

Research Article

Effect of Mix Parameters on the Strength Performance of Waste Plastics Incorporated Concrete Mixes

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Disposal of solid wastes has been a major problem all over the world. Out of all the different types of solid wastes, the major challenge of disposal is posed by the ever increasing volumes of plastic wastes. While several methods are in practice, producing newer useful materials by recycling of such plastic wastes is, by far, the best method of their disposal. One such possible method is to use the waste plastics as an ingredient in the production of the concrete mixes in the construction industry. The present study aims to investigate the relative contributions of the various mix parameters to the mechanical properties of concrete mixes produced with waste plastics as partial replacement (10–30% by volume) to coarse aggregates. Initially, strength test results of a set of trial mixes, selected based on Taguchi's design of experiments (DOE) method are obtained. A detailed analysis of the experimental results is carried out to study the effect of using waste plastics as a partial replacement to coarse aggregates on the strength parameters of these concrete mixes. It is found that all these trial mixes have performed satisfactorily in terms of workability in the fresh state and strength properties in their hardened state.

1. Introduction

In the urge of making a cleaner and sustainable environment, one important concern has been on disposing of the solid wastes. There have been many attempts to use different solid wastes as possible construction materials. The present study explores the use of waste plastics as a possible replacement to coarse aggregates in concrete mixes. The study aims at investigating the mechanical properties of concrete mixes with waste plastic aggregates incorporated in them as a partial replacement to their coarse aggregate fraction. This work is focused on developing mixes with as maximum replacement of waste plastic as possible but retaining a minimum compressive strength of grade M20.

In general, the inclusion of waste plastics into concrete has been found to decrease the strength performance characteristics of concrete. This decrease in performance is expected both in fresh and hardened properties. In fresh state, the workability of the concrete mixes produced with recycled plastic aggregates was found to be smaller as compared to

the control mixes [1–5]. The hardened properties of concrete such as the compressive strength, tensile strength, flexural strength, and modulus of elasticity reduce with increased percentage of waste plastics [1, 2, 5–10]. Though many works have been reported on the strength performance characteristics of waste plastics incorporated (as a partial replacement to both fine and coarse aggregates) concrete mixes, very few works evaluating the effect of mix parameters such as binder content and water/binder ratio along with plastic incorporation have been reported. Hence an attempt is being made to investigate the mechanical properties of such concrete mixes by considering these major control factors. Taguchi's design of experiments methodology is employed herein to analyse the test results.

2. Materials, Methodology, and Mix Design

2.1. Materials. Ordinary Portland cement conforming to IS 8112-2005 (43-grade cement) [11] was used in all the mixtures.



FIGURE 1: (a) CGC and (b) waste plastics coarse aggregates.

TABLE 1: Results of physical tests on cement.

Property	Result		
Specific gravity	3.16		
Normal consistency, %	31		
Setting time, minutes	Initial: 60		
	Final: 245		
Fineness, m^2/kg	327		
Soundness, mm	Expansion: 2 mm		
Compressive strength MPa	3 day	7 day	28 day
	31	39	56

TABLE 2: Chemical composition of cement and fly ash.

Compounds	Mass percentage	
	Cement	Fly ash
CaO	62.48	2.65
SiO ₂	20.21	60.61
Al ₂ O ₃	6.20	28.61
Fe ₂ O ₃	3.87	3.91
TiO ₂	0.36	1.70
MgO	1.32	0.77
Na ₂ O	0.21	0.14
K ₂ O	0.45	1.07
MnO	0.13	0.04
P ₂ O ₅	0.24	0.30
SO ₃	2.52	0.19

