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A STUDY ON INFLUENCE OF GRAPHENE OXIDE POWDER ON COMPRESSIVE STRENGTH OF CONCRETE

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Abstract - *Graphene oxide (GO) is an extraordinary material which is recently adopted in construction field. This material has many beneficiary properties and got attention towards it. In this experimental study, graphene oxide powder is used as an additive to the concrete mix. Compressive strength of concrete has been evaluated for various percentages of Graphene Oxide powder by weight of cement for various w/c ratios to establish mix design curves that can be referred to carry out mix proportioning of materials required for different grades of concrete. Integral Absolute Error has been used to establish the best curve fit equations for mix design.*

Mix design is calculated for M20 grade concrete, workability and compression strength tests are conducted to the concrete at 0%, 0.01%, 0.02%, 0.03% and 0.04% of graphene oxide powder for different water-cement ratio. The dimension of slump cone is 100mm (top), 200mm (bottom) and 300mm (height) for workability test and cube dimension is 100mm × 100mm ×100mm for compression test. There is high compression strength for 0.03% of graphene oxide.

Key Words: Cement, Coarse Aggregate, Fine Aggregate, Graphene Oxide (GO) Powder, Compressive Strength, Integral Absolute Error (IAE), Correlation Coefficient (R).

1. INTRODUCTION

Concrete is the material popularly adopted for the construction which is more durable, accessible and having high strength. It is a mixture of aggregates and binders i.e., Ordinary Portland cement or Portland Pozzolanic cement and water. When the OPC is mixed with aggregates and water, this creates a wet mixture that can be poured and moulded into any shape. The components react with cement to develop a strong model which binds the concrete components together to form a harsh-solid material which is more durable and high strength.

With the progress in nanotechnology, various researches have been undergone to improve the properties of concrete. By implementing nanomaterials in concrete, parameters like workability, permeability and strength of the concrete can be improved. Nowadays, many nanomaterials are popular in construction field; graphene oxide is one of the nanomaterials among them.

In this work graphene oxide powder is used as an additive to increase the compressive strength of concrete. Using Compressive strength of graphene modified concrete best curve fits for mix design are generated with different water-cement ratio for different percentages of graphene oxide powder.

2. OBJECTIVES

1. To compare the workability of fresh concrete with varying percentages of graphene oxide powder.
2. To compare the compression strength parameters of various percentages of graphene oxide powder mixed concrete for 7 days and 28 days.
3. To generate best mix design curve fit for different percentages of graphene oxide mixed concrete.

3. MATERIALS AND PROPERTIES

3.1 Cement:

In this work 43 grade OP Cement is used as a binding material.

Table 1: Physical properties of cement

Initial Setting Time	100 min
Final Setting Time	210 min
Specific gravity	3.15
Normal Consistency	32%
Compression strength	43.91 N/mm^2
Fineness	3.06%

3.2 Coarse Aggregate:

Crushed regional available 12 mm and 20 mm sieve sized coarse aggregates are used. The aggregates are clean, clear and free from foreign materials.

Table 2: Physical Properties of Coarse Aggregates

Shape	Cubical, Round, Angular
Specific Gravity(12mm)	2.66
Specific Gravity(20mm)	2.64
Water Absorption	0.72%
Bulk Density 1. Loose 2. Compacted	 14 KN/m^3 16 KN/m^3

3.3 Fine Aggregate:

Naturally available river sand which passes through 4.75mm sieve size is used as fine aggregate.

Table 3: Physical Properties of Fine Aggregates

Specific Gravity	2.63
Water Absorption	0.13%
Grading	Zone – II
Bulk Density: 1. Loose 2. Compacted	 13 KN/m^3 14 KN/m^3

3.4 Graphene oxide powder:

Graphene Oxide is an extraordinary nano-material which is accessible in powder, sheets, flakes and oxide form. It is strong, elastic and light weight in nature and recently adopted in construction field. It is having great properties which are beneficiary in construction field. When graphene oxide is added to concrete composites, it increases the strength properties of the concrete. It also increases the rate of hydration and reduces permeability and also gives high bond strength to concrete structures.

Table 4: Chemical composition of Graphene Oxide

Element	Composition in percentage
Carbon	77.5
Oxygen	16
Sulphur	0.4
Hydrogen	1.2
Nitrogen	4.9

3.5 Water:

It is the main ingredient or bonding agent in concrete which combines all the concrete composites and creates uniform paste. It is free from salts, oxides and other foreign materials. According to IS 10262:2009, proper measurement of water for the concrete is done by mix design calculation.

