2461.63	2462.30
4	0	−1	11.00	12.64	2495.80	2468.72	2278.02	2277.64
5	0	0	15.00	14.61	2428.15	2429.07	2232.10	2234.70
6	0	1	13.67	13.98	2353.58	2376.05	2205.93	2193.30
7	1	−1	10.33	9.62	2287.41	2304.99	2160.49	2166.33
8	1	0	10.33	11.08	2270.42	2260.03	2110.12	2092.32
9	1	1	10.00	9.96	2208.89	2201.70	2007.90	2019.86
10	0	0	15.00	14.61	2428.15	2429.07	2232.10	2234.70
11	0	0	15.00	14.61	2428.15	2429.07	2232.10	2234.70
12	0	0	15.00	14.61	2428.15	2429.07	2232.10	2234.70
13	0	0	15.00	14.61	2428.15	2429.07	2231.10	2234.70

with HIPS were analyzed and the design matrix of the variables in the coded units are shown in Tables 4–6 along with the actual values (experimental values) and predicted values of responses. The predicted values of responses were obtained using the Design-Expert software; for each factor, full quadratic model (second order polynomial) was employed and the coefficients of the parameters are given by the regression equation.

The regression equation gave the predicted values and the final mathematical models in terms of coded factors were arrived. Analyses of variance (ANOVA) of the predicted response surface models for all variables are presented in Tables 7–15. In this study, the P value approach is employed for hypothesis testing; that is, “Prob > F ” less than 0.05 indicates that model terms are statistically significant.

4.1. Response Surface for Fresh Properties. The experimental values show that the slump and fresh density of concrete

decrease with the increase of HIPS. The experimental values were used to study the effect of W/C ratio and HIPS (Vol%) in fresh concrete properties using RSM. Table 4 presents the actual and predicted values of slump (mm) and fresh density (kg/m³) of fresh concrete with HIPS. Tables 7 and 8 present the results of the ANOVA for slump and fresh density response surface quadratic model obtained.

Table 7 shows that the HIPS% effect ($P < 0.0001$) and the quadratic HIPS% effect ($P = 0.0005$) were statistically significant at the stipulated level of 5%. The W/C ratio effect ($P = 0.1463$), quadratic W/C ratio effect, and the effect of interaction of HIPS% and W/C ratio ($P = 0.3514$) were statistically not significant at the stipulated level of 5%. Equation (2) gives the final mathematical models in terms of coded factors:

$$\begin{aligned} \text{Slump (mm)} \\ = 14.61 - 7.22A + 0.67B - 0.5AB + 3.70A^2 - 1.3B^2. \end{aligned} \quad (2)$$

TABLE 5: Actual and predicted values of compressive strength (MPa), split tensile strength (MPa), and flexural strength (MPa) at 7 days.

Run	A HIPS (Vol %)	B W/C ratio	Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
			Actual value	Predicted value	Actual value	Predicted value	Actual value	Predicted value
1	-1	-1	25.00	25.21	2.37	2.35	6.07	6.12
2	-1	0	22.91	23.11	2.18	2.19	5.33	5.27
3	-1	1	19.14	18.73	1.96	1.97	4.47	4.48
4	0	-1	23.61	22.92	2.02	2.06	5.33	5.27
5	0	0	20.94	20.97	1.91	1.91	4.53	4.54
6	0	1	16.19	16.75	1.71	1.69	3.87	3.87
7	1	-1	16.09	16.57	1.65	1.63	4.20	4.21
8	1	0	15.11	14.78	1.49	1.49	3.60	3.60
9	1	1	10.86	10.71	1.27	1.28	3.07	3.05
10	0	0	20.94	20.97	1.91	1.91	4.53	4.54
11	0	0	20.94	20.97	1.91	1.91	4.53	4.54
12	0	0	20.94	20.97	1.91	1.91	4.53	4.54
13	0	0	20.94	20.97	1.91	1.91	4.53	4.54

TABLE 6: Actual and predicted values of compressive strength (MPa), split tensile strength (MPa), and flexural strength (MPa) at 28 days.