Table 1 presents the physical properties of cement used. Fly ash was obtained from M/s Raichur Thermal Power Station, Shaktinagar, Karnataka, India, and it conforms to the requirements of IS 3812-2007 [12]. The specific gravity of this Type-F fly ash was 2.2 and fineness by Blaine's apparatus was $295 m^2/kg$. The chemical properties of cement and fly ash used are presented in Table 2. Locally available river sand was used as fine aggregate which conforms to the requirements of Zone III of IS 2386-2007 [13]. Crushed granite rock chips (CGC) (MAS = 12.5 mm) are used as full/partial fraction of coarse aggregates. Waste plastics (Figure 1) used in this study are the discarded HDPE plastic waste collected from

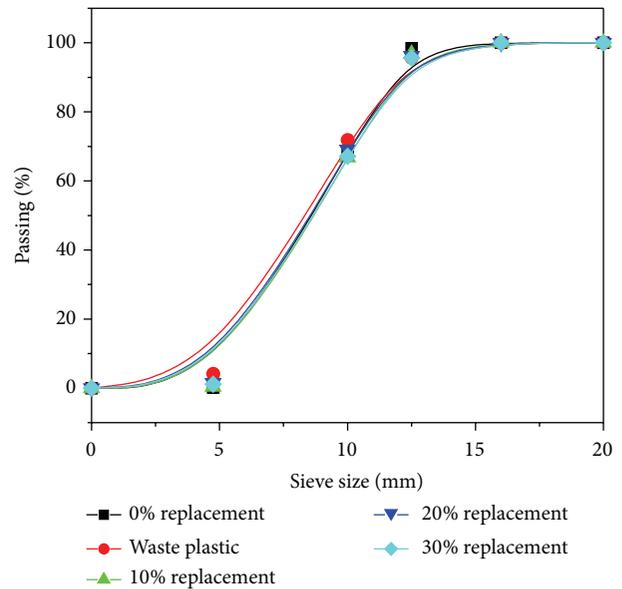


FIGURE 2: Sieve analysis for different blends of coarse aggregates.

plastic reprocessing units located in the vicinity of Bangalore, India. The physical properties of all the aggregates are listed in Table 3. The results of sieve analyses for CGC, waste plastics, and their blends, all conforming to Grade II (graded aggregates) of IS 383-2007 [14], are presented in Table 4 and Figure 2. The various trial mixes tested herein are then designed based on the general guidelines of IS 10262-2009 [15].

2.2. Design of Experiments (DOE). Strength properties of concrete mixes depend on variety of factors associated with quality and proportions of ingredients, production methods, curing regimes, and loading conditions. This is true whether natural coarse aggregates are used or they are replaced partially (or fully) by the waste plastics. An effort is made in the present work to explore the possibility of employing Taguchi's DOE technique to understand the strength performance of various waste plastics incorporated concrete mixes. Based on a general appreciation of issues connected with the strength

TABLE 3: Properties of aggregates.

Serial number	Property	River sand	CGC (12.5 mm down)	Waste plastic
1.	Specific gravity	2.63	2.67	0.94
2.	Water absorption	1%	0.5%	4.5%
3.	Fineness modulus	2.7	6.68	6.76
4.	Bulk density (loose) kg/m ³	1450	1350	530
5.	Bulk density (compact) kg/m ³	1710	1600	584

TABLE 4: Sieve analysis of aggregates.

IS sieve size	CGC	Waste plastic	Percentage passing		
			10%	20%	30%
20	100	100	100	100	100
16	100	100	100	100	100
12.5	98.4	95.7	96.8	96.2	95.6
10	68.6	71.9	66.8	69.1	67.1
4.75	0.2	4.2	0.4	1.5	1.1
Pan	0	0	0	0	0
Grading as per IS 383-1970	Zone II	Zone II	Zone II	Zone II	Zone II
Fineness modulus	6.68	6.76	6.67	6.70	6.68

TABLE 5: Details of test specimens and test methods used.