4. METHODOLOGY

1. Basic tests on materials.

2. Mix design for M20 grade concrete.

3. Slump test for workability on fresh concrete for different percentages of GO powder with varying water-cement ratio.

4. Casting, Curing and compression strength test on cubes for different percentages of GO powder with varying water-cement ratio for 7 days and 28 days.

5. Generation of best curve fit for mix design by the observed values of compression strength and by using law functions.

5. MIX DESIGN PROPORTION FOR M20 GRADE CONCRETE.

5.1 Mix Proportion:

1. Cement: 383.2 Kg/m^3

2. Fine Aggregate: 689.59 Kg/m^3

3. Coarse Aggregate: 1129.39 Kg/m^3

a). 12mm: 451.75 Kg/m^3

b). 20mm: 677.63 Kg/m^3

4. Water: 191.6 litres

5. W/C ratio: 0.5

5.2 Mix Ratio:

1: 1.79: 2.947: 0.5

6. RESULTS AND DISCUSSIONS

6.1 Workability tests Results on Fresh Concrete

The workability (slump test) results are presented in the table 5 for water-cement ratio with different percentages of graphene oxide powder. A minimum slump of 22.5mm and maximum slump of 100mm are observed for water-cement ratio of 0.40 and 0.55 respectively. In the table, M1, M2, M3, M4 and M5 are 0%, 0.01%, 0.02%, 0.03% and 0.04% of graphene oxide powder respectively.

Table 5: Workability (slump test) Results

W/C Ratio	Mix	Slump Value(mm)	Result
0.4	M1	22.5	True
	M2	22.5	True
	M3	22.5	True
	M4	22.5	True
	M5	22.5	True
0.45	M1	25	True
	M2	25	True
	M3	25	True
	M4	25	True
	M5	25	True
0.50	M1	53	True
	M2	53	True
	M3	53	True
0.50	M4	53	True
	M5	53	True
	M1	100	Collapse
	M2	100	Collapse

0.55	M3	100	Collapse
	M4	100	Collapse
	M5	100	Collapse

6.2 Compression Test Result on Harden Concrete

The compression strength test results for varying water-cement ratio with different percentages of graphene oxide powder are presented in the table 6(a) and 6(b) for 7 days and 28 days of curing period respectively.

Table 6(a). Compression Strength Test Results for 7 days

W/C Ratio	Mix	Compression Strength N/mm^2
0.40	M1	26.0
	M2	26.6
	M3	27.0
	M4	27.3
	M5	28.6
0.45	M1	23.6
	M2	24.3
	M3	25.0
	M4	25.6
	M5	24.3
0.50	M1	22.6
	M2	23.0
0.50	M3	23.3
	M4	23.3
	M5	24.3
0.55	M1	16.6
	M2	19.0
	M3	19.6
	M4	19.3
	M5	18.3

Table 6(b). Compression Strength Test Results for 28 days

W/C Ratio	Mix	Compression Strength N/mm^2
0.40	M1	37.0
	M2	38.0
	M3	38.6
	M4	39.3
	M5	36.3
0.45	M1	36.0
	M2	37.3
	M3	38.0
	M4	38.6
	M5	35.6
0.50	M1	35.0
	M2	36.6
	M3	37.3
	M4	38.0
	M5	35.0
0.55	M1	28.6
	M2	30.6
	M3	31.0
	M4	31.3
	M5	29.6

6.3 Curve Fitting For Observed Values of Compression Strength versus Water-Cement Ratio

Curve is generated for observed values of compression strength with varying percentages of graphene oxide powder for 7 days and 28 days of curing period.

6.3.1 Law Functions

Curve fitting is one of most effective and potent tool which is hugely used for analysis. By the use of law functions best curve fit is generated. The law functions adopted in this work are mentioned below:

a). Polynomial Equation, $y = Ax^2 + Bx + C$

b). Linear Equation, $y = mx + C$

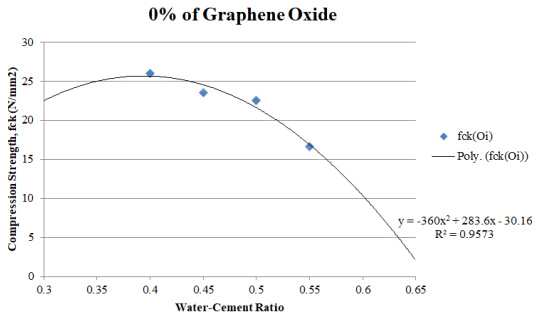
c). Power Equation, $y = A \times x^B$

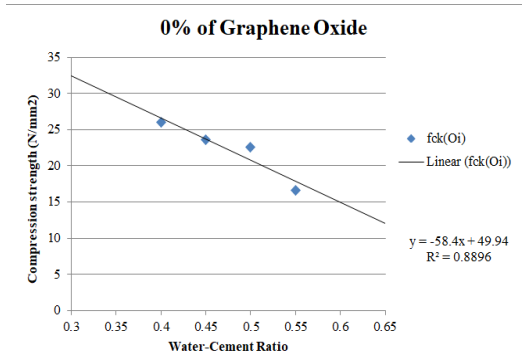
6.3.2 Compression Strength at 7 days

For 0% of GO Powder

Table 7 7 Days Compression Strength versus Water-Cement Ratio for 0% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	26.0	25.68	26.58	27.06
0.45	23.6	24.56	23.66	23.26
0.50	22.6	21.64	20.74	20.31
0.55	16.6	16.92	17.82	17.97





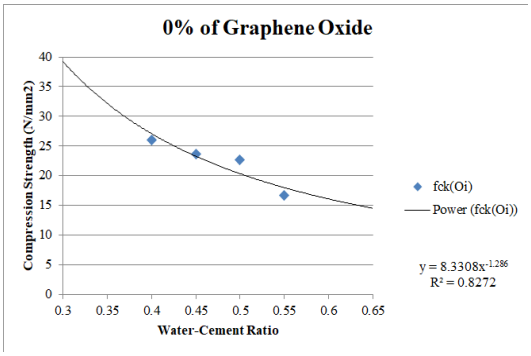


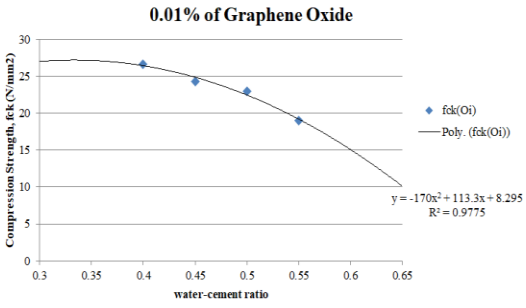
Figure 1 7 Days polynomial, linear and power curve fit for 0% of GO Powder

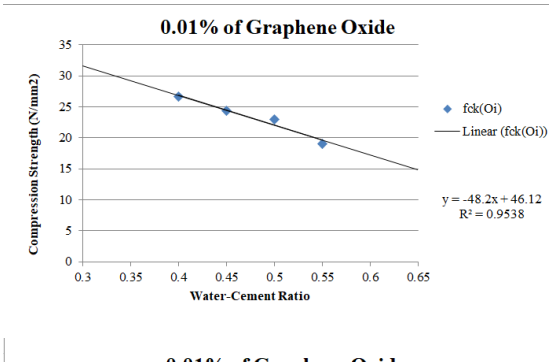
In the above charts, polynomial, linear and power curve fits are generated for 0% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9573 which is near to value 1 and treated as best curve fit.

For 0.01% of GO Powder

Table 8 7 Days Compression Strength versus Water-Cement Ratio for 0.01% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	26.6	26.41	26.84	27.15
0.45	24.3	24.85	24.43	24.16
0.50	23.0	22.44	22.02	21.76
0.55	19.0	19.18	19.61	19.80





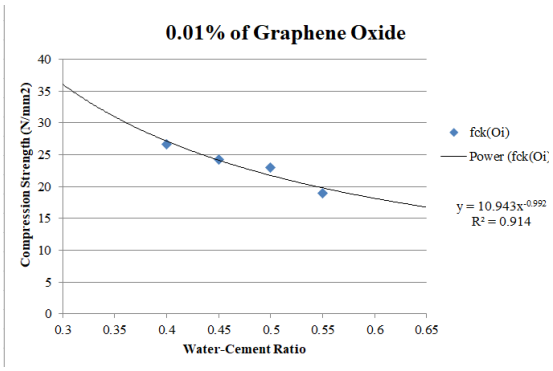


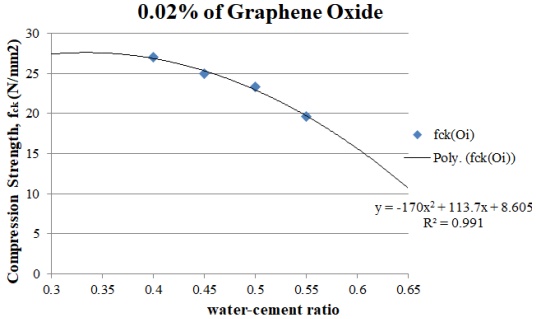
Figure 2 7 Days polynomial, linear and power curve fit for 0.01% of GO Powder