Run	A HIPS (Vol %)	B W/C ratio	Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
			Actual value	Predicted value	Actual value	Predicted value	Actual value	Predicted value
1	-1	-1	43.54	45.15	3.07	3.08	6.87	6.89
2	-1	0	37.07	35.95	2.90	2.91	6.33	6.32
3	-1	1	26.05	25.55	2.78	2.76	5.47	5.46
4	0	-1	39.60	36.16	2.47	2.49	5.67	5.65
5	0	0	27.76	28.29	2.31	2.29	5.20	5.19
6	0	1	18.46	19.23	2.05	2.12	4.40	4.45
7	1	-1	24.32	26.15	1.92	1.89	4.87	4.86
8	1	0	21.18	19.62	1.59	1.67	4.47	4.52
9	1	1	12.17	11.89	1.53	1.48	3.93	3.89
10	0	0	27.76	28.29	2.31	2.29	5.20	5.19
11	0	0	27.76	28.29	2.31	2.29	5.20	5.19
12	0	0	27.76	28.29	2.31	2.29	5.20	5.19
13	0	0	27.76	28.29	2.31	2.29	5.20	5.19

TABLE 7: Analysis of variance for slump (mm) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	354.56	5	70.91	70.65	<0.0001
A-HIPS (Vol %)	313.06	1	313.06	311.91	<0.0001
B-W/C ratio	2.68	1	2.68	2.67	0.1463
AB	1.00	1	1.00	1.00	0.3514
A ²	37.78	1	37.78	37.64	0.0005
B ²	4.64	1	4.64	4.62	0.0686
Residual	7.03	7	1.00		
Lack of fit	7.03	3	2.34		
Pure error	0.00	4	0.00		
Total	361.59	12			

TABLE 8: Analysis of variance for fresh density (kg/m^3) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	190900.00	5	38179.30	129.25	<0.0001
A-HIPS (Vol %)	177800.00	1	177800	601.85	<0.0001
B- W/C ratio	12883.45	1	12883.45	43.62	0.0003
AB	112.68	1	112.68	0.38	0.5564
A ²	26.40	1	26.40	0.089	0.7737
B ²	123.55	1	123.55	0.42	0.5384
Residual	2067.69	7	295.38		
Lack of fit	2067.69	3	689.23		
Pure error	0.000	4	0.000		
Total	193000	12

FIGURE 3: Contour plot and response surface of a slump.

The effect of each variable on this property can be seen as contour plot and response, as shown in Figure 3.

Table 8 shows the analysis of variance for fresh density (kg/m^3) response surface quadratic model. In that, the HIPS% effect ($P < 0.0001$) and the W/C ratio effect ($P = 0.0003$) were statistically significant at the stipulated level of 5%. The quadratic W/C ratio ($P = 0.5384$) and HIPS% effect ($P = 0.7737$) as well as the effect of interaction of HIPS% and W/C ratio ($P = 0.5564$) was statistically not significant at the stipulated level of 5%. Equation (3) is the final fitting equation in terms of coded factors:

$$\begin{aligned} \text{Fresh density } (\text{kg/m}^3) \\ = 2429.07 - 172.13A - 46.34B - 5.31AB \\ + 3.09A^2 - 6.69B^2. \end{aligned} \quad (3)$$

The fresh density decreases with the W/C ratio and decreases when the HIPS content increases.

The effect of each variable on this property is plotted as response and contour plot, as shown in Figure 4.

4.2. *Response Surface for Hardened Properties.* Table 4 presents actual and predicted values of dry density (kg/m^3) and Table 9 presents the results of the ANOVA for the dry density (kg/m^3). Table 8 shows that the HIPS% effect ($P < 0.0001$), the quadratic HIPS% effect ($P = 0.0001$), the W/C ratio effect ($P < 0.0001$), and the effect of interaction of HIPS% and W/C ratio ($P = 0.0005$) were statistically significant at the stipulated level of 5%. The quadratic W/C ratio effect ($P = 0.9045$) was not reached the statistically significant at the stipulated level of 5%. Equation (4) is the final mathematical equation in terms of coded factors:

$$\begin{aligned} \text{Dry density } (\text{kg/m}^3) \\ = 2234.70 - 190.16A - 42.17B - 31.06AB \\ + 47.78A^2 + 0.77B^2. \end{aligned} \quad (4)$$

The effect of each variable on this property was plotted as response and contour plot, as shown in Figure 5. It can be seen from Figure 5 that the dry density decreases with the increase of HIPS, since the density of HIPS is less when compared to

FIGURE 4: Contour plot and response surface of a fresh density.