Property	Test age (days)	Size of specimen	Number of specimens tested	Test method
Compressive strength	7	100 * 100 * 100 mm cubes	5	IS: 516 (1999) [18]
	28		5	
Split tensile strength	28	Cylinders of 150 mm dia and 300 mm height	3	IS: 5816 (1999) [19]
Flexural strength	28	Prisms of 100 * 100 * 500 mm	3	IS: 516 (1999)

development in concrete mixes, the following parameters are initially identified as primary parameters affecting the strength characteristics of a waste plastics incorporated concrete mix:

- (a) binder content (B);
- (b) water-binder ratio (W);
- (c) percentage level of replacement of aggregates with waste plastic (R).

Initially trials were done with different binder contents, w/b ratios, and plastic replacement levels. It is found that, as expected, mixes with increased plastic replacement had lesser strengths. It was also observed that, with 40% waste plastic replacement (by volume), compressive strengths lower than specified (M20 grade) were obtained. So, it was decided to replace only up to a maximum of 30% of the volume of the coarse aggregate with waste plastics. Details of specimens tested and test methods used are given in Table 5.

The following precautions were also taken during the study in order to compensate for loss in strength.

- (a) Use of higher binder content with fly ash as mineral admixture is preferred. A constant fly ash percentage of 35% of total binder content was maintained in all the mixes tested herein.
- (b) Lower range of water to binder ratio (w/b) is selected. In this study, w/b ratio is kept in the range of 0.32 to 0.36. Approximate dosages of a superplasticizer based on polycarboxylate ether (PCE) polymer were then used in the mixes, to attain required levels of workability.

The waste plastics with specific gravity around 0.94 are lighter than water and other ingredients in the concrete mix. During trial mixes, it was found that when the slump values of concrete mixes were higher than 100 mm, the plastic particles tend to come up and float on the surface when vibrated. Hence, it is decided to keep the slump range 50–75 mm for

TABLE 6: Levels and factors for an L-9 orthogonal array.

Levels	Factors		
	Binder content B (kg/m ³)	W/B ratio W	Polymer replacement R (%)
Level 1	B1 = 600	W1 = 0.32	R1 = 10
Level 2	B2 = 630	W2 = 0.34	R2 = 20
Level 3	B3 = 660	W3 = 0.36	R3 = 30

which segregation is limited and the vibration effort was kept at a minimum.

Mixes are designed so as to attain a minimum specified compressive strength of 20 MPa. With the three factors listed earlier taken at three representative levels (as given in Table 6), for the full factorial set of experiments, $3^3 = 27$ different mixes are to be tested to investigate the effect of the three parameters on the strength performance of this class of mixes since number of test specimens will be large; alternatively, Taguchi DOE method is used to reduce the number of the tests to be performed. Thus, an L9-orthogonal array of test matrix is taken into consideration which now consists of evaluating the strength performance by the experimental results obtained with just 9 different combinations [16]. The details of mix proportions of the nine waste plastic incorporated concrete mixes and the three control concrete mixes are given in Table 7.

3. Results and Discussions

3.1. Fresh Concrete Mixes. The effect of inclusion of waste plastics on workability characteristics is investigated by keeping constant both the binder content and the w/b ratio but varying the percentage content of waste plastics. In general, it is found that the workability of the concrete mixes decreased on increased addition of plastics and hence increased water demand for the same level of workability (50 ± 10 mm slump) (Figure 3). The average increase in water demand was about 1.5% for every 10% increase in waste plastic replacement to obtain similar range of workability. This decrease in workability (slump) is compensated by using appropriately increased dosage of a superplasticizer (SP). A polycarboxylate ether (PCE) based superplasticizer was used and the required dosage used in each of the mixes in the L-9 orthogonal array is given in Table 8.

