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ENGLISH VERSION...

Statistical characteristics of compressive strength of normal & high strength concrete and concrete made with recycled aggregate

Características estadísticas de las resistencias a la compresión del hormigón normal y de alta resistencia y del hormigón preparado con materiales reciclados

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Abstract

The paper presents the statistical analysis on the compressive strength of concrete with strength ranging from 30 MPa to 130 MPa. To obtain these concrete strengths, concrete mixes with virgin aggregates were prepared with four different wate r to cementitious content (w/c) ratios i.e., 0.45, 0.36, 0.24, and 0.18. With w/c ratio of 0.45, a mix is also designed using recycled construction and demolition coarse aggregate to compare statistical characteristics with respect to concrete made using virgin aggregates. The presented statistical analysis includes measure of central tendency, dispersion of the data, distribution shape properties, and precision of the mean. A normal and a log-normal distribution has been established and validated for the experimental data set of all the mixes. A correlation has also been established for the compressive strength of 100mm cube and 150mm cube. Analysis shows an increase in dispersion of data with increase in the mean compressive strength of the mix. The mix with Construction and demolition waste aggregate shows a higher standard deviation than the mix with virgin aggregates at the same w/c ratio. The correlation curve for the compressive strength of 100 mm and 150 mm size cubes, shows a conversion factor of 1.04, suggesting an insignificant difference of the compressive strength values of 100 mm and 150 mm cubes for the mix studied.

Keywords: Characteristic strength; recycled aggregate; standard deviation; statistical analysis.

Resumen

En este estudio se presenta un análisis estadístico de las resistencias a la compresión del hormigón, con resistencias que varían desde los 30MPa a los 130 MPa. Para obtener dichas resistencias, se prepararon mezclas de hormigón con áridos vírgenes para las siguientes cuatro diferentes razones agua-cemento (a/c): 0,45, 0,36, 0,24 y 0,18. Así, por ejemplo, para una razón a/c de 0,45, también se diseñó una mezcla usando áridos gruesos reciclados de construcción y demolición a fin de comparar las características estadísticas con las del hormigón preparado con áridos vírgenes. El análisis estadístico incluye la medida de tendencia central, dispersión de los datos, propiedades de la forma de distribución y precisión de la media. Se estableció y validó una distribución normal y log-normal para el conjunto de datos experimentales de todas las mezclas. También se estableció una correlación para la resistencia a la compresión los cubos de 100 mm y 150 mm. El análisis muestra un aumento en la dispersión de los datos al aumentar la resistencia a la compresión media de la mezcla. La mezcla con árido de residuos de construcción y demolición presenta una desviación estándar mayor que la mezcla con áridos vírgenes a la misma relación a/c. La curva de correlación para la resistencia a la compresión de los cubos de 100 mm y 150 mm muestra un factor de conversión de 1,04, sugiriendo una diferencia insignificante de los valores de resistencia a la compresión de los cubos de 100 mm y 150 mm para la mezcla estudiada.

Palabras clave: Resistencia característica; áridos reciclados; desviación estándar; análisis estadístico

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1. Introduction

Innovations in the concrete technology has made it possible to design higher strength concrete (Arora et al., 2017) as well as concrete with waste utilization (Ojha et al., 2021); (Ojha et al., 2021); (Topçu and Günçan, 1995). Based on its compressive strength, concrete can be classified into three major group. This includes (i) Normal Strength concrete (<50MPa), (ii) High Strength Concrete (50MPa to 100MPa) and very high strength concrete (>100MPa). Higher strength concrete shows an improved mechanical (Arora et al., 2016); (Ojha et al., 2021); (Singh et al., 2018) and fracture (Ojha et al., 2022); (Patel et al., 2020) characteristic than the normal strength concrete. Well established and standardised mix design parameters are available for Normal strength concrete and some initial range of high strength concrete in standard codes. But an extensive verification and standardisation of the mix design parameters needs to be done for entire range of high and very high strength concrete. Another category of concrete catering to the environmental aspect is construction and demolition (C&D) waste aggregate concrete. The mix design for the C&D waste aggregate concrete is being done using the corresponding normal aggregate concrete. A verification of the method is needed and any change require needs to be proposed.

