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Compressive Strength of Concrete containing Fly Ash, Copper Slag, Silica Fume and Fibres - Prediction

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Abstract

Experiments have been conducted to study the effect of addition of fly ash, copper slag, silica fume together with/without steel fibres or/and polypropylene fibres on 28-day compressive strength of concrete. While fly ash and copper slag are used for partial replacement of cement and fine aggregate respectively, defined quantity of steel fibres or/and polypropylene fibres were simply added to the mix proportions considered for the study. It is found from the experimental study that, in general, irrespective of the presence or absence of fibres, (i) for a given copper slag-fine aggregate ratio, increase in fly ash-cement ratio decreases 28-day compressive strength of the concrete and, the rate of decrease in the 28-day strength decrease with increase in copper slag-sand ratio (ii) for a given fly ash-cement ratio, increase in copper slag-fine aggregate ratio increases 28-day compressive strength of the concrete. Approximate equation is proposed to determine the 28-day compressive strength of the concrete containing fly ash, copper slag, silica fume and fibres.

Keywords: Concrete, Compressive strength, Fly Ash, Copper Slag, Steel fibres, Polypropylene fibres

1.0 INTRODUCTION

It has been reported that manufacture of Portland cement accounts for 6-7% of total carbon-di-oxide emission produced by humans1. Therefore, to curb further declination of environment, it would be better to look for materials to replace cement, atleast to some extent if not 100%, in the construction industry. Fly ash and copper slag are industrial wastes which have played vital role in replacing cement and fine aggregates, in making concrete. Poon et al.[2] have studied the effect of addition of large volume of low calcium fly ash in concrete. They have observed that 28-day compressive strength of 80MPa could be obtained with water-cement of 0.24 together with fly ash content of 45%. Heat of hydration, chloride diffusivity, degree of hydration and pore structures of fly ash/cement concrete are other parameters that have been explored by them. Siddique[3] has studied the effect of replacement of cement by fly ash in affecting the compressive strength, splitting tensile strength, flexural strength, modulus of elasticity and abrasion resistance of fly ash concrete. It was observed that addition of fly ash decreased the performance of the concrete with respect to the parameters that have been explored. He also concludes that fly ash can be used to replace only upto 50% of cement content.

Rajamane et al. [4] have proposed formula to determine the compressive strength of concrete in which fly ash has been used as sand replacement material. Atis and Karahan[5] have studied the properties of concrete containing fly ash and steel fibres. They have observed that the inclusion of steel fibres improved the tensile strength, drying shrinkage and freeze-thaw resistance but reduced workability and sorptivity coefficient. It has been noted by them that fly ash concrete behaved similar to that of Portland cement concrete. Al-Jabri et al.[6] have investigated the effect of using copper slag as a material to replace fine aggregate in concrete. It has been observed that addition of copper slag improved the density of the concrete together with rapid increase in the workability with increased percentage of copper slag. Also, they have noted that upto 50% replacement of fine aggregate yielded strength nearly to that of control mix. Khanzadi and Behnood[7] have studied the mechanical properties of high strength concrete containing silica fume as replacement for cement and copper slag as replacement for coarse aggregate.

They observed that addition of copper slag improved the 28-day compressive strength of the concrete. Mazloom et al.[8] have studied the short-term and long-term mechanical properties of high-strength concrete containing different levels of silica fume. They have observed that increasing the quantity of silica fume reduced workability but increased 28-day compressive strength and secant modulus. Also they noted that, while the addition of silica fume did not significantly affect total shrinkage, autogenous shrinkage increased as the amount of silica fume increased.

2.0 SCOPE OF THE STUDY

Since the literature that deal with replacing both the cement and fine aggregates with suitable substitutes are very scarce, the scope of the present study has been framed so as to study the effect of addition of fly ash, copper slag, silica fume together with/without steel fibres or/and polypropylene fibres on 28-day compressive strength of concrete. The target compressive strength for the control specimen is chosen as 58MPa. While fly ash and copper slag are used for partial replacement of cement and fine aggregate respectively, defined quantity of steel fibres or/and polypropylene fibres are simply added to the mix proportions considered for the study. The 28-day compressive strength is determined by testing cured 150 mm concrete cubes. The mix proportions considered for the experimental study are given in Table 1.

