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Empirical Equations for Concrete Compressive Strength Prediction Using Recycled Coarse Aggregate

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ABSTRACT

Concrete is the major construction material which plays a vital role in the development of current civilization. Construction and demolition waste are one among the various types of waste materials which can be reused in concrete production. Construction wastes are obtained during construction, renovation and demolition of a building. Dumping of these wastes to landfill causes serious environmental issues. The major factor that affects the quality of recycled coarse aggregate which is obtained from construction and demolition waste is the large amount of cement mortar that remains on the surface of it. Hence, it is essential to determine the properties of concrete containing construction and demolition waste as recycled coarse aggregate (RCA). The objective of this study is to develop the equations in order to predict compressive strength of concrete for different cement content with varying water cement ratio using RCA.

1. Introduction

Due to the large-scale demolitions of buildings, a huge amount of debris is generated all over the world, which causes serious environmental pollutions including a disposal problem. In India, about 14.5 million tonnes of solid wastes are generated annually from construction industries, which include waste sand, gravel, bitumen, bricks, masonry, and concrete. The land area required for filling this huge amount of debris is equivalent to accumulation of waste. Aggregates derived from the demolition of concrete members and structures, generally referred to as Recycled Aggregates (RA). These hardened concretes can be crushed and reused as coarse aggregate in the production of new concrete, leading to particular kind of concrete known as “green concrete”. In this, natural coarse aggregates are partially or totally replaced by recycled aggregates obtained from construction and demolition waste (CDW) thus reducing the use of natural aggregates and the problem of mining. However, in comparison to natural aggregate (NA) the quality of CDW aggregate is poor, which restricts its use in varieties of construction applications.

Several studies highlight that Recycled coarse aggregates (RCAs) are more porous than the natural aggregates (NAs). This higher porosity is attributed to the presence of capillary pores, micro cracks which is accessible to water. Therefore, determination of properties of recycled coarse aggregates is essential for construction.

2. Past studies

Yu-chang et al. (2015) [7] stated that the 100% replacements of natural coarse aggregates with recycled coarse aggregate gives 41.4 MPa at 28 days which can be used for structural applications. Surface pre-treatments can improve the properties of fresh and hardened concrete where it seals the pores and workability is enhanced.

Ahmed (2013) [6] stated that the workability of recycled aggregate concrete is decreased with increase in recycled coarse aggregate. Recycled aggregate concrete containing 25% of recycled coarse aggregates gives improved compressive, tensile and flexural strength of concrete. Water absorption increases with increase in recycled aggregate. In addition, 40% of fly ash reduced the water absorption of recycled concrete aggregate and compressive strength is increased for 56 and 91 days.

Revathi Purushothaman et al. (2015) [5] concluded that the Pre-soaking recycled aggregate in H_2SO_4 is more efficient than HCl in removing the attached mortar of recycled aggregate. Hence, the properties of recycled aggregate as well as the recycled aggregate concrete are improved. Among the mechanical treatment methods, heating and scrubbing technique improves the quality of recycled aggregate and hence the property of recycled aggregate concrete.

Rattapon Somna et al. (2012) [4] concluded that the Ground fly ash can slightly improve the compressive strength of recycled aggregate concrete. The use of ground fly ash to replace cement in recycled aggregate concrete was more effective for reducing the water permeability coefficient than the reduction of the W/B ratio.

Daniel Matias et al. (2014) [1] concluded that higher the RA particle density results in higher concrete’s specific density. The use of superplasticizers resulted in a decreasing trend of concrete workability, suggesting that superplasticizers lose efficiency with increasing RA ratio. Compressive strength tends to decrease with the incorporation of RA, but the addition of super plasticizers can

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enhance the mix compactness, compensating for most of the strength loss.

Thus, the literatures summarise, that the use of mineral admixtures like flyash and ground granulated blast furnace slag in recycled aggregate concrete could produce greater compressive strength than that of using recycled aggregates in concrete alone. proper surface pre-treatment and mixing approach can improve the quality of RCA significantly.

This study investigated the material properties such as specific gravity, water absorption, fineness modulus for the recycled coarse aggregates and to develop the equations in-order to predict compressive strength of concrete for different cement content with varying W/C for RCA, so that the future designers can predict the compressive strength of concrete for RCA with confidence.

3. Experimental investigation

Recycled aggregates used in this investigation were obtained from a demolished building in Tiruchirapalli, Tamil Nadu. Different samples of coarse aggregates were taken from the same demolished building.

Physical properties of Recycled coarse aggregates (RCA) were determined. Different number of trails (I, II, III, IV, V) were taken from a single demolished building.

3.1 Fineness Modulus

Particle size distribution of the coarse aggregates was determined with the help of sieve analysis. This was done by sieving the aggregates as per IS: 2386 (Part I) – 1963. In this method, different sieves as standardized by the IS code were used and made aggregates to pass through them and thus collected different sized particles left over different sieves.

