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Interpolation and extrapolation of flexural strength of rubber crumbs and coal ash with graphene oxide concrete

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ABSTRACT

The utilisation of various resources, specifically industrial wastes, in the manufacturing of concrete is the main emphasis of today's knowledge of concrete technology. One of the key concerns in the global protection of the environment is waste management. The growing growth of the Indian automobile industry has ultimately led to a rise in the garbage that is dumped, such as used tyres. Coal ash was also added to the improvised concrete mix (CRAC) in a frozen percentage within the cement mantle of the concrete matrix for the stabilization of the binding qualities. For sustaining the required qualities of supplied 30 MPa or other base values for concrete with reference to a specific purpose, it was found that an optimal proportional combination of 12% waste rubber tyre crumbs and 9% coal ash was the most technologically and economically effective solution. Flexural strength of 5.18 MPa, which was attained, confirmed that this optimum proportionate combination was the best and most durable.

Keywords: rubber Crumb; coal ash; graphene oxide; concrete; flexural strength.

1. INTRODUCTION

As the improvement of material efficiency can be largely achieved by nano-engineering of cement, cement products, and concrete, a detailed literature survey was carried out to understand the recent past advancements in the area of nano-engineered concrete. The usage of rubber-based materials in multifaceted applications results in a growing volume of rubber waste crumbs and fine fractions. With the ever-growing increase in demand for automobiles, the manufacturing and use of tires have been accelerated quite each in the advanced and growing countries. By and large, 65% of worldwide rubber production and an equally higher percentage of rubber disposals consists of automobile and truck tyres (this study has been chosen to focus on rubber waste from tyres). At the end of their work, tyres get worn out and should be discarded and replaced. Disposal and reuse of used tyres are challenging problems since tyre pieces and crumbs have a virtually indefinite lifespan. The present thesis research was contemplated to highlight the inevitability of partial material substitution of rubber wastes and coal ash with the aggregate components of Concrete without affecting the strength and other properties [1]. The waste disposal problem is construed as one of the most complicated issues the world has been facing as an inseparable malady of environmental pollution. One of the harmful wastes to be managed in the present scenario of a pollution or contamination-free environment is 'waste tyre dumps' as an offshoot to an ever-increasing population of different vehicles inevitably requiring tyres for on-road transportation and logistics. Waste tyres disposal is continuously generated due to wear and tear becoming global waste disposal and management menace. Records have it that annually, around 1.2 billion waste tyre rubber has been produced all over the world. 275 million waste rubber fractions are generated in the United States and 180 million in other European Countries. One hundred seventy thousand tons of waste tyres are produced in Australia, while three corners of waste tyres are manufactured in India every year. Estimations in the present scenario reveal that 10 to 12 percent of used-up tyres are exported, around 62 percent are subjected to reuse possibilities followed by recycling for energy recovery and the rest 26 to 28 percent are unscrupulously dumped in landfill, and stockpiles.

AHMED [2] and AHMED and LOVELL [3] comprised investigations related to Tyre rubber waste recycling. ALI *et al.* [4] have reported on the ill effects of possible air entrapment within the finished and cured