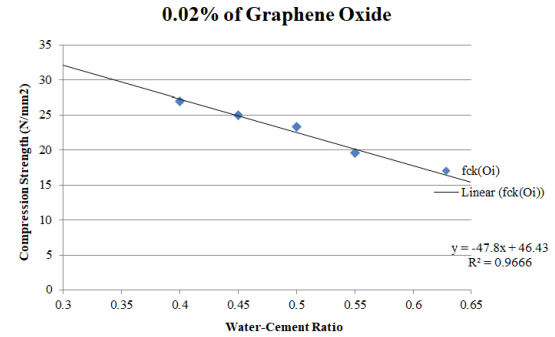
In the above charts, polynomial, linear and power curve fits are generated for 0.01% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9775 which near to value 1 and treated as best curve fit.

For 0.02% of GO Powder

Table 9 7 Days Compression Strength versus Water-Cement Ratio for 0.02% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	27.0	26.88	27.31	27.61
0.45	25.0	25.34	24.92	24.65
0.50	23.3	22.95	22.53	22.28
0.55	19.6	19.71	20.14	20.33





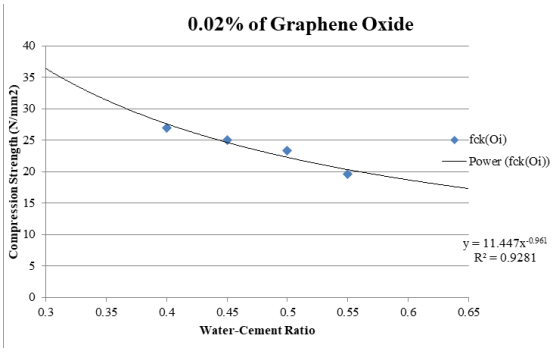


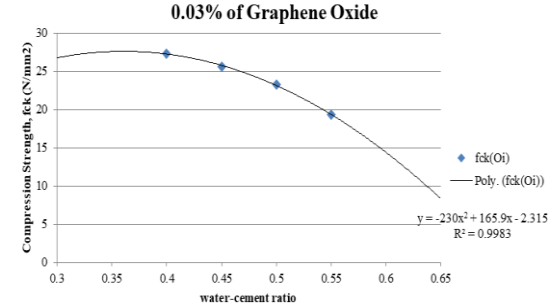
Figure 3 7 Days polynomial, linear and power curve fit for 0.02% of GO Powder

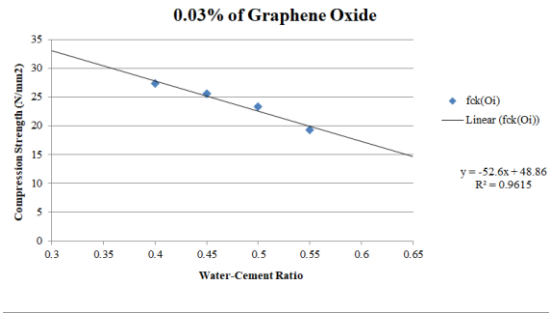
The above charts, polynomial, linear and power curve fits are generated for 0.02% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.991 which near to value 1 and treated as best curve fit.

For 0.03% of GO Powder

Table 10 7 Days Compression Strength versus Water-Cement Ratio for 0.03% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	27.3	27.24	27.82	28.17
0.45	25.6	25.76	25.19	24.88
0.50	23.3	23.13	22.56	22.26
0.55	19.3	19.35	19.93	20.13





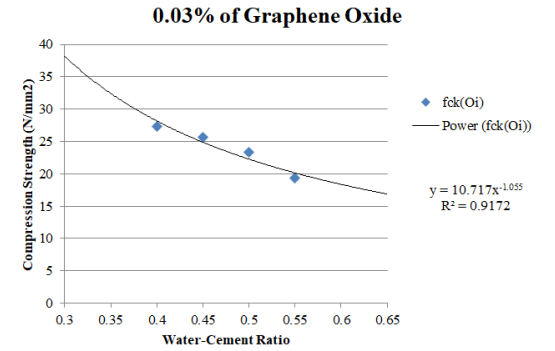


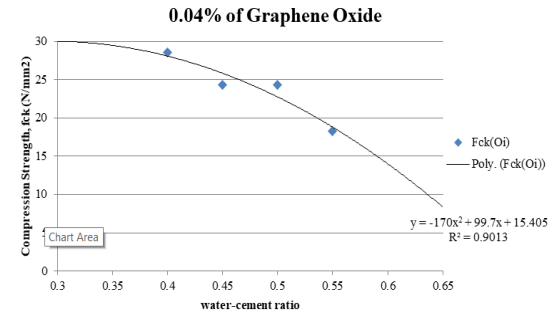
Figure 4 7 Days polynomial, linear and power curve fit for 0.03% of GO Powder