FIGURE 5: Contour plot and response surface of a dry density.

TABLE 9: Analysis of variance for dry density (kg/m³) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	239000	5	47791.78	451.76	<0.0001
A-HIPS (Vol %)	217000	1	217000	2050.85	<0.0001
B- W/C ratio	10670.70	1	10670.70	100.87	<0.0001
AB	3858.89	1	3858.89	36.48	0.0005
A ²	6305.28	1	6305.28	59.60	0.0001
B ²	1.64	1	1.64	0.015	0.9045
Residual	740.54	7	105.79		
Lack of fit	740.54	3	246.85		
Pure error	0.000	4	0.000		
Total	239700	12			

TABLE 10: Analysis of variance for 7-day compressive strength (MPa) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	<i>F</i> value	<i>P</i> value
Model	184.36	5	36.87	183.13	<0.0001
A-HIPS (Vol %)	104.08	1	104.08	516.93	<0.0001
B-W/C ratio	57.10	1	57.10	283.60	<0.0001
AB	0.099	1	0.099	0.49	0.5053
A ²	11.33	1	11.33	56.27	0.0001
B ²	3.56	1	3.56	17.68	0.0040
Residual	1.41	7	0.20		
Lack of fit	1.41	3	0.47		
Pure error	0.000	4	0.000		
Total	185.77	12			

TABLE 11: Analysis of variance for 28-day compressive strength (MPa) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	<i>F</i> value	<i>P</i> value
Model	839.64	5	167.93	49.36	<0.0001
A-HIPS (Vol %)	400.00	1	400.00	117.57	<0.0001
B-W/C ratio	429.77	1	429.77	126.32	<0.0001
AB	7.13	1	7.13	2.10	0.1910
A ²	0.71	1	0.71	0.21	0.6625
B ²	1.00	1	1.00	0.29	0.6051
Residual	23.81	7	3.40		
Lack of fit	23.81	3	7.94		
Pure error	0.000	4	0.000		
Total	863.45	12			

natural coarse aggregate. This type of concrete can be used in situation where mass reduction is required.

Tables 5 and 6 present the actual and predicted values of 7-day and 28-day compressive strength of concrete cube specimens of size 150 mm. Tables 10 and 11 present the results of the variance analysis for the 7-day and 28-day compressive strength using the response surface model. The compressive strength decreases with the increase of HIPS; for all W/C ratios, since the shape of HIPS is flaky and smooth in texture, there is lack of bond between the HIPS and mortar.

Table 10 shows that the linear and quadratic W/C ratio effects ($P < 0.0001$ and 0.0040 , resp.) are statistically significant at the stipulated level of 5%. The linear and quadratic HIPS% effects ($P < 0.0001$ and 0.001 , resp.) are statistically significant at the stipulated level of 5%. Equation (5) is the final fitting equation:

$$\begin{aligned} & \text{7 day Compressive strength (MPa)} \\ & = 20.97 - 4.16A - 3.08B + 0.16AB - 2.03A^2 - 1.14B^2. \end{aligned} \quad (5)$$

Table 11 shows that only the linear HIPS% and W/C ratio effects ($P < 0.0001$ and $P < 0.0001$, resp.) are statistically significant at the stipulated level of 5%. Equation (6) is the final fitting equation:

$$\begin{aligned} & \text{28 day Compressive strength (MPa)} \\ & = 28.29 - 8.17A - 8.46B + 1.34AB - 0.51A^2 - 0.6B^2. \end{aligned} \quad (6)$$

The effect of each variable on 7-day and 28-day compressive strength is plotted as response and contour plot, as shown in Figures 6 and 7.

Tables 5 and 6 show the actual and predicted values of 7-day and 28-day spilt tensile strength of concrete cylinder specimens of size 150×300 mm.