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concrete product due to the relatively larger and irregular size distribution of wasted tyre rubber crumb fractions incorporated by material substitution [5]. SETHI and THANVI [6] concentrated on the techno-economic aspects of rubberized concrete compounds. It demonstrates that used rubber tyres can be used to improve concrete's varied qualities and safeguard the environment. Using hand-chopped waste rubber tyre aggregates with a maximum size of 20 mm, the experimental programme for the current study was carried out to partially substitute natural coarse aggregate. In this investigation, rubber tyre aggregates were used in place of natural coarse aggregates in amounts of 5%, 7.5%, and 10% by weight of the coarse aggregate [7]. At 7 and 28 days, the compressive and flexural strengths were measured, and the outcomes were compared to plain concrete of the same grade (Controlled mix). As a baseline, regular concrete (controlled mix) made with natural aggregate and 0% replacement of rubber particles is employed [8]. The concrete of M20 grade has been used. The Compressive strength of rubberized concrete is less than the compressive strength of normal/controlled mix. The decrement in compressive strength at 5%, 7.5%, 10% was found to be 18.21%, 32.25%, 40.55% respectively compressive strength of controlled mix. The flexural strength of rubberized concrete at 5%, 7.5%, 10% was respectively found to be increased by 27.78%, 81.39%, 61.94% of the flexural strength of a controlled mix. In 2017, LV *et al*. [9] studied the presence of a few layered GO nanosheets in the cement paste. The dosage was started from 0.03 percent and examined up to 0.07 percent with a 0.02 percent increment. The compressive strength varies from 42 percent to 64 percent when compared with the control sample. GOULIAS and ALI [10] suggested as a possible remedy to combat environmental maladies. This team conducted a continued investigation related to the possible deformations in the concrete material due to the natural biodegradability of the transformed rubber crumbs incorporated. FAIRBURN and LARSON [7] studied the features of concrete infused with shredded rubber crumbs in rectifying the fractures and cracks due to atmospheric effects on pavements. The desirable traits of such rubberized concrete also established its prowess in fireproofing, waterproofing, slip resistance, and above all, its feasibility as an insulation material. GRRICK [11] confirmed the analysis of waste tyre-modified concrete employed 15% by volume of the coarse aggregate while transformed via the waste tyre as a two-segment material as tyre fibre and chips dispersed in a concrete mix. The ultimate consequence could be plastic deformation, an improvement in lifetime, and increased impact and cracking resistance. Despite the rubberized sample's reduced strength and stiffness. When top load was attained, the control concrete collapsed, and the rubber aggregate concrete experienced significant distortion without segregation as a result of tyre-induced bridging. For every 50 lbs of crumb rubber added, the combination's unit weight decreased by around 6 pcf. While the rubber content material accelerated, the compressive strength decreased concurrently. LI *et al.* [12] looked at fibres and chips. The tyre surfaces are cleaned with a saturated sodium hydroxide solution, and physical anchorage by drilling a hole through the middle of the rubber aggregates has also been studied. The results show that fibres outperform chips in terms of performance. For large-sized tyre chips, sodium hydroxide treatment is no longer effective due to the effects of physical attachment. HOSSAIN *et al.* [13] cited that many research investigations had been carried out in the recent past decade as regards the use of shredded tyre rubber waste from shredded tyres in constructing cheaper and stronger rural roads for the transport of farm materials. The research focused on the development of a chunk rubber infused (as part of aggregates) asphalt concrete mix design for low-volume road construction. LARSON [14] studied the applicability of rubberized crumbs incorporated concrete for temperature effects by thermal expansion and contraction, shrinkage prevention upon drying, alternate freezing-thawing effects, ride time noises, brittleness and the dead cum moving weight impulses over road pavements. The workability of crumb rubberized concrete upon substitution against fine aggregates was also enunciated with experimental proof. GRANZOTTO and SOUZA [15], 2013 initiated experimental test verifications on the physic-chemical properties of rubberized concrete imbibed with wasted tyre crumbs. AMIRKHANIAN and MANUGIAN [5] conducted a satisfactory wet process tensile strength performance of the finished-up roads having the main component layer with crumb rubber asphalt with concrete. LARSON [14] found that crumb rubber in concrete could minimize thermal expansion and contraction, freeze-thaw damage, drying shrinkage, ride noise, weight, and brittleness t in road pavements. LI *et al.* [16] concentrated on the side effects of adding degradable wasted crumbs of tyre in concrete with the main apprehension on possible reductions in densities of the overall concrete mix obtained. Invariably they advised not to use more than 10% wasted rubber crumbs by weight of the concrete and they took up research on the suitability of shredded tyres as lightweight embankment filler material for water storage cum overhead transport and crossing. NAGDI [17] could also endorse this weakening attitude of air getting trapped in the void spaces, thereby inflicting the strength and other quality criteria besides imparting some buoyancy of the wet concrete material by air inflation within the void tubes.

According to an important study of the literature, the proportion of rubber aggregate in the concrete must be limited to avoid a significant loss in mechanical qualities. The performance, deflection, and ductility of reinforced cement concrete beams made from TRAC may also not have been studied in any specific literature.

In the tensile zone, however, there is also an attempt to employ rubber strips as rebar. Because the cloth itself is still in its infancy, the research concentrates on discarded tyre rubber [18–22]. There isn't much literature accessible in the area where structural applications are made. To improve its major structural applications in concrete construction in these circumstances, tyre rubber combination concrete beams must be thoroughly studied for their appropriate qualities. Reduced weight, improved toughness, faster ductility, and impact resistance are among the potential benefits. The results of the investigation are reported in this paper as a limited study on the development of MSC's tensile strength. The splitting tensile method was used to test the tensile strength of the MSC cubes, and the effects of the water-cement ratio and the amount of stone powder were examined. According to test results, MSC's long-term tensile strength was improved by producing sand with a maximum stone powder percentage of 13%.

2. MATERIALS AND SAMPLE PREPARATION

Graphene oxide (GO): "Ceramics and Fibers Technologies Private Limited, erode" is where you can buy graphene oxide [23].

Cement: Portland cement of 53 Grade [24]

Fine aggregate: Natural River Sand [25]

Coarse aggregate: Natural aggregates [26]

Admixtures: Waste tyre crumbs obtained from four-wheelers and coal ash [27]

Water: Potable water [28]

Rubber crumb aggregate: properties are shown in Table 1 and Table 2 indicates the specimen details of GOCA concrete.

Coal ash: Coal ash is used in the finished product as a cement substitute (5%, 10%, and 15% by weight) [29–31]. As indicated in Table 3, the chemical compositions of coal ash.