Design and development of any concrete mix for a particular strength grade requires statistical characteristics of compressive strength for that particular concrete mix particularly, its mean compressive strength value and standard deviation. Standard deviation of compressive strength of concrete shows the fluctuations and variations in the strength of concrete. Higher value of standard deviation of strength indicates higher degree of inconsistency in quality of concrete and will lead to higher value of trial strength (Zhang et al., 2013). Standard deviation for any particular grade of concrete mix is used for evaluation of its target mean strength for which the concrete shall be designed and developed. As per IS 10262: 2019, target strength for mix proportioning of conventional concrete mix is calculated as per the formula mentioned below in (Equation 1).

$$f_m \geq f_{ck} + 1.65\sigma \qquad (1)$$

Where,
fm = target mean compressive strength at 28 days in N/mm2
fck = characteristic compressive strength at 28 days in N/mm2
σ = standard deviation in N/mm2

In IS 10262: 2019, standard deviation (σ) shall either be calculated based on compressive strength results of at least 30 cubes at site. In absence of site data, (Table 2) of IS 10262: 2019 suggests values of standard deviation based on grade of concrete mix for design of conventional concrete mix of a particular grade.

Construction activities occurring to meet the demands of rapid urbanisation and industrialisation has led to significant consumption of natural resources, particularly aggregates by the construction industry which has led to over exploitation of natural reserves resulting into their depletion and subsequently causing several environmental issues (Wang et al., 2020). Presently, around 11.5 billion tonnes of concrete is being consumed per year all across the globe and this rate of consumption is estimated to increase to 18 billion tonnes per year by 2050. On a parallel note, massive scale of developmental activities has also created a major issue of disposal of construction waste which are generated from deteriorated and obsolete structures (Chandra, 2004); (Topçu and Günçan, 1995). To cope up with the increasing demand of aggregates, conservation of natural resources and find a sustainable alternative to virgin aggregate, attempts are being made to enhance the utilisation of recycled aggregates as a replacement of conventional aggregates for making concrete (Ojha et al., 2021). Physical characteristics of recycled aggregates are not at par with those of conventional aggregates and there is a significant level of inconsistency in the behaviour of recycled aggregates which will affect the overall mechanical performance of hardened concrete (Malešev et al., 2010).

Research work is being carried out all across the globe to study the behaviour of concrete made with recycled aggregates as replacement of conventional aggregates and compare its performance with concrete made with conventional aggregates. Several researchers have reported that compressive strength of concrete made with recycled aggregates is around 20 to 25% lower than that of concrete of similar mix composition made using conventional aggregates. Such performance of concrete made with recycled aggregates can be attributed to different physical characteristics of recycled aggregate such as higher water absorption and higher porosity of recycled aggregates in comparison to conventional aggregates along with weaker interfacial transition zone (ITZ) between hydrated cement matrix and recycled aggregate (Mandal and Gupta. A, 2002). In view of above, several studies (Limbachiya et al., 1998); (Olorunsogo, n.d.); (Xiao et al., 2005a) were conducted to study the compressive strength of concrete prepared using different proportions of recycled aggregates and the findings of those studies show degree of variability in compressive strength of concrete increases with increase in the proportion of recycled aggregates in concrete, which ultimately leads to higher standard deviation values for compressive strength of concrete made with recycled aggregates in comparison to concrete made with conventional aggregates. Statistical parameters of compressive strength of any concrete mix such as mean strength, standard deviation along with probabilistic distribution are very critical for design, development and analysis of structural members to be made using that concrete mix (Xiao et al., 2005b). In the absence of experimental data, values of statistical parameters especially standard deviation are assumed (based on the grade of concrete) as per the values mentioned in codes. However, the value mentioned in codes are generalised values (for concrete made with conventional materials)

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and may not be directly applicable to any new concrete made using new type of aggregate (such as recycled aggregates). Therefore, it is very important to evaluate the standard deviation of concrete made using any new unconventional aggregate and compare it with values specified in the national/international codes and establish its applicability for concrete made using recycled aggregates.

The study presents statistical analysis on five different mixes. Four mixes correspond to different w/c ratios and the fifth mix is prepared using construction and demolition waste aggregate. Based on the experimental data a normal and a log-normal model has been proposed. The study also finds a correlation between the compressive strength of a particular mix for cubes with 100 mm and 150 mm size.

2. Research significance

The research significance of the present study can be given as follow:

a) *Indian standard code provides standard deviation for calculating the target mean strength for a mix design of the concrete with grade between M 10 to M 100. The present study will attempt to validate the adopted standard deviations and suggest any change if required.*
b) *Indian standard code does not give a separate value of standard deviation for construction and demolition waste aggregate concrete. The present study attempted to find the difference between the standard deviation of virgin aggregate concrete and construction and demolition waste aggregate concrete.*
c) *Test for the compressive strength in Indian sub-continent is popularly performed on the 150 mm cubes, but for higher strength concrete 150mm cubes needs a compression testing machine of higher load capacity. Pertaining to this issue the study has been attempted to find a correlation between the recorded compressive strength for 100mm and 150mm cubes.*

3. Materials and mix proportions

The present section details the used materials and the mix proportion for the making the concrete used in the study.