In the above charts, polynomial, linear and power curve fits are generated for 0.03% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9983 which near to value 1 and treated as best curve fit.

For 0.04% of GO Powder

Table 11 7 Days Compression Strength versus Water-Cement Ratio for 0.04% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	28.6	28.08	28.51	28.97
0.45	24.3	25.84	25.42	25.00
0.50	24.3	22.75	22.33	21.92
0.55	18.3	18.81	19.24	19.46



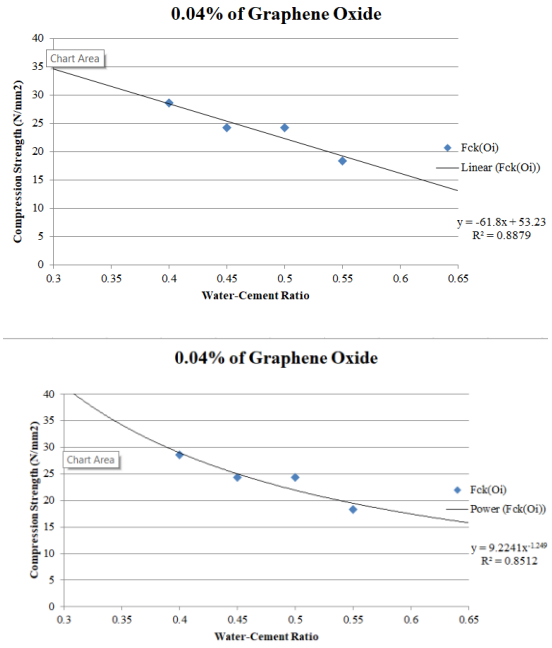


Figure 5 7 Days polynomial, linear and power curve fit for 0.04% of GO Powder

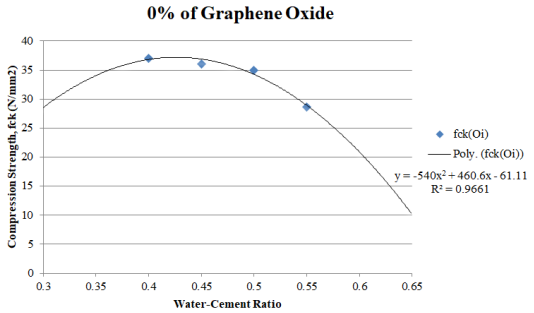
In the above charts, polynomial, linear and power curve fits are generated for 0.04% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9013 which near to value 1 and treated as best curve fit.

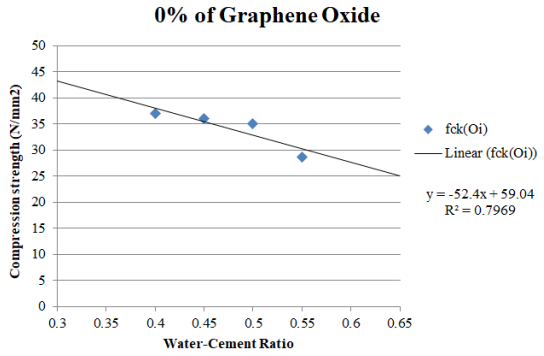
6.3.3 Compression Strength At 28 Days

For 0% of GO Powder

Table 12 28 Days Compression Strength versus Water-Cement Ratio for 0% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	37	36.73	38.08	38.35
0.45	36	36.81	35.46	35.17
0.50	35	34.19	32.84	32.54
0.55	28.6	28.87	30.22	30.34