Table 1: Material properties of fine aggregate, rubber crumbs and coarse aggregates.

PROPERTIES	FINE AGGREGATE		COARSE AGGREGATE
	SAND	WASTE RUBBER CRUMBS	
Specific Gravity	2.63	1.14	2.61
Fineness Modulus	4.91	5.35	7.42
Water Absorption	2.00	1.14	1.00

Table 2: Specimen index.

INDEX	0.1% GO	0.2% GO	0.3% GO	0.4% GO	0.5% GO
5% Coal Ash	1GOCA5	2GOCA5	3GOCA5	4GOCA5	5GOCA5
10% Coal Ash	1GOCA10	2GOCA10	3GOCA10	4GOCA10	5GOCA10
15% Coal Ash	1GOCA15	2GOCA15	3GOCA15	4GOCA15	5GOCA15

Table 3: Chemical element of coal ash.

ELEMENTS	% OF COMPOSITION
K_2O	0.57
MgO	0.87
CaO	0.89
LOI	4.01
SO_3	4.28
Fe_2O_3	7.64
Al_2O_3	29.2
SiO_2	51.4

3. EXPERIMENTAL STUDY

3.1. Flexural strength test

The intense stress calculated at the failure of the specimen is known as the modulus of rupture. It's also known as an indirect measure of predicting the tensile strength of concrete [32]. A specimen of size 100 × 100 × 500 mm had been cast and examined to determine the modulus of rupture or the flexural strength particularly to determine the bending potential of concrete, and the test has been done on the prism size of 100 × 500 mm with a thickness of 100 mm [33–35]. A prism of the above-stated size has been cast and tested at the compression-testing machine and frequently at the standard testing machine based totally on the length of the prism. A compression testing machine (CTM) is favoured when the size of the beam is prolonged and determines the structural properties of a concrete specimen [36]. The load is carried out on the prism, and the failure load has been noted very just like that of compressive and split tensile strength. The flexural strength is acquired through the use of the formula and expressed in N/mm^2 [37]. Figure 1 depicts the flexural strength test setup.

Flexural Strength in MPa = FL/bd^2

Where F = load at break point in N

L = Length in mm

b = breadth in mm

d = Thickness in mm

4. RESULTS AND DISCUSSION

The flexural strength of the concrete has been significantly increased by the addition of graphene oxide at concentrations ranging from 1% to 5%. The test results show that 4GOCA concrete in normal water curing achieved its maximum flexural strength of 6.32 N/mm^2 and 6.37 N/mm^2 after 28 days [38]. In comparison to conventional concrete, the 28-day flexural strength improvement for all mixes is found to range from 13% to 50% for 1GOCA5, to 5GOCA15, respectively.

4.1. Flexural strength endorsement for CRACS (crumb rubber aggregate concrete infused with coal ash)

Apart from the principal criterion of compressive strength, the endorsement was also backed up by the split tensile strength for the basic fact that concrete is stronger in compressive than tensile strength which should

Figure 1: Flexural strength test setup.

Table 4: Flexural strength (fcr) of CRAC (crumb rubber aggregate concrete).

TREATMENT	SPECIMEN ID	7 DAYS N/mm²	14 DAYS N/mm²	28 DAYS N/mm²	56 DAYS N/mm²
(C)	RFA 0	4.58	4.91	5.67	5.72
T1	RFA 1	4.75	5.25	5.98	6.14
T2	RFA 2	4.86	5.37	6.21	6.38
T3	RFA 3	4.66	5.18	5.81	6.12
T4	RFA 4	4.42	5.00	5.74	5.94
T5	RFA 5	4.25	4.76	5.45	5.65

Table 5: Flexural Strength (fcr) of SSIC (coal ash infused concrete).

TREATMENT	SPECIMEN ID	7 DAYS N/mm²	14 DAYS N/mm²	28 DAYS N/mm²	56 DAYS N/mm²
(C)	SS 0	4.58	4.91	5.67	5.72
T1	SS 3	4.81	5.39	6.27	6.32
T2	SS 6	4.90	5.47	6.48	6.53
T3	SS 9	4.76	5.26	6.36	6.42
T4	SS 12	4.55	4.98	5.92	5.98
T5	SS 15	4.38	4.72	5.48	5.87

Table 6: Flexural Strength (fcr) of CRACS (crumb rubber aggregate concrete infused with coal ash).