3.2. Tests on Hardened Concrete

3.2.1. Compression Tests. The results of compression tests are shown in Figure 4. The strength values of 100 mm cube specimens were corrected by multiplying with a factor of 0.9, again a value obtained experimentally, for obtaining equivalent strength values for 150 mm cube specimens. It can be observed that the compressive strengths of these mixes tend to reduce with increase in percentage of waste plastic replacement. The average percentage decreases in strengths for 10, 20, and 30% replacement of waste plastic are 2.3, 7.8,

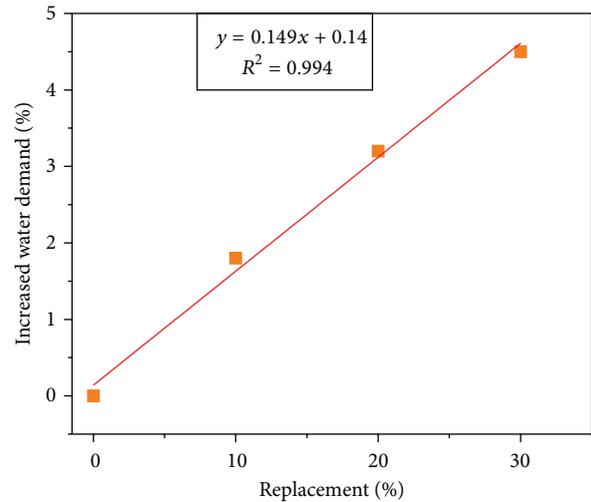


FIGURE 3: % waste plastic replacement versus increased water demand to obtain similar levels of workability.

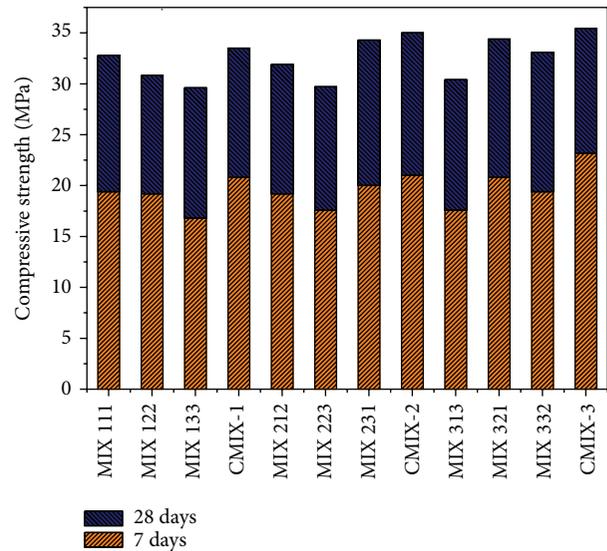


FIGURE 4: Variation of compressive strengths of different mixes.

and 13.6%, respectively. Though there is a consistent strength loss, it can be observed that all the mixes have attained satisfactory compressive strengths varying between 30 and 35 MPa.

The rupture surfaces of all test specimens after failure under compression testing were visually inspected for assessing the distribution of waste plastic particles. It is found that the plastic aggregates had been distributed uniformly all over the concrete matrix. The cubes failed in a normal trapezoidal type of failure pattern.

By using Taguchi's DOE method, the response table for mean of means of 28 days of compressive strength of waste plastics incorporated concrete mixes is generated (Table 9). Figure 5 shows the main-effect plots of the three chosen mix parameters with respect to 28-day compressive strengths of the different concrete mixes. Also, relevant calculations

TABLE 7: Details of concrete mixes in the L-9 orthogonal array.

Mix code	Binder content B kg/m ³	Cement kg/m ³	Fly ash kg/m ³	River sand kg/m ³	W/B	Water kg/m ³	Polymer replacement R %	Coarse aggregates kg/m ³	
								CGC	WP
MIX 111	600	390	210	774.7	0.32	192	10	707.8	28.0
MIX 122	600	390	210	758.9	0.34	204	20	616.4	54.8
MIX 133	600	390	210	743.1	0.36	216	30	528.1	80.5
CMIX-1	600	390	210	743.1	0.36	216	0	754.5	0.0
MIX 212	630	409.5	220.5	747.7	0.32	201.6	20	607.3	54.0
MIX 223	630	409.5	220.5	731.1	0.34	214.2	30	519.6	79.2
MIX 231	630	409.5	220.5	714.6	0.36	226.8	10	652.9	25.8
CMIX-2	630	409.5	220.5	714.6	0.36	226.8	0	725.4	0.0
MIX 313	660	429	231	720.7	0.32	211.2	30	512.1	78.1
MIX 321	660	429	231	703.3	0.34	224.4	10	642.6	25.4
MIX 332	660	429	231	686.0	0.36	237.6	20	557.1	49.6
CMIX-3	660	429	231	686.0	0.36	237.6	0	696.4	0.0

*WP: waste plastic.