Table 12 shows that only the linear HIPS% and W/C ratio effects ($P < 0.0001$ and $P < 0.0001$, resp.) are statistically significant at the stipulated level of 5%. Equation (7) is the final fitting equation:

$$\begin{aligned} & \text{7 day Spilt tensile strength (MPa)} \\ & = 1.91 - 0.35A - 0.18B + 0.0075AB - 0.064A^2 \\ & \quad - 0.034B^2. \end{aligned} \quad (7)$$

Table 13 shows that only the linear HIPS% and W/C ratio effects ($P < 0.0001$ and $P < 0.0001$, resp.) are statistically significant at the stipulated level of 5%. Equation (8) is the final fitting equation:

$$\begin{aligned} & \text{28 day Spilt tensile strength (MPa)} \\ & = 2.29 - 0.62A - 0.18B - 0.025AB - 0.022A^2 + 0.013B^2. \end{aligned} \quad (8)$$

The effect of each variable on 7-day and 28-day spilt tensile strength is plotted as response and contour plot, as shown in Figures 8 and 9.

FIGURE 6: Contour plot and response surface of a 7-day compressive strength.

FIGURE 7: Contour plot and response surface of a 28-day compressive strength.

TABLE 12: Analysis of variance for 7-day split tensile strength (MPa) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	0.96	5	0.19	474.17	<0.0001
A-HIPS (Vol %)	0.73	1	0.73	1816.44	<0.0001
B-W/C ratio	0.20	1	0.20	498.39	<0.0001
AB	0.000225	1	0.0002250	0.56	0.4801
A ²	0.011	1	0.011	28.08	0.0011
B ²	0.003219	1	0.003219	7.95	0.0258
Residual	0.002832	7	0.0004046		
Lack of fit	0.002832	3	0.0009442		
Pure error	0.000	4	0.000		
Total	0.96	12			

TABLE 13: Analysis of variance for 28-day split tensile strength (MPa) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	2.50	5	0.50	196.28	<0.0001
A-HIPS (Vol %)	2.29	1	2.29	901.04	<0.0001
B- W/C ratio	0.20	1	0.20	79.21	<0.0001
AB	0.002500	1	0.002500	0.98	0.3547
A ²	0.00001388	1	0.00001388	0.005450	0.9432
B ²	0.0004496	1	0.0004496	0.18	0.6869
Residual	0.018	7	0.002546		
Lack of fit	0.018	3	0.005941		
Pure error	0.000	4	0.000		
Total	2.52	12

FIGURE 8: Contour plot and response surface of a 7-day split tensile strength.

FIGURE 9: Contour plot and response surface of a 28-day split tensile strength.

FIGURE 10: Contour plot and response surface of a 7-day flexural strength.

FIGURE 11: Contour plot and response surface of a 28-day flexural strength.

TABLE 14: Analysis of variance for 7-day flexural strength (MPa) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	7.18	5	1.44	938.32	<0.0001
A-HIPS (Vol %)	4.17	1	4.17	2723.15	<0.0001
B-W/C ratio	2.93	1	2.93	1912.32	<0.0001
AB	0.055	1	0.055	36.09	0.0005
A ²	0.030	1	0.030	19.84	0.0030
B ²	0.002514	1	0.002514	1.64	0.2407
Residual	0.011	7	0.001530		
Lack of fit	0.011	3	0.003570		
Pure error	0.000	4	0.000		
Total	7.19	12

FIGURE 12: Predicted response for 28-day split tensile strength.

TABLE 15: Analysis of variance for 28-day flexural strength (MPa) response surface quadratic model.

Source	Sum of squares	Degrees of freedom	Mean square	F value	P value
Model	7.23	5	1.45	1305.46	<0.0001
A-HIPS (Vol %)	4.86	1	4.86	4385.45	<0.0001
B-W/C ratio	2.17	1	2.17	1959.93	<0.0001
AB	0.053	1	0.053	47.73	0.0002
A ²	0.14	1	0.14	125.20	<0.0001
B ²	0.055	1	0.055	49.45	0.0002
Residual	0.007757	7	0.001108		
Lack of fit	0.007757	3	0.002586		
Pure error	0.000	4	0.000		
Total	7.24	12			

Table 14 shows that only the linear HIPS%, W/C ratio effects, and interaction effect ($P < 0.0001$, $P < 0.0001$, and $P = 0.0005$, resp.) are statistically significant at the stipulated level of 5%. Equation (9) is the final fitting equation:

$$\begin{aligned} & \text{7 day Flexural strength (MPa)} \\ & = 4.54 - 0.83A - 0.7B - 0.12AB - 0.1A^2 + 0.03B^2. \end{aligned} \quad (9)$$

Table 15 shows that the linear HIPS%, linear W/C ratio effects, interaction effect, and quadratic effects of HIPS and W/C ratio are statistically significant at the stipulated level of 5%. Equation (10) is the final fitting equation:

$$\begin{aligned} & \text{28 day Flexural strength (MPa)} \\ & = 5.19 - 0.90A - 0.6B + 0.12AB + 0.22A^2 - 0.14B^2. \end{aligned} \quad (10)$$

The effect of each variable on 7-day and 28-day flexural tensile strength is plotted as response and contour plot, as shown in Figures 10 and 11. Like the compressive strength, the split tensile strength and flexural strength decrease with the increase of HIPS for all W/C ratios and for all curing periods.