It can be seen from Table 1 that the amount of cement replaced by fly ash is varied from 40% to 60% (by weight). For each percentage of replacement of cement by fly ash, the amount of fine aggregate replaced by copper slag is varied from 30% to 60% (by weight). Amount of silica fume and water-binder ratio are kept constant as 6% of binder content and 0.35, respectively, for all the specimens. Amount of super plasticizer (Enfiiq super plast-400) is varied from 2.0 to 2.2% by weight of binder content to maintain appropriate slump. Amount of steel fibres and polypropylene fibres added are based on the percentage of volume of binder content. The percentage is 0.25% when both fibres are present and 0.5% when any one type of fibre is present.

Table 1: Mix proportions (in kg/m^3) considered for experimental study

Mix ID	*Cement*	*Fly ash*	*Silica fume*	*Fine aggregate*	*Copper Slag*	*Coarse aggregate*	*Steel fibre*	*Polypropylene Fibre*
S0	400	-	-	652.0	-	1294	-	-
S1	216	160	24	456.4	195.6	1294	-	-
S2	176	200	24	456.4	195.6	1294	-	-
S3	136	240	24	456.4	195.6	1294	-	-
S4	216	160	24	391.2	260.8	1294	-	-
S5	176	200	24	391.2	260.8	1294	-	-
S6	136	240	24	391.2	260.8	1294	-	-
S7	216	160	24	326.0	326.0	1294	-	-
S8	176	200	24	326.0	326.0	1294	-	-
S9	136	240	24	326.0	326.0	1294	-	-
S10	216	160	24	456.4	195.6	1294	2	-
S11	176	200	24	456.4	195.6	1294	2	-
S12	136	240	24	456.4	195.6	1294	2	-
S13	216	160	24	391.2	260.8	1294	2	-
S14	176	200	24	391.2	260.8	1294	2	-
S15	136	240	24	391.2	260.8	1294	2	-
S16	216	160	24	326.0	326.0	1294	2	-
S17	176	200	24	326.0	326.0	1294	2	-
S18	136	240	24	326.0	326.0	1294	2	-
S19	216	160	24	456.4	195.6	1294	-	2
S20	176	200	24	456.4	195.6	1294	-	2
S21	136	240	24	456.4	195.6	1294	-	2
S22	216	160	24	391.2	260.8	1294	-	2
S23	176	200	24	391.2	260.8	1294	-	2
S24	136	240	24	391.2	260.8	1294	-	2
S25	216	160	24	326.0	326.0	1294	-	2
S26	176	200	24	326.0	326.0	1294	-	2
S27	136	240	24	326.0	326.0	1294	-	2
S28	216	160	24	456.4	195.6	1294	1	1
S29	176	200	24	456.4	195.6	1294	1	1
S30	136	240	24	456.4	195.6	1294	1	1
S31	216	160	24	391.2	260.8	1294	1	1
S32	176	200	24	391.2	260.8	1294	1	1
S33	136	240	24	391.2	260.8	1294	1	1
S34	216	160	24	326.0	326.0	1294	1	1
S35	176	200	24	326.0	326.0	1294	1	1
S36	136	240	24	326.0	326.0	1294	1	1

3.0 MATERIALS PROPERTIES

The properties of the materials used for the preparing concrete are given below.

Table 2: Material properties

Description	Property
Cement	OPC 53 grade
Fly ash	Low calcium Class F Specific gravity = 2.04
Silica fume	Specific gravity = 2.02
Fine aggregate	Specific gravity = 2.64
Coarse aggregate	Specific gravity = 2.78
Super plasticizer	Enfiiq super plast 400
Copper slag	Specific gravity = 2.92 Fineness modulus = 3.47
Steel fibres	Fineness modulus = 7.85 Aspect ratio = 50 Tensile strength = 1100 MPa
Polypropylene	ASTM C 1116, Type III Fiber Length: [Graded] [Single-cut lengths] w\c ratio reduced to 0.3 from 0.40

4.0 ANALYSIS OF TEST DATA

The results of compression tests are given in Table 3 and presented graphically in Figures 1-8.