TABLE 8: Properties of mixes in fresh states.

Mix designation	SP dosage (mL/kg)	Slump (mm)
Mix 111	0.9	45
Mix 122	0.4	55
Mix 133	0.6	50
Cmix-1	0	60
Mix 212	1.6	45
Mix 223	0.8	55
Mix 231	1.4	40
CMix-2	0.3	55
Mix 313	1.5	50
Mix 321	1.0	40
Mix 332	1.0	45
CMix-3	0	60

TABLE 9: Response table for mean of means of 28 days of compressive strengths of waste plastics incorporated concrete mixes.

Level	Binder content kg/m ³ B	Water-binder ratio W	Replacement of WP aggregate (%) R
1	31.07	31.69	33.82
2	31.96	31.64	31.91
3	32.62	32.31	29.91
Delta	1.56	0.67	3.91
Rank	2	3	1

based on analysis of variances (ANOVA) for the series of the experiments conducted herein for 28-day compressive strengths are presented in Table 10.

From both Taguchi's mean of means (highest rank) and ANOVA (highest dominant factor, F) methods, it is found that amongst the parameters considered herein, the mix

parameter R (waste plastics replacement %) is the most significant factor which determines the strength characteristics of these mixes followed by the parameters, binder content, and water-binder ratio, in that order.

3.2.2. Split Tensile and Flexural Strengths. The split tensile and flexural strengths of waste plastics incorporated concrete mixes are also determined and are given in Figure 6. It is found that, as expected, these mixes possess lower flexural and split tensile strengths also, as compared to the corresponding mixes with CGC aggregates only. The reductions in flexural strengths are not as pronounced as that of split tensile strengths. The lower tensile strength is due to the loose bonding characteristics of waste plastic coarse aggregates with the cement paste. Weak transition zone in waste plastic coarse aggregates may also be the reason for these lowered strengths.

The overall reductions in various strengths were determined for each of the mixes. The summary of percentage reductions in compression, split, and flexural strengths of the mixes is given in Table 11. Strengths of each set of three mixes are compared with the corresponding control mix. For example, strengths of first set of 03 mixes, that is, MIX 111, MIX 122, and MIX 133, are compared with CMIX-1 as a reference. Similarly second and third sets of the mixes are compared with CMIX-2 and CMIX-3, respectively.

3.2.3. Modulus of Elasticity (E). Experiments were conducted to obtain the modulus of elasticity (E) for all the concrete mixes and it is observed that the E values are lower compared to the respective control mixes (Figure 7). The reduction in E values varied in a limited range of 1.7–8.7% of the values of the control mixes.

3.3. Regression Equations for Predicting Strength of the Mixes. The results of the initial set of nine experiments specified by the L-9 array have suggested the relative importance of the

TABLE 10: Main effects plot for 28 days of compressive strength (ANOVA).

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean square (MS)	Dominant factor (F)	P value
B	2	3.7	1.85	0.46	0.652
W	2	0.9	0.45	0.1	0.906
R	2	23.2	11.6	15.03	0.0046
Total	8	27.8			