3.1 Materials

Conventional coarse aggregates (20 mm and 10 mm), conventional fine aggregate(Arora et al., 2019); (Arora et al., 2021); (Singh et al., 2021) and recycled coarse aggregate (20 mm and 10 mm) were characterised for different physical parameters mentioned in IS 383: 2016 and their physical characteristics have been tabulated below in (Table 1). Conventional natural riverbed sand confirming to Zone II as per IS: 383-2016 was used as fine aggregate. The recycled coarse aggregates were collected from a plant situated in Delhi, India (as show in (Figure1).

Figure 1. C&D Waste Plant at Delhi, India

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Table 1. Properties of Aggregates

Property		Conventional Coarse aggregates 20 mm	Conventional Coarse aggregates 10 mm	Recycled Coarse aggregates 20 mm	Recycled Coarse aggregates 10 mm	Fine Aggregate
Specific gravity		2.83	2.83	2.39	2.37	2.64
Water absorption (%)		0.3	0.3	4.58	4.75	0.8
Sieve Analysis Cumulative Percentage Passing (%)	40 mm	100	100	100	100	
	20mm	98	100	93	100	100
	10 mm	1	68	2	74	100
	4.75 mm	0	2	1	6	95
	2.36 mm	0	0	0	0	87
	1.18 mm	0	0	0	0	68
	600 μ	0	0	0	0	38
	300 μ	0	0	0	0	10
	150 μ	0	0	0	0	2
	Pan	0	0	0	0	0
Abrasion, Impact & Crushing Value		19, 13, 19	-	24, 25, 20	-	-

For preparation of concrete mixes, commercially available Ordinary Portland cement (OPC 53 Grade) along with fly ash (conforming to requirements of IS 3812 (Part-I): 2003) and silica fume (conforming to requirements of IS 15388: 2003) were used as cementitious binders in this study. Chemical and physical characteristics of OPC 53, fly ash and silica fume (Ojha, et al., 2022); (Ojha et al., 2021) have been tabulated in (Table 2). Polycarboxylic (PCE) based chemical admixture complying with requirements of IS 9103 has been used for all the mixes to achieve suitable degree of initial workability. Water complying with requirements of IS: 456-2000 was used for preparation of concrete mixes.

Table 2. Physical and Chemical Characteristics of OPC, fly ash and silica fume

Characteristics		OPC -53 Grade	Silica Fume	Fly Ash
Physical Tests				
Fineness (m^2/kg)		320.00	22000	403
Soundness (Autoclave) (%)		00.05	-	-
Soundness (Le Chatelier's) (mm)		1.00	-	-
Setting Time Initial (min.) & (max.)		170.00 & 220.00	-	-
Specific gravity		3.16	2.24	2.2
Chemical Tests				
Loss of Ignition (LOI) (%)		1.50	1.16	-
Silica (SiO_2) (%)		20.38	95.02	-
Iron Oxide (Fe_2O_3) (%)		3.96	0.80	-
Aluminium Oxide (Al_2O_3)		4.95	-	-
Calcium Oxide (CaO) (%)		60.73	-	-
Magnesium Oxide (MgO) (%)		4.78	-	-
Sulphate (SO_3) (%)		2.07	-	-
Alkali (%)	Na_2O & K_2O	0.57 & 0.59	-	
Chloride (Cl) (%)		0.04	-	-
IR (%)		1.20	-	-
Moisture (%)		-	0.43	-

3.2ª Concrete mix proportions

Some of the commonly used mix design methods available are British DoE method of BS, American Concrete Institute Method and mix design method as per IS:10262. In the study, four conventional concrete mixes were prepared as per IS:10262 using 100% conventional coarse and fine aggregates at water to cementitious content ratios of 0.45, 0.36, 0.24 and 0.18. One mix was prepared using 100% recycled coarse aggregates at water to cementitious content ratios of 0.45. Chemical admixture dosage was varied for individual mixes to keep slump of fresh concrete in the range of 75 to 100 mm. For conducting studies, the concrete mixes were prepared in pan type concrete mixer. The laboratory conditions of temperature and relative humidity were monitored during the different ages at 27±2oC and relative humidity 65% or more. The specimens were taken out from the tank and allowed for surface drying and then tested in saturated surface dried condition.