Table 3 28-day compressive strength of specimens (in MPa)

S.No.	Compressive Strength	
	7-days	28-day
S0	42.47	54.40
S1	38.16	48.87
S2	27.74	42.32
S3	22.30	32.77
S4	37.38	52.46
S5	38.17	49.47
S6	32.04	47.38
S7	33.96	53.69
S8	31.76	49.48
S9	13.75	23.45
S10	37.14	49.42
S11	29.33	43.91
S12	24.29	34.74
S13	39.35	54.26
S14	39.84	51.30
S15	34.01	49.00
S16	35.32	55.66
S17	33.70	50.89
S18	14.86	26.30
S19	36.53	48.56
S20	35.20	46.76
S21	23.66	31.60
S22	32.18	47.85
S23	33.11	41.54
S24	26.35	38.78
S25	42.38	50.94
S26	27.70	39.83
S27	17.92	28.30
S28	39.45	50.89
S29	33.40	44.31
S30	27.11	36.07
S31	40.54	48.72
S32	28.66	39.42
S33	27.69	44.22
S34	40.27	53.14
S35	27.95	44.96
S36	23.61	35.92

Note:
Notations used in the figures:- FA-C: Fly ash-cement ratio; CS-S: Copper slag-fine aggregate ratio

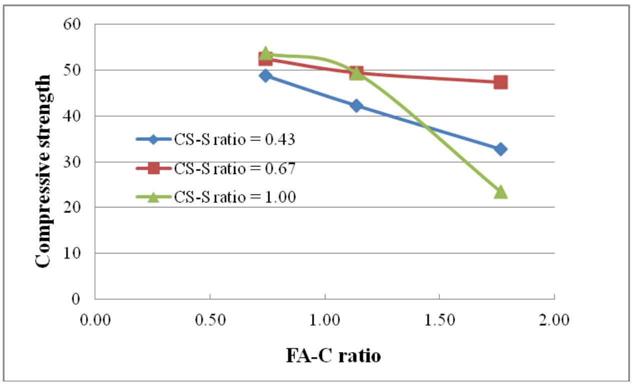

Figure 1: Compressive strength vs FA-C ratio [Specimens S1-S9: without fibres]

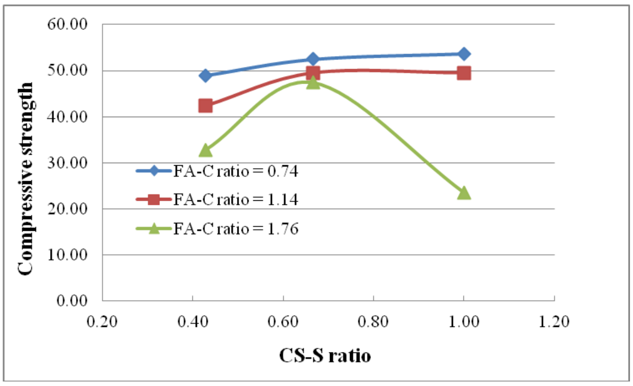

Figure 2: Compressive strength vs CS-S ratio [Specimens S1-S9: without fibres]

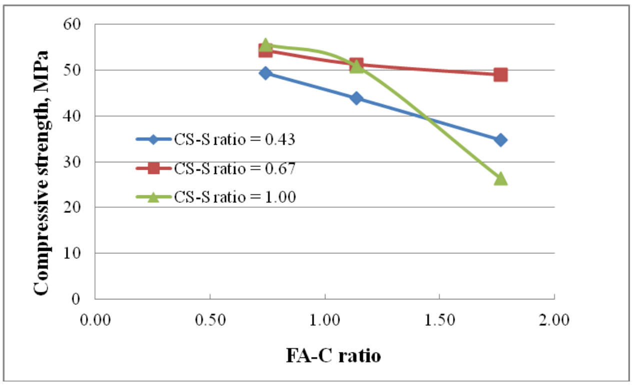

Figure 3: Compressive strength vs FA-C ratio [Specimens S10-S18: with steel fibres]

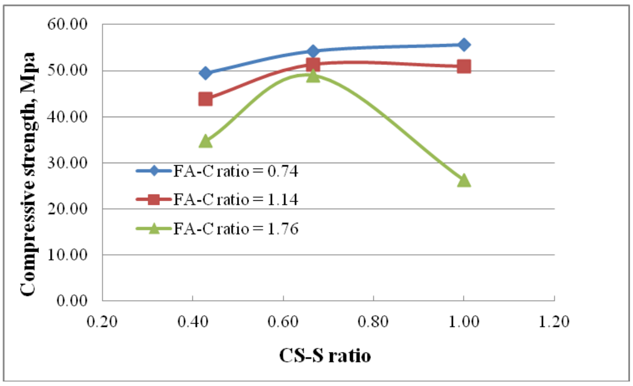

Figure 4: Compressive strength vs CS-S ratio [Specimens S10-S18: with steel fibres]