TREATMENT	SPECIMEN ID	7 DAYS N/mm²	14 DAYS N/mm²	28 DAYS N/mm²	56 DAYS N/mm²
(C)	SS 0 + RFA 0	4.58	4.91	5.67	5.72
T1	SS 9 + RFA 1	4.76	5.27	6.12	6.23
T2	SS 9 + RFA 2	4.85	5.35	6.34	6.47
T3	SS 9 + RFA 3	4.74	5.19	6.22	6.38
T4	SS 9 + RFA 4	4.51	5.11	5.80	5.92
T5	SS 9 + RFA 5	4.32	4.65	5.28	5.37

also be improved. In line with the cube test for compressive and cylinder test for tension, the prism test was conducted to assess the deflection responses to the impact loads [39]. Tables 4, 5 and 6 and Figure 2 furnish the flexural strength's alongside three tests of families of a curve for crumb rubber alone, coal ash alone and the combination of crumb rubber and coal ash.

4.1.1. A Family of curves on flexural strength for crumb rubber addition alone

With respect to the curing, spell variations were obtained alongside incremental additions of rubber crumb alone up to 15% to replace fine aggregates in steps of 3%. The flexural strength is otherwise termed as modulus of rupture corresponding to the critical load at which the rupture of the prism begins. A person of the family of curves, by and large, corroborated the relative supremacy of the improvised concrete mixes either with independent additions of rubber crumbs or coal ash as well as the combined proportional addition of both, maintaining a higher critical load level, to begin with the ruptures compare to the conventional concrete mix.

4.1.1.1. Addition of rubber crumbs alone from 3% to 15% fine aggregates in steps of 3% by volume

Even though data has been observed for the prenominal curing spells of 7 and 14 days and the post-nominal spell of 56 days alongside the universal nominal curing spell of 28 days, the flexural strength attained for the nominal

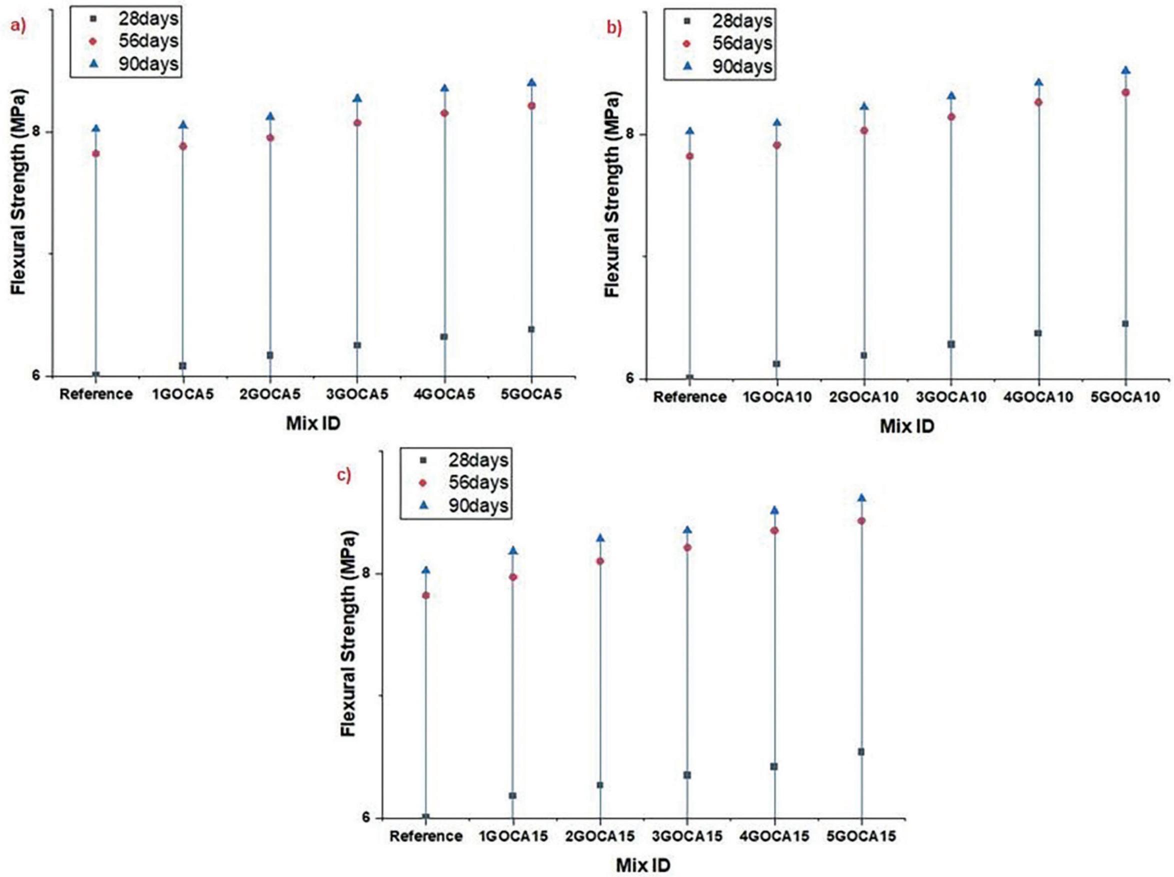

Figure 2: Flexural strength of Coal ash (5% to 15%) concrete with graphene oxide (0.1% to 0.5%).

spell of 28 days is considered for discussion. Accordingly, the conventional concrete registered a relatively lower value of 5.72MPa at which the first crack appeared for incremental additions in steps of 3% of rubber crumbs alone this critical flexural load to develop cracks was extended to a maximum of 6.21MPa for 6% addition and for other combination it showed declinations 5.45MPa against 15% addition the tabular values indicate the critical higher load value of 5.74MPa for 12% addition of crumb rubber addition and 5.81MPa for 9% addition which is still more than that for the conventional concrete [40]. Hence as a first approximation from the family of curves pertaining to incremental additions of rubber crumbs alone 9 to 12% additions can be safer in achieving the critical flexural strength value against rupture.