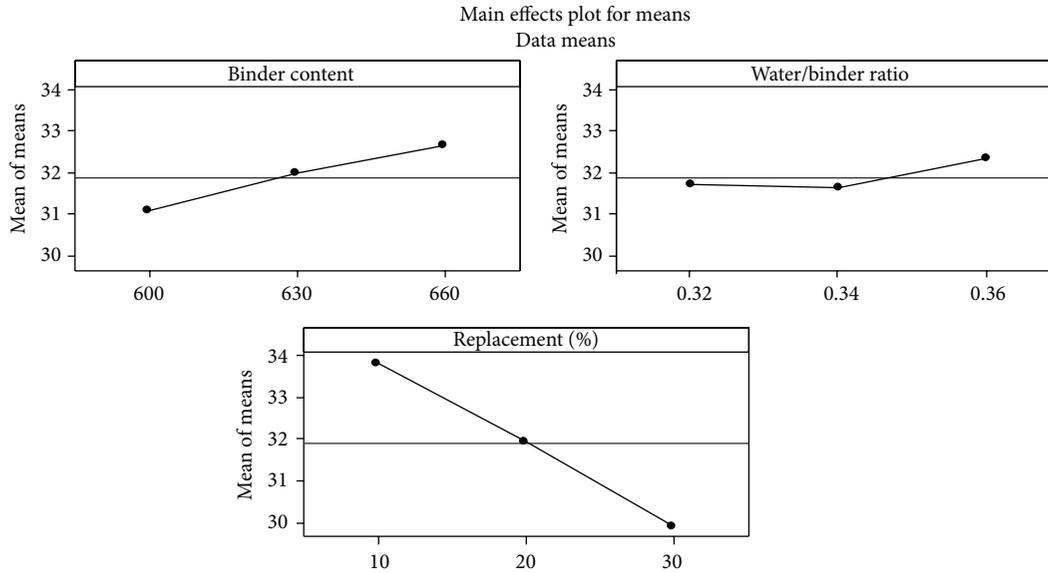


FIGURE 5: Main effects plots of mean of means for 28 days of compressive strength.

TABLE 11: Percentage reductions in strengths.

Mix designation	% reduction in strength at 28-day testing		
	Compressive strength	Flexural strength	Split tensile strength
MIX 111	2.1	2.3	2.76
MIX 122	8.1	14.6	24.37
MIX 133	11.6	16.4	35.17
MIX 212	8.9	14	21.07
MIX 223	15.1	18.4	28.97
MIX 231	2	2.6	2.66
MIX 313	14.1	21	24.98
MIX 321	2.8	3.7	14.97
MIX 332	6.5	18	4.97

three mix design factors in deciding the strength parameters. These results are now used to develop multilinear regression equations for possible prediction of the strength parameters. The following regression equation is developed for possible prediction of the 28-day compressive strength of these mixes:

$$\begin{aligned} \text{Predicted 28-day compressive strength} \\ = f_{c-28} = 14.0 + 0.0261B + 15.8W - 0.197R, \quad (1) \\ (R^2 = 0.987). \end{aligned}$$

On similar lines, regression equations are developed for flexural and split tensile strength of mixes:

$$\begin{aligned} \text{Predicted 28-day flexural strength} \\ = f_{cr} = 0.29 + 0.0111B + 1.67W - 0.0600R \\ (R^2 = 0.913), \end{aligned}$$

$$\begin{aligned} \text{Predicted 28-day split tensile strength} \\ = f_t = -1.22 + 0.00628B + 0.67W - 0.0355R \\ (R^2 = 0.899). \end{aligned}$$

(2)

An attempt was also made to study the relation between compressive and tensile strengths of the plastics incorporated mixes and an empirical formula has been obtained for the same (Figure 8).