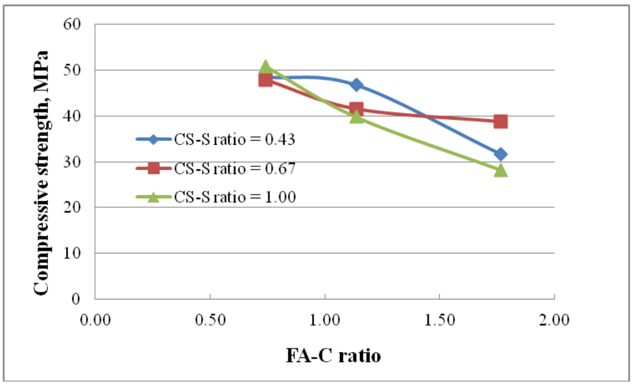

Figure 5: Compressive strength vs FA-C ratio [Specimens S19-S27: with polypropylene fibres]

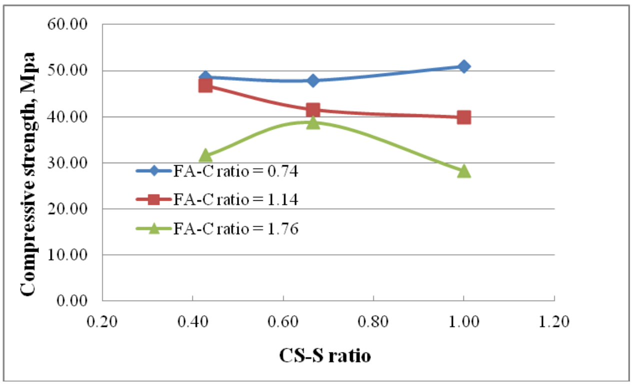

Figure 6: Compressive strength vs CS-S ratio [Specimens S19-S27: with polypropylene fibres]

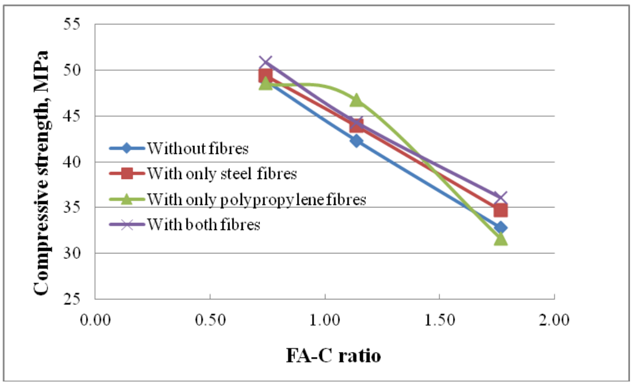

Figure 7: Effect of addition of fibres (CS-S ratio = 0.43)

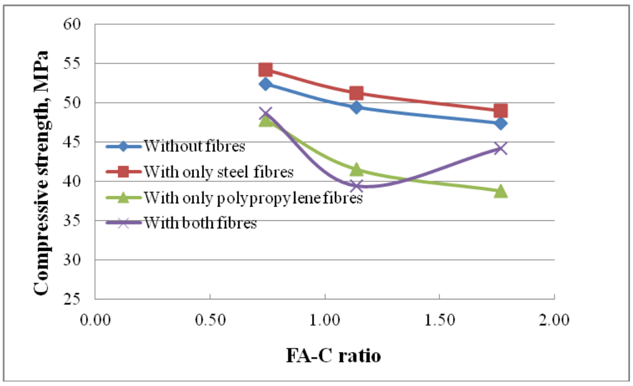

Figure 8: Effect of addition of fibres (CS-S ratio = 0.67)

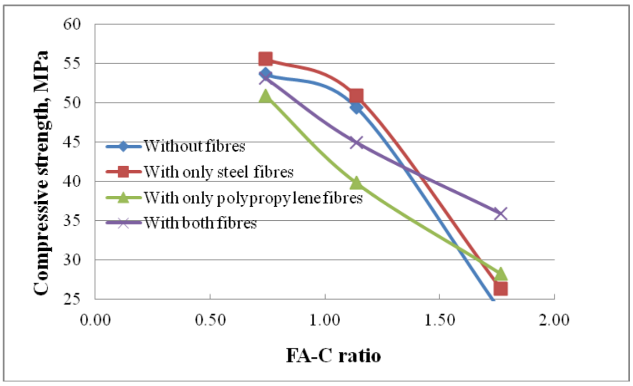

Figure 9: Effect of addition of fibres (CS-S ratio = 1.0)