4.1.1.2. Addition of coal ash alone in the range of 3 to 15% in steps of 3% was experimented for fixing the critical flexural strength against rupture

With respect to the standard nominal curing spell of 28 days, the conventional concrete registered a critical flexural strength of 5.67MPa against 6 to 12% additions of coal ash registering the same in the range of 6.48MPa to 5.92MPa. Hence as a visa media solution and as a first approximation 9% addition of coal ash has been found to reflect an optimal critical flexural strength to resist rupture at 4.36MPa, which is 12% increase in the critical rupture causing flexural strength. Hence this family of curves irrespective of the curing spells has established the optional proportional combination of coal ash in replacing cement at 9%, which could be the frozen value for varied combinations with crumb rubber with further experimental analysis.

4.1.1.3. Family of curves for a combinational proportion of crumb rubber with 9% frozen value of coal ash

In this case also for the nominal curing spell of 28 days, 9% addition of rubber crumbs in the fine aggregate mantle alongside a frozen combinational addition of 9% coal ash in the cement mantle the optimal critical rupture load of 6.22MPa was registered as the flexural strength this showed around 9% increase in the critical rupture resisting flexural strength of the improvised concrete mix composed of 9% each of rubber crumbs and coal ash compare to the conventional concrete mix. Hence from the technical feasibility point of view, these three families of curves for critical rupture barring flexural strength versus the optimal proportional combination of rubber crumbs alongside nine % frozen value of coal ash addition revealed the supremacy of the improvised concrete mix (9% additions of both coal ash and crumb rubber) over the control mix [41]. Hence from the foregoing discussions, it can be concluded that has an endorsement by first approximation using the family of curves for critical flexural strength Vs. Optimal percentage replacements with coal ash and rubber crumbs the safer and technically feasible combination can be limited 9% addition o rubber crumbs with 9% addition of coal ash. Figure 3, 4, and 5 depicts the strength value of rubber crumb and coal ash concrete at different curing period.

4.2. Regression model

4.2.1. Endorsement by regression analysis on flexural strength vs. incremental additions of crumb rubber alone pertaining to 28 days nominal curing spells

It was observed that the base flexural strength attainable by the conventional concrete at 28 days curing spell was found to be 5.67MPa. As the increased additions in steps of 3% crumb rubber could replace the fine aggregates

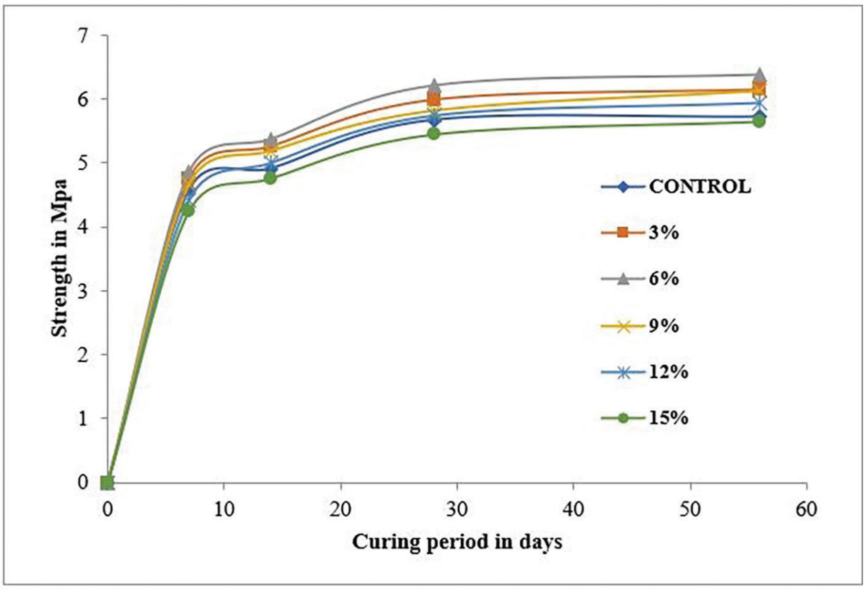

Figure 3: A family of curves (rubber crumbs against fine aggregate) for flexural strength Vs. curing spell in days.