3.2 Specific gravity

To measure the strength and quality of the coarse aggregates specific gravity test is considered. Aggregates having low specific gravity are generally weaker than those with higher specific gravity values. Figure 1 shows an image of 20mm recycled aggregates sample that has been used for specific gravity test.

Figure 1. Recycled aggregate samples

3.3 Water Absorption

Water absorption of coarse aggregates was determined according to IS: 2386 (Part III) – 1963. Figure 2 shows an image of recycled coarse aggregates immersed in water for water absorption test.

Figure 2. Recycled coarse aggregates in water

3.4 Compressive strength

Compressive strength for 7, 28 and 56 days with 20mm RCA was determined with 150×150mm cube. Mix design was carried out for different cement content with varying water to cement ratio. Table 1 shows the combination for different cement content with varying W/C. For mix containing low water to cement ratio super plasticizer is added to make the concrete workable. Super plasticizer used for this investigation is conplast sp 430 and Figure 3 shows the casting of concrete cube with RCA's.

Table 1 Combinations for cement content and W/C

Mix	Cement content (Kg/m^3)	W/C	SP
1	300	0.55	-
2		0.45	-
3		0.35	1.5%
4	350	0.5	-
5		0.4	1.5%
6		0.35	1.5%
7	400	0.48	-
8		0.4	-
9		0.3	1.5%
10	450	0.45	-
11		0.35	0.3%
12		0.3	1.5%

Figure 3. Casting of concrete cubes with RA

4. Results and Discussions

The obtained fineness modulus of recycled coarse aggregate is shown in Table 2.

Table 2 Results of Fineness Modulus for RA

S.NO	Fineness Modulus
1	7.85
2	7.68
3	7.74
4	7.35
5	7.57

For 20mm natural coarse aggregates, the fineness modulus ranges from 6 to 6.9. Whereas form table 2 the fineness modulus of 20mm RCA has the average value of 7.638

The obtained specific gravity of recycled coarse aggregate is shown in Table 3.

Table 3 Results of specific gravity for RA

S.NO	Trail	Specific gravity
1	I	2.53
2	II	2.44
3	III	2.47
4	IV	2.52
5	V	2.51

For 20mm natural coarse aggregates, the specific gravity ranges from 2.5 to 3. Whereas from table 3 the specific gravity for 20mm RCA has the average value as 2.49

The obtained water absorption (%) of recycled coarse aggregate is shown in Table 4.

Table 4 Results of Water Absorption of RA

S.NO	Trail	Water absorption (%)
1	I	2.14
2	II	2.17
3	III	2.24
4	IV	2.21
5	V	1.98

For 20mm natural coarse aggregates, the water absorption ranges from 0.1 to 2%. Whereas form table 4 the water absorption for 20mm RCA has the average value of 2.15

Table 5 shows the compressive strength results at 7, 28 and 56 days.

Table 5 Compressive strength for various cement content

Mix	CC (Kg/m^3)	W/C	slump (mm)	Average compressive strength (MPa)		
				7 d	28 d	56 d
1	300	0.55	50	18.18	28.07	34.87
2		0.45	50	21.75	31.93	38.70
3		0.35	-	33.60	40.08	43.76
4		0.5	60	23.15	30.46	34.95
5		0.4	100	26.49	34.22	38.80
6		0.35	40	30.48	38.87	43.42
7		0.48	75	25.57	33.61	38.57
8		0.4	40	26.77	33.99	36.53
9		0.3	30	40.16	49.89	54.33
10		0.45	150	22.22	28.28	31.45
11		0.35	50	28.41	36.50	41.78
12		0.3	90	33.24	43.89	50.36

A relationship curve between compressive strength and age of concrete for different cement content is plotted with varying W/C. Hence for varying W/C, the compressive strength of concrete is predicted for different age of concrete using the developed equations. Fig 4 -7 shows the relationship curve between compressive strength (CS) and age of concrete for different cement content.