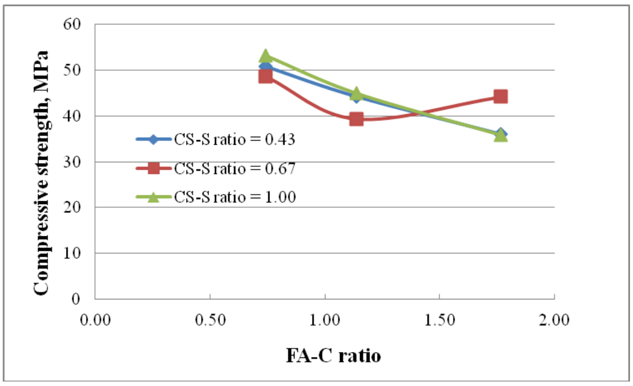

Figure 10: Compressive strength vs FA-C ratio [Specimens S28-S36: with both fibres]

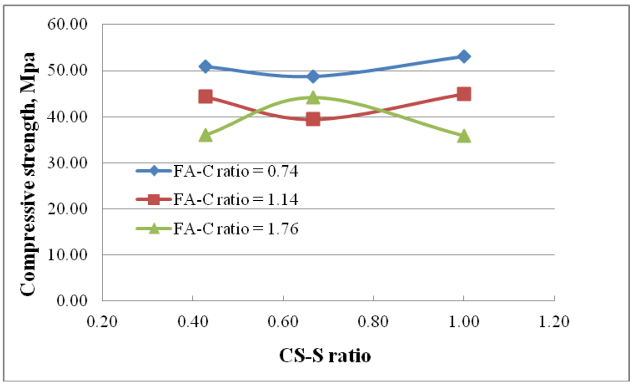

Figure 11: Compressive strength vs CS-S ratio [Specimens S28-S36: with both fibres]

From the Figures 1-11 the following inferences are made.

Inferences without considering the presence of steel and polypropylene fibres:

(i) for a given copper slag-fine aggregate ratio, increase in fly ash-cement ratio decreased 28-day compressive strength of the concrete and, the rate of decrease in the strength decreased with increase in copper slag-sand ratio and for a given fly ash-cement ratio, increase in copper slag-fine aggregate ratio increased 28-day compressive strength of the concrete.

(iii) for a given copper slag-fine aggregate ratio, the 28-day compressive strength of concrete seem to vary linearly with variation in fly ash-cement ratio and for a given fly ash-cement ratio, the 28-day compressive strength of concrete seem to vary non-linearly with variation in copper slag-fine aggregate. It is also interesting to note that, as long as both ratios (viz., fly ash-cement or copper slag-sand) are not ≈ ≥ 1.0, there seem to be no abrupt change in the trend of variation of 28-day compressive strength.

Recommendation: If fly ash is used for replacing the cement, it is recommended to substitute the fine aggregate also by copper slag to get the compressive strength comparable to that of the control mix but ensuring that not both the ratios (viz., fly ash-cement or copper slag-sand) are allowed to exceed 1.0.

Inferences considering the presence of steel and polypropylene fibres:

(iv) Generally, for all the specimens considered for this study, it is noted that the addition of steel fibres increased the 28-day compressive strength by around 3% on the average, but addition of polypropylene fibres decreased the 28-day compressive strength by around 3% on the average.

(v) Additions of polypropylene fibres seem to affect the linear variation of 28-day compressive strength with variation in fly ash-cement ratio. The non-linearity in the relation between 28-day compressive strength of concrete and variation of fly ash-cement ratio seem to be higher for higher copper slag-fine aggregate ratio.

5.0 Determination Of Approximate Equations

At attempt was made to determine an equation using which the 28-day compressive of concrete containing fly ash, copper slag, silica fume and fibres could be determined. To determine the equations, fly ash-cement ratio and copper slag-fine aggregate ratio are considered as variables. The form of the equation is chosen based on separate preliminary investigation carried out to determine the trend of variation of the 28-day compressive strength of concrete with variation in selected variable. The form of the equation chosen is as,

$$28\,\text{days Compressive Strength} = k_1 \times (r_1)^2 + k_2 \times (r2) + k_3$$

where,

r_1 - Fly ash-cement ratio

r_2 - Copper slag-fine aggregate ratio

k_1, k_2, k_3 - Constants

The constants k_1 and k_2 are determined by performing non-linear regression analysis of the experimental data of specimens S1-S8 in MATLAB[9]. Since the specimen S9 showed wide deviation, it has been considered as out-layer and hence has not been used for regression analysis. The non-linear regression analysis yielded the values of k_1, k_2, k_3 as -3.6, 13.7 and 14.3, respectively. Therefore, the equation becomes,

$$28\,\text{days Compressive Strength} = -3.6 \times (r_1)^2 + 13.7 \times (r2) + 14.3$$

Comparison of 28-day compressive strength of concrete read from the experiment and predicted is shown in Table 4.