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Concrete mix details for conventional concrete mixes at water to cementitious binder ratio of 0.45, 0.36, 0.24 and 0.18 has been tabulated in (Table 3). Mix composition for concrete prepared using 100% recycled coarse aggregates at water to cementitious binder ratio of 0.45 has been tabulated in (Table 4).

Table 3. Mix Design Details of mixes prepared using conventional aggregates

Mix Id	W/C	Total Cementitious Content (OPC+ Fly ash + Silica Fume) (Kg/m^3)	Water Content (Kg/m^3)	Admixture % by weight of Cement	Fine Aggregate (Kg/m^3)	Conventional Coarse Aggregate (Kg/m^3)	
						10 mm	20 mm
A	**0.45**	**362** (290+72+0)	163	0.40	650	777	518
B	**0.36**	**417** (334+83+0)	150	0.35	726	730	487
C	**0.24**	**600** (400+125+75)	140	1.00	680	732	402
D	**0.18**	**750** (548+112+90)	135	1.25	536	640	427

Table 4. Mix composition of concrete mix prepared using 100% recycled coarse aggregates

Mix Id	W/C	Total Cementitious Content (OPC+ Fly ash + Silica Fume) (Kg/m^3)	Water Content (Kg/m^3)	Admixture % by weight of Cement	Fine Aggregate (Kg/m^3)	Recycled Coarse Aggregate (Kg/m^3)	
						10 mm	20 mm
E	**0.45**	**362** (290+72+0)	163	0.80	650	656	437

4. Test results and discussions

4.1ª Statistical Parameters for the Compressive Strength Datasets

The statistical parameters for the compressive strength values of the mixes have been presented in (Table 5). Statistical parameters studied includes measure of central tendency, dispersion, distribution shape properties and the precision of the mean.

4.2 Probability Distribution Characteristic of the Compressive Strength

The histogram for the distribution of the compressive strength datasets for the mixes has been shown in (Figure 2(A-E)). Histograms suggests that the distribution of the compressive strength data assumes a normal distribution and log-normal distribution. And a model curve can be fitted to the distribution reasonably. The normal and log-normal distribution curve has been overlapped over the histograms. The details of the proposed normal and log-normal distribution fit for the mixes has been presented in the subsequent sections.

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***Table 5.** Statistical Parameters for the compressive strength data*

Mix Id	A	B	C	D	E
Central Tendency					
Mean	43.66	62.59	89.11	107.54	38.34
Median	42.79	62.18	88.05	107.4	38.76
Dispersion					
Standard Deviation	3.65	4.12	5.18	8.53	4.89
Sample Variance	13.34	16.94	26.82	72.76	23.91
Range	12.56	13.44	19.42	33.3	21.40
Distribution Shape Properties					
Kurtosis	-0.65	-1.13	-0.79	0.04	-0.37
Skewness	0.35	-0.02	0.27	0.70	0.26
The precision of the mean					
Standard Error	0.69	0.68	0.82	1.27	0.47
Confidence Level (95.0%)	43.66±1.42	62.59±1.37	89.11±1.66	107.54±2.56	38.34±0.93