In this study, all models are statically significant for chosen significant level of 5%. The predicted R -squared, adjusted R -squared values and F values for all responses are presented in Table 16.

4.3. Validation of Experiments. To validate the calculated statistical models for fresh and hardened properties of concrete with HIPS, experiments were conducted. For validation, the concrete mix with 25% HIPS volume percentage and 0.49 W/C ratio were taken, responses were calculated using the models, and measurements were taken experimentally and are shown in Table 17. It can be seen from Table 16 that the experimental value closely agreed with the predicted value, which validates the calculated response surface models with desirability = 1. A visual example for one response, that is, 28-day split tensile strength, using design expert is shown in Figure 12.

5. Conclusion

In this study, E-waste plastic (HIPS) was used as partial replacement of coarse aggregates in concrete. The experimental study has been conducted to assess the engineering properties of concrete with HIPS aggregate. The fresh and hardened properties of concrete with E-waste plastic (HIPS) such as slump, fresh density, dry density, 7-day compressive strength, 28-day compressive strength, 7-day split tensile strength, 28-day split tensile strength, 7-day flexural strength, and 28-day flexural strength were found experimentally. It was observed that the slump and fresh density have shown a significant decrease upon increasing the HIPS quantity.

TABLE 16: Model statistics for all response variables.

Responses	Predicted R-squared	Adjusted R-squared	F value	Prob > F	Model comment
Slump	0.8538	0.9667	70.65	<0.0001	Significant
Fresh density	0.9743	0.9857	129.25	<0.0001	Significant
Dry density	0.9720	0.9947	451.76	<0.0001	Significant
7-day compressive strength	0.9232	0.9870	183.13	<0.0001	Significant
28-day compressive strength	0.9083	0.9532	49.36	<0.0001	Significant
7-day split tensile strength	0.9712	0.9950	474.17	<0.0001	Significant
28-day split tensile strength	0.9435	0.9879	196.28	<0.0001	Significant
7-day flexural strength	0.9870	0.9974	938.32	<0.0001	Significant
28-day flexural strength	0.9899	0.9982	1305.46	<0.0001	Significant

TABLE 17: Validation of the response surface model (25% HIPS, 0.49 W/C ratio).

Properties	Experiment	Predicted
Slump (mm)	17.00	16.64
Fresh density (kg/m ³)	2469.12	2472.61
Dry density (kg/m ³)	2291.65	2285.02
7-day compressive strength (MPa)	21.66	21.84
28-day compressive strength (MPa)	31.62	30.26
7-day split tensile strength (MPa)	1.97	1.98
28-day split tensile strength (MPa)	2.35	2.44
7-day flexural strength (MPa)	4.72	4.75
28-day flexural strength (MPa)	5.52	5.43

The concrete specimens were tested on 7 and 28 days. The compressive strength, splitting tensile strength, and flexural strength were found to be decreased by replacement of HIPS compared to control concrete. With the help of Design-Expert software, the measured experiment values were analyzed by face-centered composite surface design. Full quadratic model is employed and all models are found as significant. In all the models, linear effect of HIPS (Vol%) was more significant when compared to other effects for a given stipulated level of 5%. Finally, the predicted models were validated by experiments with 25% HIPS and 0.49 W/C ratio. The results closely agreed with the predicted model, which implies that the predicted model is reliable. In future, these models can be used for framing guidelines for concrete mix design. Based on this investigation, it can be inferred that the concrete with HIPS up to 30% of replacement can be used for structural concrete. However, incorporation of E-waste plastic (HIPS) waste as an aggregate replacement in concrete has given scope to develop new construction materials valuable for both the construction and the electronic waste recycling industries.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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