4. Conclusions

An exploratory study on the strength characteristics of a class of waste plastics incorporated concrete mixes has been reported. Based on the experimental results obtained in this

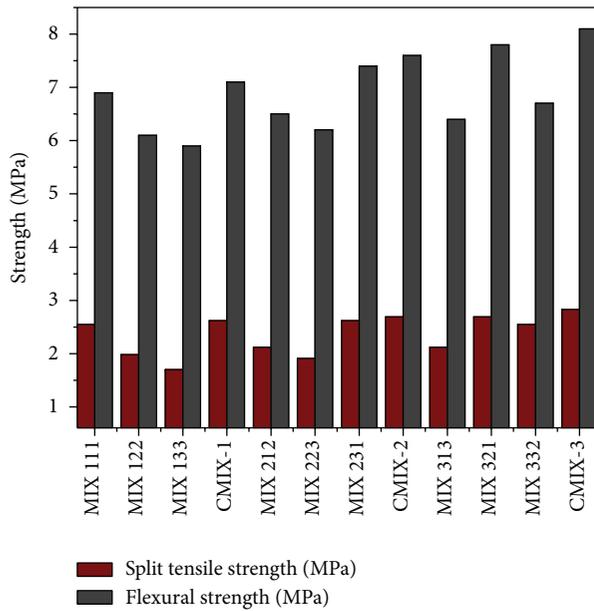


FIGURE 6: Split tensile and flexural strengths.

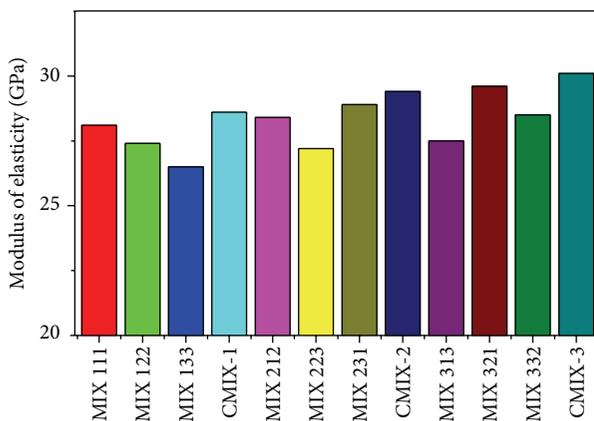


FIGURE 7: Modulus of elasticity of concrete mixes.

study, it can be said that waste plastics can be used as partial replacement to coarse aggregates, in preparation of structural grade concrete mixes (say M20–M25).

- (i) It is found that the workability of the concrete mixes decreased on increased addition of waste plastics. The average increase in water demand so as to obtain similar range of workability was about 1.5% for every 10% increase in waste plastic replacement.
- (ii) It is found that the strengths of the waste plastics incorporated mixes are always lower than mixes with only natural coarse aggregates. The reduction in strengths increases with increase in the percentage of waste plastics replacement. Mixes with a maximum replacement of up to 30% by volume of the coarse aggregates are found to be satisfactory.
- (iii) Of the three factors considered to be influencing the strength performances of waste plastic incorporated

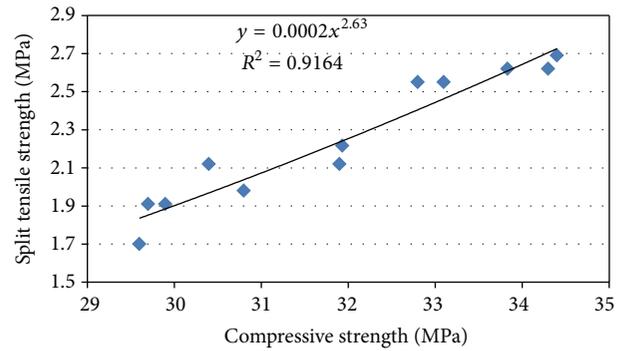


FIGURE 8: Relation between compressive and tensile strength of concrete mixes.

mixes, replacement level of plastics is shown to be the most dominant factor, followed by the binder content and w/b ratio in that order.

- (iv) The waste plastics incorporated concrete mixes are also found to possess lower flexural and split tensile strengths and so also lower modulus of elasticity than the corresponding mixes with natural CRC aggregates only.
- (v) Concrete mixes with flexural strengths greater than 4.5 MPa and above are considered satisfactory for concrete pavements for rural roads as per IRC-58 (2002) [17]. In the present study, all the mixes qualify this flexural strength criterion. Hence, it can be concluded that the waste plastic incorporated concrete mixes could be used for concrete pavements for rural roads.
- (vi) Multilinear regression equations, with satisfactory predictive capabilities, have been derived for each of the strength parameters, based on DOE approach ($R^2 = 0.85\text{--}0.99$).