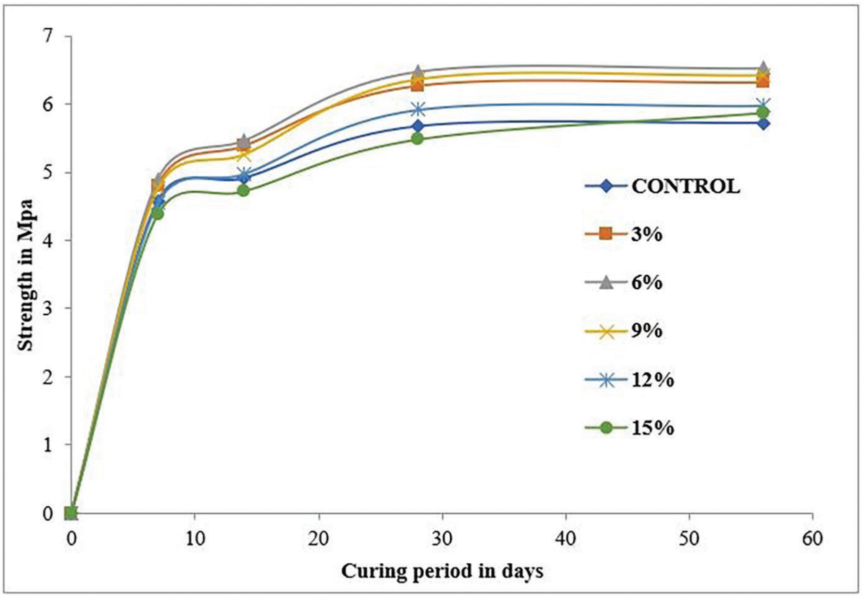

Figure 4: A family of curves (coal ash against cement) for flexural strength Vs. curing spell in days.

high flexural strength at 6.21MPa was registered with 6% addition of rubber crumbs. Thereafter the declining trend was observed falling below 5.67MPa for the control mix 5.45MPa with 15% additions of rubber crumbs from the technical point of view the point of inflexion and from the economic point of view the point of tolerance can be predicted by using the regression model equation $y = -0.008x^2 + 0.0103x + 5.718$ at data correlation level of around 82% only due to the flexible nature of the rubber crumbs. Figure 6, 7, 8 depicts a regression analysis at different curing spell. Accordingly, the flexural strength corresponding to the point of inflexion was 6.05MPa corresponding to 6% addition of rubber crumbs from the economic point of view the flexural strength at the point of tolerance was found to be 5.75 MPa against 12% addition of crumb rubber to on the safer side we consider only 6% addition of rubber crumbs to withstand the rupture failure at a critical flexural strength.

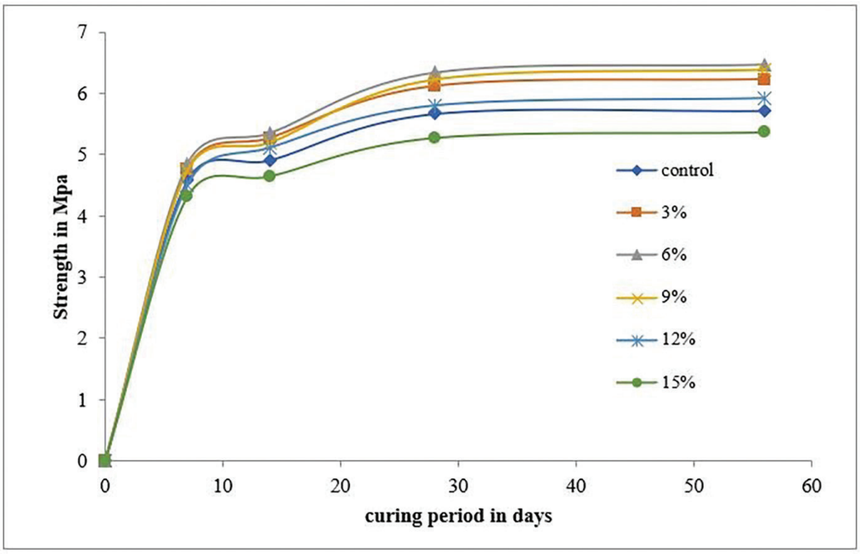

Figure 5: A family of curves (rubber crumbs and coal ash against fine aggregate and cement) for flexural strength Vs. curing spell in days.