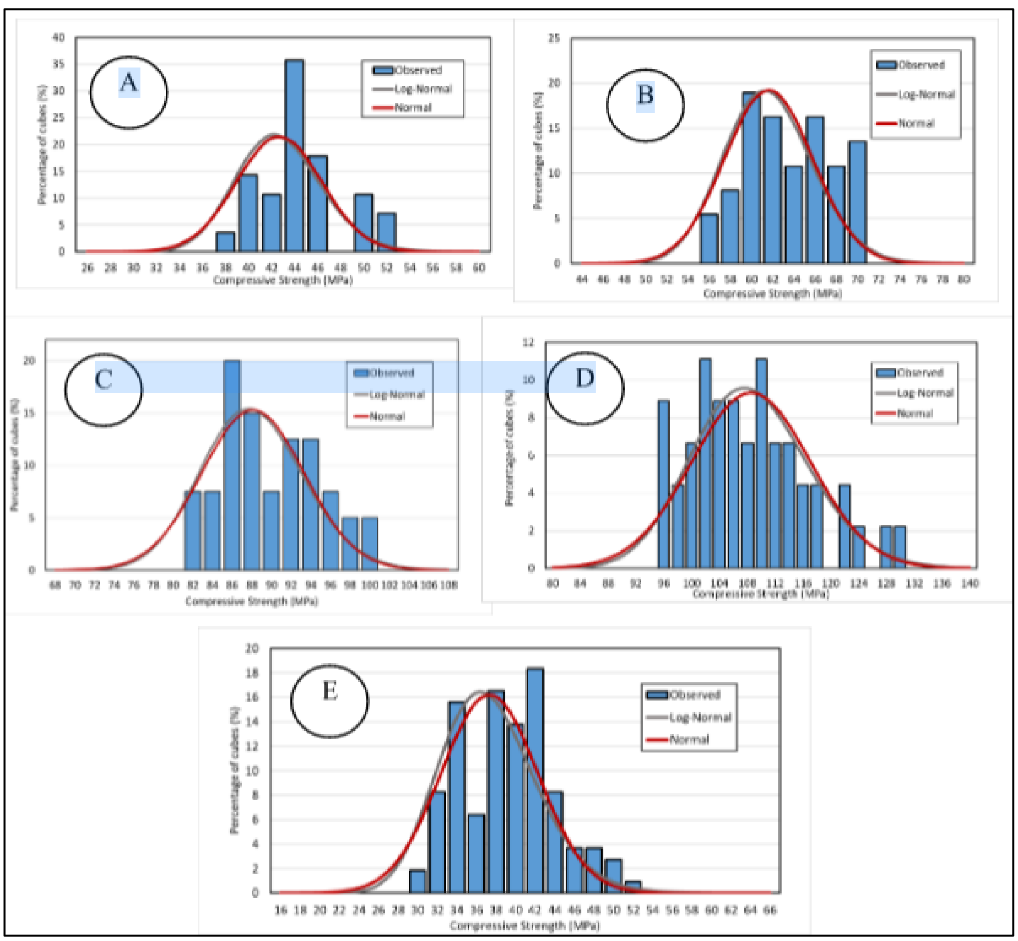

Figure 2. (A-E) Observed compressive strength and modelled distribution curves for mix A to E

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Normal distribution and Log normal distributions considered has two characteristic values. These are mean and the standard deviation. Based on the mean and standard deviation values a normal and log-normal model can be presented for the compressive strengths. The mean and standard deviation vales has been adopted as calculated in the previous section for each of the mix.

In order to verify whether the assumed model is a good representation of the datasets or not, Pearson's χ2-test has been performed. The hypothesis H for the test is given for the normal distribution in (Equation 2) and for log-normal distribution in (Equation 3):

$$f_{cu} \sim N(\mu_{f_{cu}}, \sigma^2{}_{f_{cu}}) \quad (2)$$

$$f_{cu} \sim LN(\mu_{\ln(f_{cu})}, \sigma^2{}_{\ln(f_{cu})}) \quad (3)$$

The result of the χ2-test is shown in (Table 6) and (Table 7). As can be seen from the table for all the mixes our assumed hypothesis is acceptable at 95% confidence level. The proposed normal distribution can be assumed to represent the distribution of the compressive strength data for all the mix designs.

Table 6. Chi-square test for Normal distribution

Mix ID	χ^2 -Value	P-Value	Test
A	27.92	0.06	>0.05, Accept
B	24.91	0.73	>0.05, Accept
C	14.27	0.77	>0.05, Accept
D	17.60	0.96	>0.05, Accept
E	35.99	0.07	>0.05, Accept

Table 7. Chi-square test for Log-Normal distribution

Mix ID	χ^2 -Value	P-Value	Test
A	24.95	0.13	>0.05, Accept
B	23.79	0.78	>0.05, Accept
C	13.58	0.81	>0.05, Accept
D	15.49	0.99	>0.05, Accept
E	32.04	0.16	>0.05, Accept

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4.3 Distribution Parameters and Probability Density Functions of the Compressive Strength

The model parameters for the normal distribution proposed for the mix has been presented in (Table 8) and (Table 9). The value of the characteristic compressive strength of the mix can be calculated using (Equation 4) as presented below:

$$f_m \geq f_{ck} + 1.65\sigma \quad (4)$$

Characteristic strength represents the lower 5% confidence interval of the probability distribution and the mean represents 50% confidence interval. The confidence interval represents the percentage of area of the probability density curve for the proposed models.