Conflict of Interests

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

References

- [1] R. Siddique, J. Khatib, and I. Kaur, "Use of recycled plastic in concrete: a review," *Waste Management*, vol. 28, no. 10, pp. 1835–1852, 2008.
- [2] Z. Z. Ismail and E. A. AL-Hashmi, "Use of waste plastic in concrete mixture as aggregate replacement," *Waste Management*, vol. 28, no. 11, pp. 2041–2047, 2008.
- [3] S. C. Kou, G. Lee, C. S. Poon, and W. L. Lai, "Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes," *Waste Management*, vol. 29, no. 2, pp. 621–628, 2009.
- [4] C. Albano, N. Camacho, M. Hernández, A. Matheus, and A. Gutiérrez, "Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios," *Waste Management*, vol. 29, no. 10, pp. 2707–2716, 2009.

- [5] F. Pacheco-Torgal, Y. Ding, and S. Jalali, "Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): an overview," *Construction and Building Materials*, vol. 30, pp. 714–724, 2012.
- [6] A. A. Al-Manaseer and T. R. Dalal, "Concrete containing plastic aggregates," *Concrete International*, vol. 19, no. 8, pp. 47–52, 1997.
- [7] P. Panyakapo and M. Panyakapo, "Reuse of thermosetting plastic waste for lightweight concrete," *Waste Management*, vol. 28, no. 9, pp. 1581–1588, 2008.
- [8] Y. W. Choi, D. J. Moon, Y. J. Kim, and M. Lachemi, "Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles," *Construction and Building Materials*, vol. 23, no. 8, pp. 2829–2835, 2009.
- [9] M. Frigione, "Recycling of PET bottles as fine aggregate in concrete," *Waste Management*, vol. 30, no. 6, pp. 1101–1106, 2010.
- [10] N. Saikia and J. De Brito, "Use of plastic waste as aggregate in cement mortar and concrete preparation: a review," *Construction and Building Materials*, vol. 34, pp. 385–401, 2012.
- [11] Indian Standard, "43 grade ordinary Portland cement-specification," Tech. Rep. IS:8112, Bureau of Indian Standards, New Delhi, India, 2005.
- [12] IS:3812 (Part-2): Indian Standard, "Pulverized fuel ash-specification for use as admixture in cement mortar and concrete," Bureau of Indian Standards, New Delhi, India, 2007.
- [13] Bureau of Indian Standards, "Methods of test for aggregates for concrete," Indian Standard IS :2386 (Part-1), Bureau of Indian Standards, New Delhi, India, 2007.
- [14] IS:383 Indian Standard, *Specifications for Coarse and Fine Aggregates from Natural Sources for Concrete*, Bureau of Indian Standards, New Delhi, India, 2007.
- [15] Indian Standard, "Recommended guidelines for concrete mix design," Tech. Rep. IS:10262, Bureau of Indian Standards, New Delhi, India, 2009.
- [16] M. V. Chitawadagi, M. C. Narasimhan, and S. M. Kulkarni, "Axial capacity of rectangular concrete-filled steel tube columns—DOE approach," *Construction and Building Materials*, vol. 24, no. 4, pp. 585–595, 2010.
- [17] IRC:58, *Guidelines for the Design of Plain Jointed Rigid Pavements for Highways*, The Indian Roads Congress, New Delhi, India, 2002.
- [18] IS, "Methods of tests for Strength of concrete," Indian Standard 516, Bureau of Indian Standards, New Delhi, India, 2008.
- [19] Indian Standard, "Splitting tensile strength of concrete-method of test," Tech. Rep. IS:5816, Bureau of Indian Standards, New Delhi, India, 2008.



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