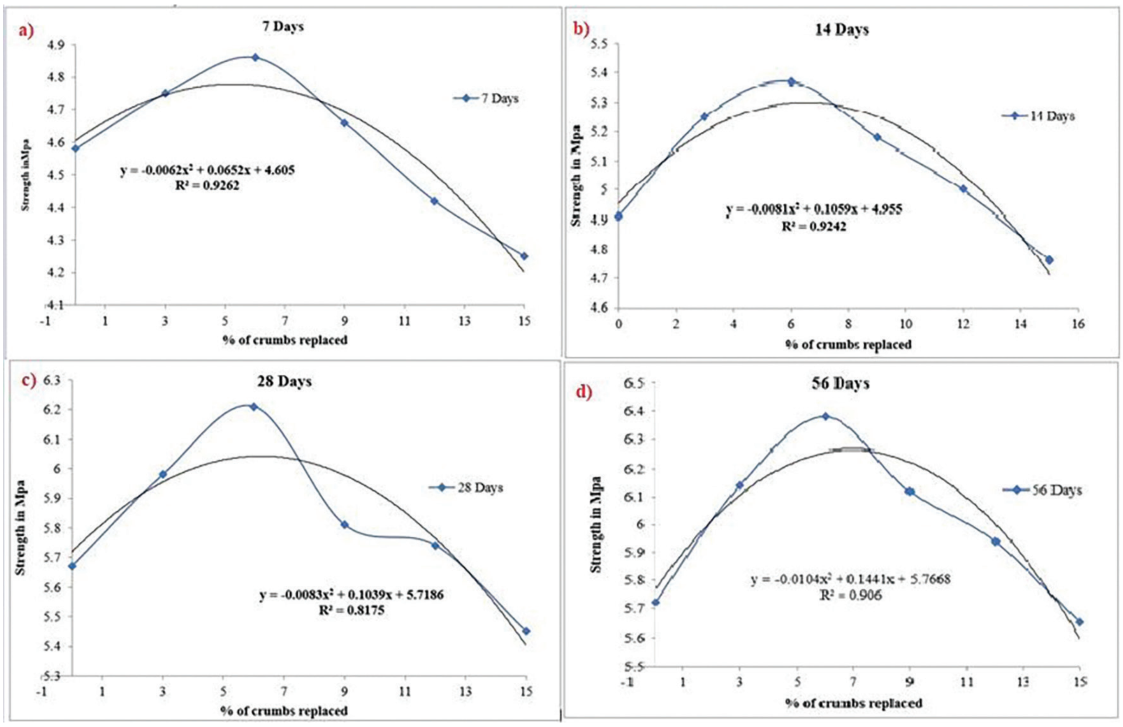

Figure 6: (a) A trend of flexural strength Vs. % of rubber crumbs for 7 days curing spell, **(b)** A trend of flexural strength Vs. % of rubber crumbs for 14 days curing spell, **(c)** A trend of flexural strength Vs. % of rubber crumbs for 28 days curing spell, **(d)** A trend of flexural strength Vs. % of rubber crumbs for 56 days curing spell.

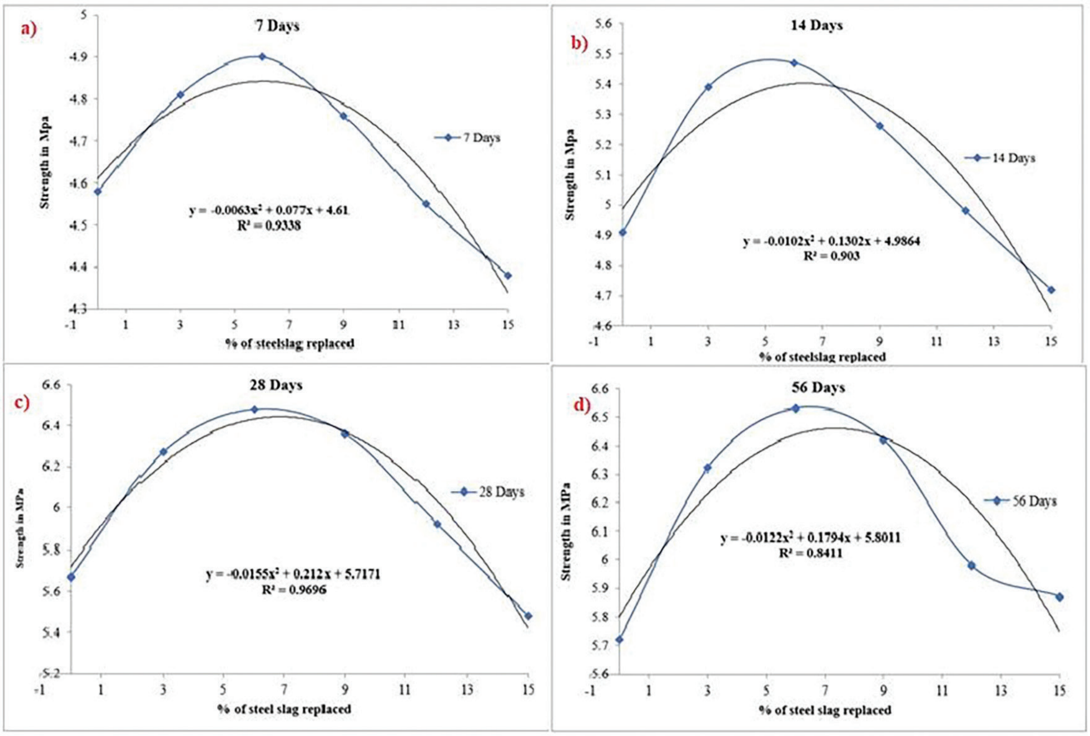

Figure 7: (a) A trend of flexural strength Vs. % of coal ash for 7 days curing spell, **(b)** A trend of flexural strength Vs. % of coal ash for 14 days curing spell, **(c)** A trend of flexural strength Vs. % of coal ash for 28 days curing spell, **(d)** A trend of flexural strength Vs. % of coal ash for 56 days curing spell.