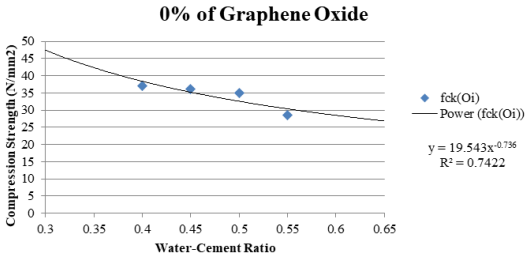


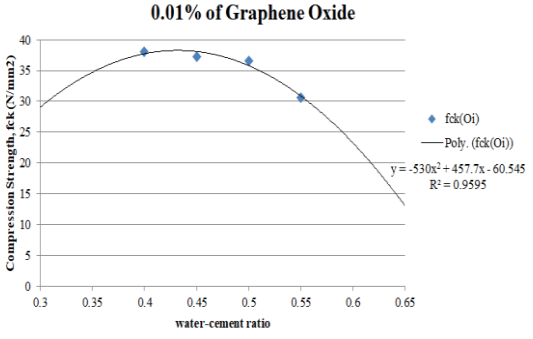
Figure 6 28 Days polynomial, linear and power curve fit for 0% of GO Powder

In the above charts for 28 days of curing period, polynomial, linear and power curve fits are generated for 0% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9661 which near to value 1 and treated as best curve fit.

For 0.01% of GO Powder

Table 12 28 Days Compression Strength versus Water-Cement Ratio for 0.01% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	38	37.73	39.06	39.26
0.45	37.3	38.095	36.77	36.52
0.50	36.6	35.80	34.48	34.24
0.55	30.6	30.86	32.19	32.29



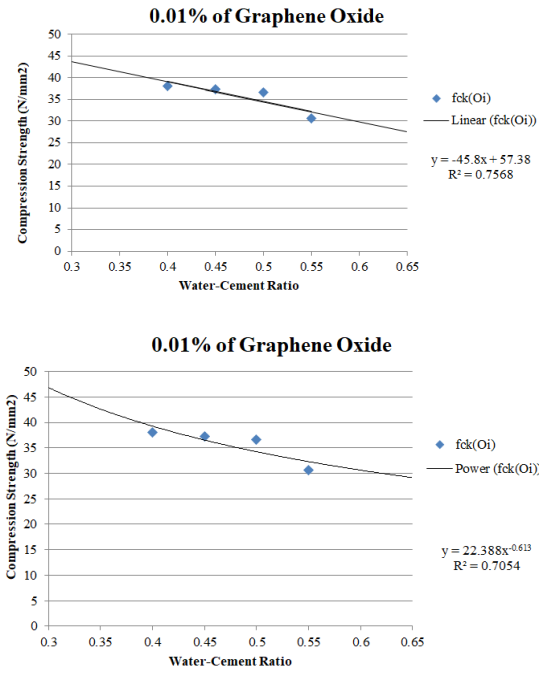


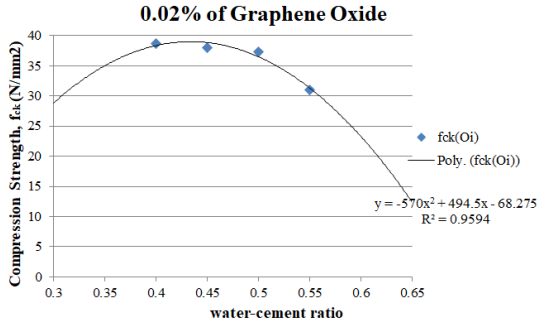
Figure 7 28 Days polynomial, linear and power curve fit for 0.01% of GO Powder

In the above charts for 28 days of curing period, polynomial, linear and power curve fits are generated for 0.01% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9595 which near to value 1 and treated as best curve fit.

For 0.02% of GO Powder

Table 13 28 Days Compression Strength versus Water-Cement Ratio for 0.02% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	38.6	38.33	39.75	39.98
0.45	38	38.83	37.4	37.16
0.50	37.3	36.48	35.05	34.81
0.55	31	31.28	32.7	32.81