Table 4: Comparison of 28-day compressive strengths (Specimens: S1-S8)

SI.No.	28-day compressive strength, MPa		Experiment/ Predicted
	Experiment	Predicted	
S1	48.87	47.19	0.97
S2	42.32	44.49	1.05
S3	32.77	37.87	1.16
S4	52.46	50.45	0.96
S5	49.47	47.75	0.97
S6	47.38	41.13	0.87
S7	53.69	55.01	1.02
S8	49.48	52.32	1.06

From Table 4, it is noted that the 28-day compressive strength predicted by the equation matches well with the experimental data. The equation that has been determined is further used to check the strength predictability for the specimens S10-S36 (specimens with fibres) and the comparison is given in Table 5.

Table 5 Comparison of 28-day compressive strength (in MPa) (Specimens: S10-S36)

SI.No.	28-day Compressive strength, MPa		Experiment/ Predicted
	Experiment	Predicted	

S10	49.42	47.19	0.95
S11	43.91	44.49	1.01
S12	34.74	37.87	1.09
S13	54.26	50.45	0.93
S14	51.30	47.75	0.93
S15	49.00	41.13	0.84
S16	55.66	55.01	0.99
S17	50.89	52.32	1.03
S18	26.30	45.70	1.74
S19	48.56	47.19	0.97
S20	46.76	44.49	0.95
S21	31.60	37.87	1.20
S22	47.85	50.45	1.05
S23	41.54	47.75	1.15
S24	38.78	41.13	1.06
S25	50.94	55.01	1.08
S26	39.83	52.32	1.31
S27	28.30	45.70	1.61
S28	50.89	47.19	0.93
S29	44.31	44.49	1.00
S30	36.07	37.87	1.05
S31	48.72	50.45	1.04
S32	39.42	47.75	1.21
S33	44.22	41.13	0.93
S34	53.14	55.01	1.04
S35	44.96	52.32	1.16
S36	35.92	45.70	1.27

It is observed from Table 5 that except for specimens whose result is encircled, the strength predicted by the equation are comparable to the strength read from the experiments.

The following points are noted, in general, with respect to strength prediction by the proposed equation.

1. When no fibres are present or when only steel fibre is present, the strength predicted is reasonable when compared with the experimental data as long as when both the ratios (viz., fly ash-cement or copper slag-sand) are less than 1.0.
2. When polypropylene fibres or both fibres are present, the strength predictions seem to be reasonable as long as when any one of the ratios (viz., fly ash-cement or copper slag-sand) are less than 0.6 while the other is not > 1.0.

It should not be forgotten that the proposed equation is valid only for the concrete mix with water-binder ratio of 0.35 and containing silica fume of 6% of cement (by weight) and super plasticizer of 2.0-2.2% of binder content (by weight). The validity of the equation proposed for other percentages of water-cement/binder ratio, silica fume and fibres can be ensured only with experimental data.

6.0 Conclusion

The effect of addition of fly ash, copper slag, silica fume and fibres on the 28-day compressive strength of concrete has been studied. In general, it is observed that, (i) for a given copper slag-fine aggregate ratio, increase in fly ash-cement ratio decreases 28-day compressive strength of the concrete and, the rate of decrease in the 28-day strength decrease with increase in copper slag-sand ratio (ii) for a given fly ash-cement ratio, increase in copper slag-fine aggregate ratio increases 28-day compressive strength of the concrete. Interestingly, it was found that, as long as both ratios (viz., fly ash-cement or copper slag-sand) are not ≈ > 1.0, there seem to be no abrupt change in the trend of variation of 28-day compressive strength. Also, an equation has been proposed to determine the 28-day compressive strength of concrete with fly ash-cement ratio and Copper slag-fine aggregate ratio as variables. The 28-day compressive strength predicted by the proposed equation seems to match well with the experimental data as long as the ratios (viz., fly ash-cement or copper slag-sand) are within the limits specified.

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