Table 8. Normal distribution model

Normal Distribution			Confidence value				
Mix Id	Mean	SD	5% Lower	25% Lower	50%	25% Upper	5% Upper
A	43.66	3.65	37.66	41.20	43.66	46.13	49.85
B	62.59	4.12	55.82	59.82	62.59	65.37	69.57
C	89.11	5.18	80.59	85.61	89.11	92.60	97.89
D	107.54	8.53	93.51	101.79	107.54	113.29	122.00
E	38.34	4.89	30.29	35.04	38.34	41.63	46.63

Table 9. Log distribution model

Log-Normal Distribution				Confidence value				
Mix Id	Mean(Log)	SD(Log)	Exp (Mean)	5% Lower	25% Lower	50%	25% Upper	5% Upper
A	3.77	0.08	43.52	37.97	41.15	43.52	46.02	49.88
B	4.13	0.07	62.46	56.04	59.74	62.46	65.30	69.62
C	4.49	0.06	88.96	80.89	85.56	88.96	92.50	97.84
D	4.67	0.08	107.22	94.35	101.74	107.22	112.99	121.84
E	3.64	0.13	38.03	30.83	34.89	38.03	41.45	46.91

(Figure 3) shows all the probability density curves for the normal and log-normal models for all the mixes. The curves gradually spread out with increase in the mean compressive strength of the mixes depicting an increasing standard deviation.

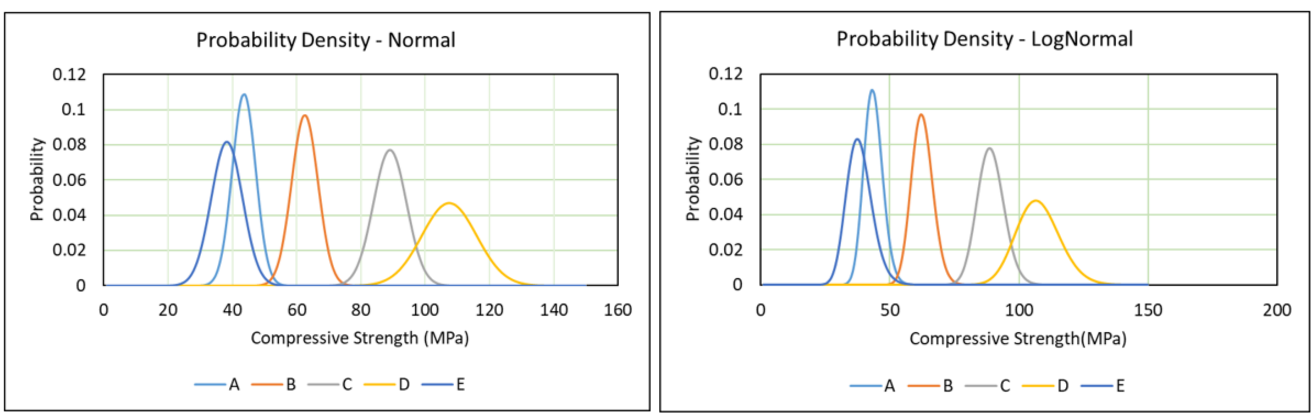

Figure 3. Probability density models for mix A, B, C, D and E

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4.4 Comparison of results from The Indian standard code

Indian standard code for concrete, IS 456 gives a fixed value of the standard deviation for the mixes with a particular 28-day compressive strength. IS code groups the mixes based its characteristic strength into different grades. For a particular grade of concrete. The target mean compressive strength is dependent on the standard deviation for the mix. This makes standard deviation a very critical factor for any mix design. For safety purposes the fixed standard deviation in the code should be slightly higher than the practically observed standard deviation values. Based on the observed datasets for the compressive strength, the standard deviation values and the characteristic strength pertaining to the normal and log normal distribution proposed in the study has been presented in the (Table 10). As a general observation it can be inferred that, with increase in the mean compressive strength of the mixes the value of standard deviation increases.

Table 10. Comparison with Indian standard code

Mix Id	Experimentally Obtained Data				Indian Standard Code IS 516		
	Mean	Standard Deviation	Characteristic strength (normal distribution)	Characteristic strength (log-normal distribution)	Equivalent Grade (characteristic strength)	Standard deviation	Target Mean Strength
A	43.66	3.65	37.66	37.97	M35	5.0	43.25
B	62.59	4.12	55.82	56.04	M55	5.0	63.25
C	89.11	5.18	80.59	80.89	M80	6.0	89.90
D	107.54	8.53	93.51	94.35	M95	6.0	104.9
E	38.34	4.89	30.29	30.83	M30	5.0	38.25

From the table it can be also observed that for the mixes with mean compressive strength up to M80 the observed characteristic strength is higher than the equivalent grade for the particular target mean strength, suggesting a safer value of the standard deviation. But as can be observed for the for the mix D the observed mean strength is higher than the target mean strength for M95 but the observed characteristic strength is lower than 95. This suggests an underestimated value of the standard deviation in the IS code for M95. The higher variation the concrete above M90 can be credited to the variations in achieving the super optimization required to achieve the higher strength. Also for the mixes of higher strength, specialised materials like silica fume, Ultra fine particles and different curing regimes are followed. All these results in a higher variation in the obtained compressive strength for a single mix of prepared for higher strength.