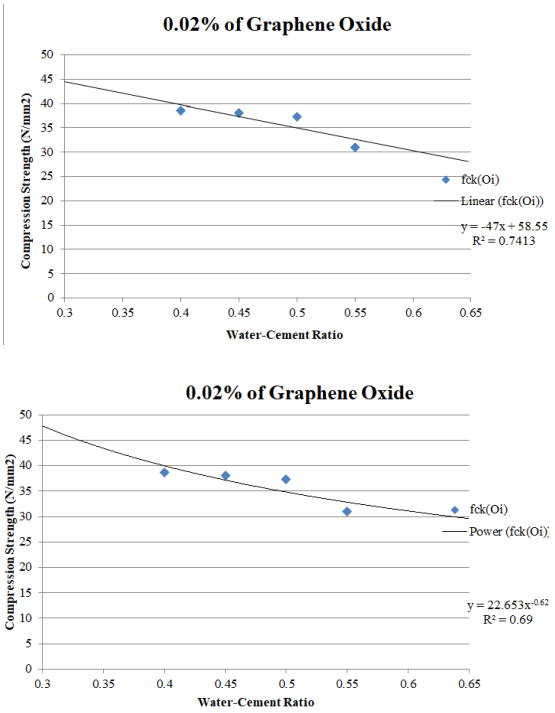


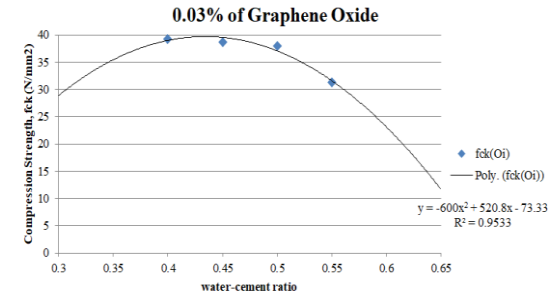
Figure 8 28 Days polynomial, linear and power curve fit for 0.02% of GO Powder

In the above charts for 28 days of curing period, polynomial, linear and power curve fits are generated for 0.02% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9594 which near to value 1 and treated as best curve fit.

For 0.03% of GO Powder

Table 13 28 Days Compression Strength versus Water-Cement Ratio for 0.03% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	39.3	38.39	40.49	40.73
0.45	38.6	39.53	38.03	37.77
0.50	38.0	37.07	35.57	35.31
0.55	31.3	31.61	33.11	33.22



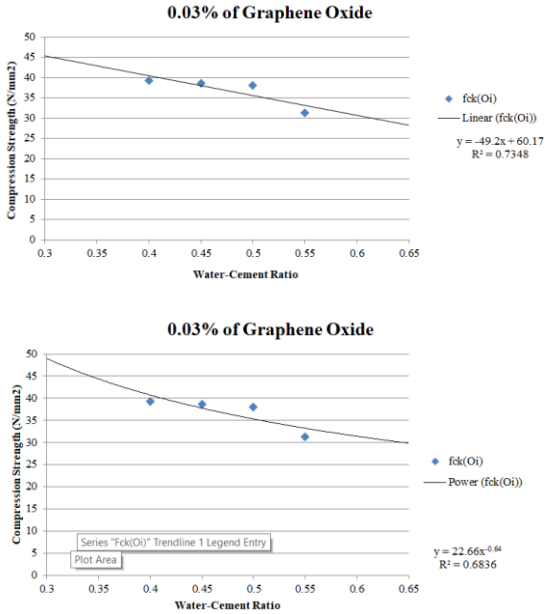


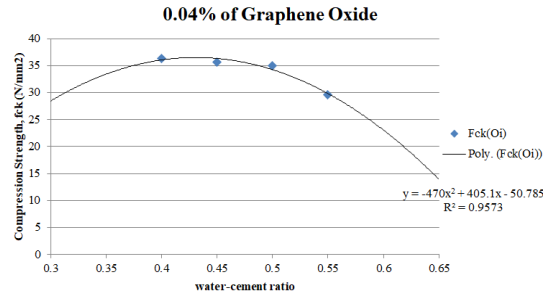
Figure 9 28 Days polynomial, linear and power curve fit for 0.03% of GO Powder

In the above charts for 28 days of curing period, polynomial, linear and power curve fits are generated for 0.03% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9533 which near to value 1 and treated as best curve fit.

For 0.04% of GO Powder

Table 13 28 Days Compression Strength versus Water-Cement Ratio for 0.04% of GO Powder

W/C Ratio	f_{ck} (Oi)	f_{ck} (Pi)		
		Polynomial	Linear	Power
0.40	36.3	36.05	37.23	37.40
0.45	35.6	36.33	35.16	34.94
0.50	35	34.26	33.09	32.88
0.55	29.6	29.84	31.02	31.12