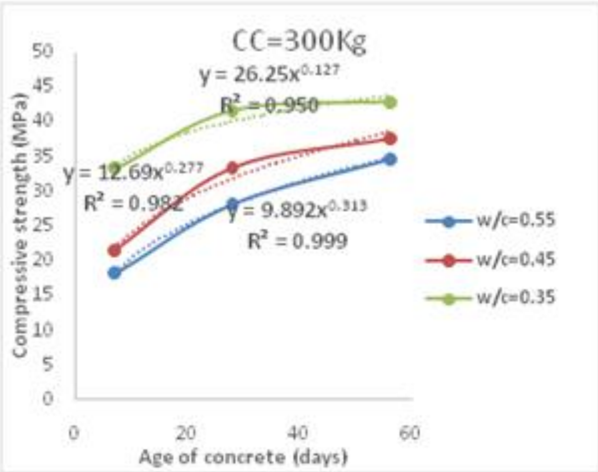

Figure 4. Relationship curve between CS and Age for CC 300Kg/m^3

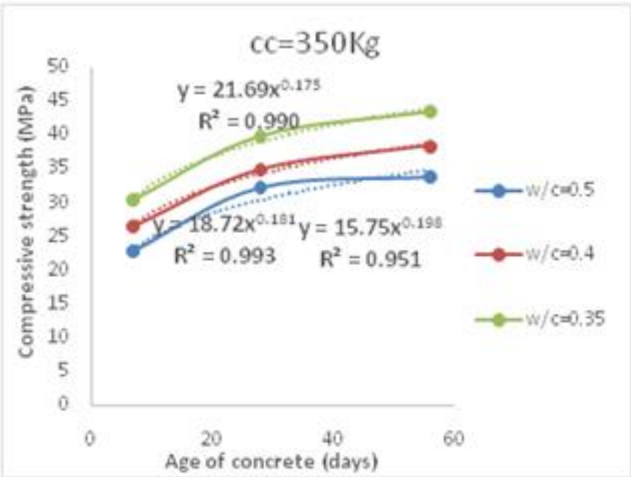

Figure 5. Relationship curve between CS and Age for CC 350Kg/m^3

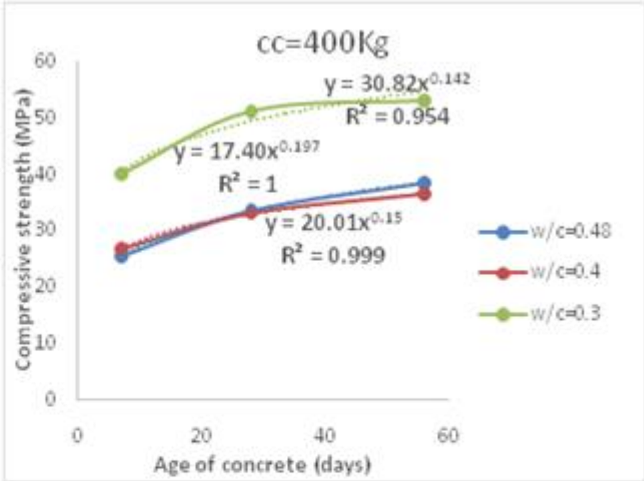

Figure 6. Relationship curve between CS and Age for CC 400Kg/m^3

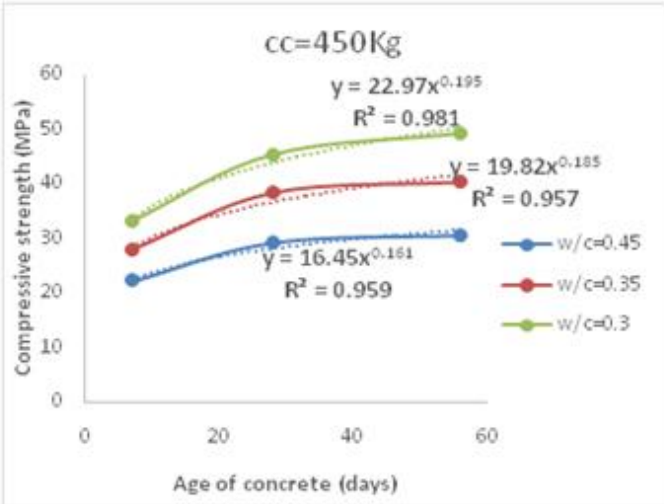

Figure 7. Relationship curve between CS and Age for CC 450Kg/m^3

Table 6 shows the developed equations for predicting compressive strength of concrete.

Table 6 Equations for predicting compressive strength of concrete.

Mix	Cement content (Kg/m^3)	W/C	SP	Developed Equations
1	300	0.55	-	$y = 9.892x^{0.313}$
2		0.45	-	$y = 12.69x^{0.277}$
3		0.35	1.5%	$y = 26.25x^{0.127}$
4	350	0.5	-	$y = 15.75x^{0.198}$
5		0.4	1.5%	$y = 18.72x^{0.181}$
6		0.35	1.5%	$y = 21.69x^{0.175}$
7	400	0.48	-	$y = 17.40x^{0.197}$
8		0.4	-	$y = 20.01x^{0.15}$
9		0.3	1.5%	$y = 30.82x^{0.142}$
10	450	0.45	-	$y = 16.45x^{0.161}$
11		0.35	0.3%	$y = 19.82x^{0.185}$
12		0.3	1.5%	$y = 22.97x^{0.195}$

Conclusions

The average value of fineness modulus for recycled aggregates was found to be 7.638 which is approximately 20% higher than the natural coarse aggregate.

The average value of specific gravity for RA was found to be 2.49 which show a slightly lesser value as compared to natural coarse aggregates.

The average value of water absorption for RA was found to be 2.15% which is slightly greater than that of natural coarse aggregates.

For same cement content with minimum W/C, the compressive strength of RCA is increased.

By increasing sp dosage, the compressive strength of RCA is increased and the concrete becomes more workable.

Among other mixes, cement content of 400kg/m^3 was found to be optimum result.

Existing equations relating to compressive strength and age of concrete for RCA were presented and a potential equation for RCA has been appraised by fitting to the experimental data.

The developed equations provides a stronger relationship between compressive strength and age of concrete with a model regression statistic R^2 upto 0.9.

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