Mix E pertains to the Construction and Demolition waste aggregate mix. Mix A is similar to Mix E in terms of its w/c ratio and is prepared from the virgin aggregate. On comparing both the mix A and B, it can be observed that, although the mix E has a slightly lower mean compressive strength, it shows a higher standard deviation value than the mix A. The variation grater variation in mix E is caused by the inhomogeneity in the aggregate properties. Due to the variation of the aggregate mix E assumes a higher value. Also from the table we observe that mix is gives a safer characteristic strength based on the modelled normal and log normal probability distribution curves. The margin of safety is extremely small. Therefore, to keep a safe margin for concrete with construction and demolition waste aggregate a factor of 1.4 should be used for the particular strength. 1.4 is the ratio of the observed standard deviation for the mix E and mix A. The experimental characteristic strength value of the mixes has been shown in the figure 4. The shaded area represents 5% of the area of the entire bell curve.

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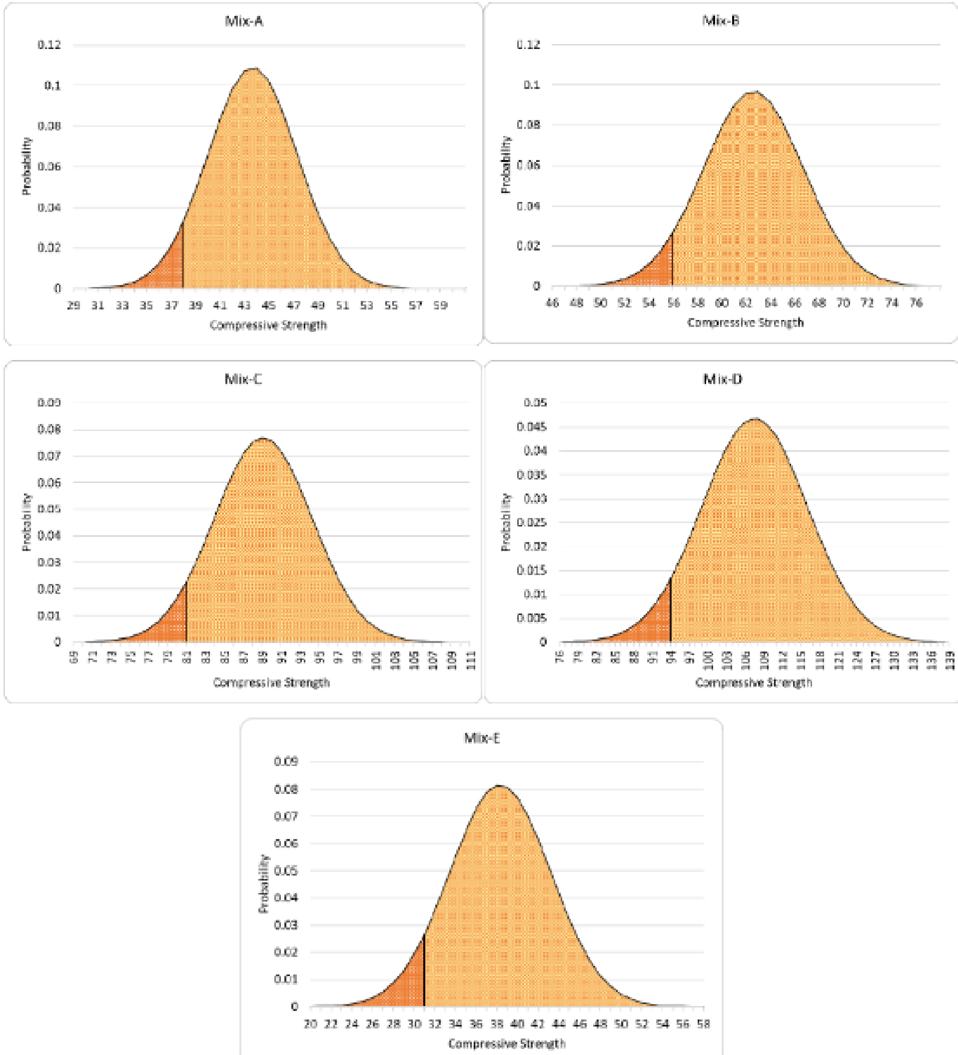

Figure 4. Characteristic strength calculation for experimental data

5. Effect of size of the cubes on the compressive strength

Based on the experimental data on compressive strength of 100mm and 150mm cubes tested in the past by the authors, a correlation on the 100mm and 150mm cube's compressive strength value has been presented in this section. The correlation curve has been shown in (Figure 5).