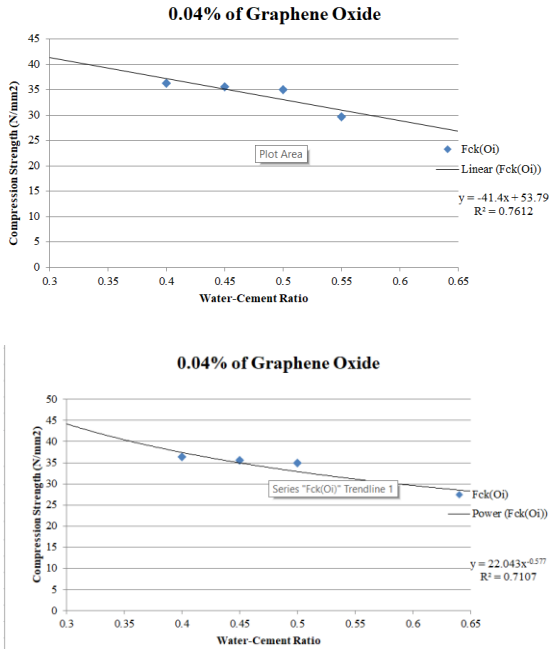


Figure 10 28 Days polynomial, linear and power curve fit for 0.04% of GO Powder

In the above charts for 28 days of curing period, polynomial, linear and power curve fits are generated for 0.04% of graphene oxide powder. The correlation coefficient (R) for polynomial curve fit is 0.9573 which near to value 1 and treated as best curve fit.

6.3.4 Integral Absolute Error

Integral absolute error is the index used to assess the correct curve fit for the expected correlation. The equation for IAE is under followed and it is stated in percentage.

$$IAE = \{\sum [(Oi - Pi)] / \sum Oi\} \times 100$$

6.3.5 Results for Correlation Coefficient and Integral Absolute Error (IAE)

Functions, equations, correlation coefficient and integral absolute error (IAE) for different percentages of graphene oxide powder are presented in the table 14(a) and 14(b) for 7 days and 28 days of curing respectively. For polynomial function the correlation coefficient is near to value 1 for 0% to 0.04% of graphene oxide powder and it is absolutely correlated. The IAE value is least for polynomial function for 0% to 0.04% of graphene oxide powder.

Table 14(a) Result Description (7 days)

GO in %	Functions	Equations
0	Polynomial	$y = -360x^2 + 283.6x - 30.16$
	Linear	y = -58.4x + 49.94

	Power	$y = 8.3308x^{-1.286}$
0.01	Polynomial	$y = -170x^2 + 113.3x + 8.295$
	Linear	$y = -48.2x + 46.12$
	Power	$y = 10.943x^{-0.992}$
0.02	Polynomial	$y = -170x^2 + 113.7x + 8.605$
	Linear	$y = -47.8x + 46.43$
	Power	$y = 11.447x^{-0.961}$
0.03 0.03	Polynomial	$y = -230x^2 + 165.9x - 2.315$
	Linear	$y = -52.6x + 48.86$
	Power	$y = 10.717x^{-1.055}$
0.04	Polynomial	$y = -170x^2 + 99.7x + 15.405$
	Linear	$y = -61.8x + 53.23$
	Power	$y = 9.2241x^{-1.249}$

Table 14(b) Result Description (28 days)

GO in %	Functions	Equations
0	Polynomial	$y = -540x^2 + 460.6x - 61.11$
	Linear	$y = -52.4x + 59.04$
	Power	$y = 19.543x^{-0.736}$
0.01	Polynomial	$y = -530x^2 + 457.7x - 60.545$
	Linear	$y = -45.8x + 57.38$
	Power	$y = 22.388x^{-0.613}$
0.02	Polynomial	$y = -570x^2 + 494.5x - 68.275$
	Linear	$y = -47x + 58.55$
	Power	$y = 22.653x^{-0.62}$
0.03	Polynomial	$y = -600x^2 + 520.8x - 73.33$
	Linear	$y = -49.2x + 60.17$
	Power	$y = 22.66x^{-0.64}$
0.04 0.04	Polynomial	$y = -470x^2 + 405.1x - 50.785$
	Linear	$y = -41.4x + 53.79$
	Power	$y = 22.043x^{-0.577}$

7 CONCLUSIONS

1. There are no changes in workability of the fresh concrete with varying percentages of graphene oxide powder.

2. According to M_{20} design mix, for 0.50 water-cement ratio, there is maximum rise in compression strength of the concrete when 0.03% of Graphene Oxide is added to the concrete mix.

3. For 0.40 water-cement ratio, there is maximum compression strength for 0.03% of Graphene Oxide powder compared to 0.45, 0.50, 0.55 water-cement ratio.

4. There is a reduction in compression strength when 0.04% of Graphene Oxide powder is mixed to the concrete.

5. For 7 days and 28 days compression strength, Integral Absolute Error (IAE) is least for polynomial equation and the best curve fit for the data.

6. By using polynomial curve and equation we can produce mix design for graphene modified concrete from M15 to M40 grade concrete.

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