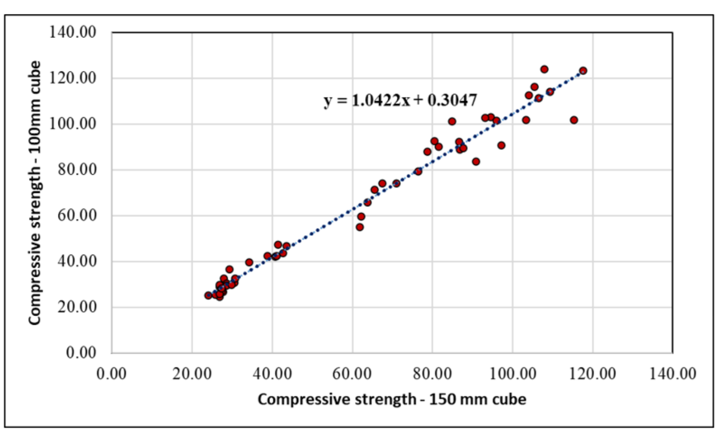

Figure 5. Correlation between the observed compressive strength for 100mm and 150mm cubes

The tested cubes pertain to different w/c ratios and are tested over a past several years. The cube strength approximately varies from 20 MPa to 130 MPa. The correlation has been presented in (Figure 00). Compressive strength value of 150mm cube has been presented on the X-axis and for the corresponding mix, the compressive strength of 100 mm cube has been presented on Y-axis. The observed compressive strength approximately fits a straight line with slope of 1.042. The factor 1.042 can be approximated as unity and it can be suitably stated that the compressive strength values for a particular mix is approximately equal for the 100 mm and 150 mm cubes.

6. Conclusions

The study presents a statistical analysis on the compressive strength data of five different mixes corresponding to four different w/c ratios. The w/c ratios are 0.45, 0.36, 0.24 and 0.18. Four mixes were prepared with virgin aggregates corresponding to each w/c ratios to obtain the concrete with compressive strength ranging from 30 MPa to 130MPa. One of the mix is prepared with construction and demolition waste aggregate and w/c ratio of 0.45. The data for this mix is compared with the corresponding mix prepared with virgin aggregates. The study also presents an analysis on compressive strength values of 100mm and 150mm sized concrete cubes of different strength ranging from 20 MPa to 120 MPa. The findings from the study can be summarized as follows:

1.) Dispersion of the compressive strength data increases with the increase in mean value of the compressive strength of a mix.
2.) One of the most important measure of the dispersion of the data is standard deviation. Based on the standard deviation, characteristic strength of the concrete is defined in the Indian Standard codes. The standard deviation of the concrete of grade M 65 to M 100 is adopted to be 6.0 in the IS 456. The present study found the standard deviation adopted by IS code holds good up to M80 only. For Concrete with mean strength of 107 MPa (M95), results suggest the standard deviation value of 9.0.
3.) Indian standard codes do not provide separate standard deviation values for the concrete with construction and demolition waste aggregate. The present study suggests a higher value of standard deviation for the construction and demolition waste aggregate concrete for the same w/c ratio of the virgin aggregate concrete. Considering the similar margin for the adopted standard deviation in the Indian standard code, a 40% higher value, i.e. 1.4 time the standard deviation for virgin aggregate concrete can be adopted for construction and demolition waste aggregate concrete or in other words standard deviation for C&D waste aggregate concrete can be increase to 7 from 5 for strength level upto M50.
4.) The size effect of the tested cube on the observed compressive strength of the concrete in compression testing has been studied and a conversion factor of 1.04 has been observed for the cubes of 100mm size and 150mm size for the compressive strength of 20 MPa to 120 MPa. From the results it can be concluded that there is negligible difference between the compressive strength recorded for 100mm and 150mm cubes for compressive strength up to 120 MPa.

7. References

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