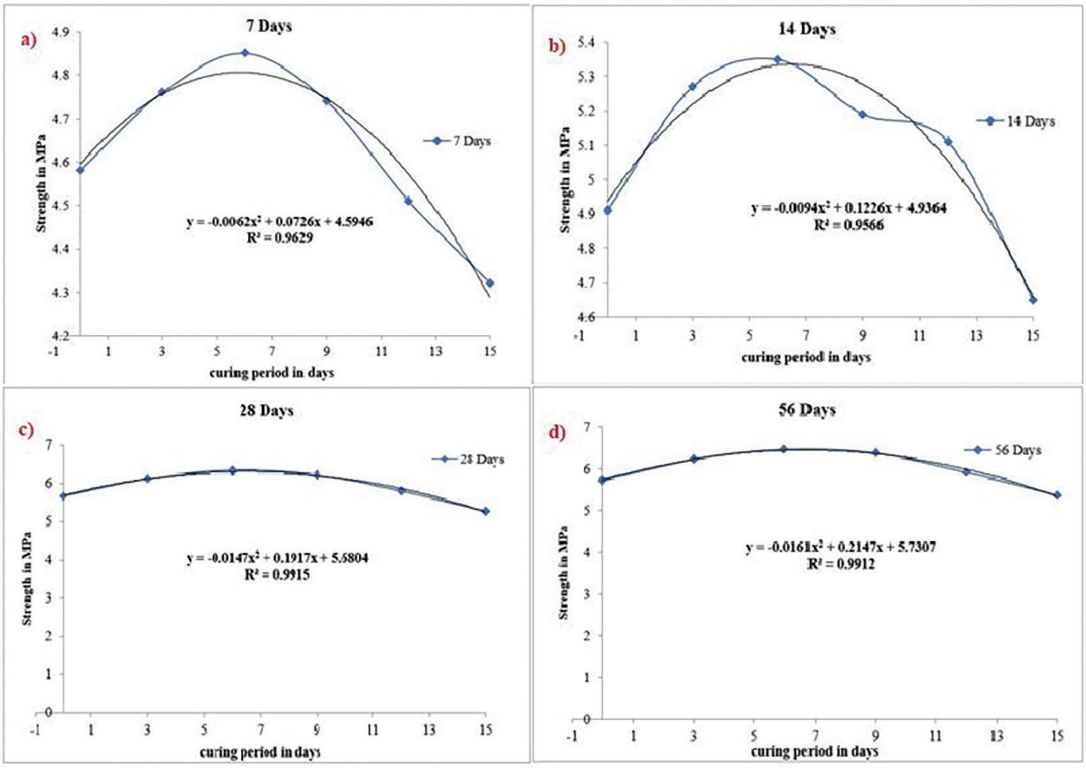

Figure 8: (a) A trend of flexural strength Vs. % of rubber crumbs and coal ash for 7 days curing spell, **(b)** A trend of flexural strength Vs. % of rubber crumbs and coal ash for 14 days curing spell, **(c)** A trend of flexural strength Vs. % of rubber crumbs and coal ash for 28 days curing spell, **(d)** A trend of flexural strength Vs. % of rubber crumbs and coal ash for 56 days curing spell.

4.2.2. Flexural strength analysis for freezing the value of coal ash addition

By the same token, for the nominal curing spell of 28 days the critical maximum flexural strength for technical feasibility was found to be 6.45MPa against 9% coal ash from the economic point of view this can be extended up to 12%, still maintaining the critical flexural strength at 5.8MPa against 5.67MPa for the control concrete mix. Hence from the safer side of technical feasibility, 9% addition of coal ash is endorsed for obtaining a critical maximum flexural strength against rupture.

4.2.3. Flexural strength endorsement with the combination of coal ash and rubber crumbs

For the nominal curing spell of 28 days, the conventional concrete registered 5.67MPa as the critical flexural strength against rupture. In case of 9% addition of rubber crumbs with the frozen combination of 9% coal ash addition, the critical flexural strength against rupture was found to be 6.22MPa which is still higher than that for the control concrete mix. Hence the family of curves, as well as the regression model equations, confirms an optimal proportion combination of 9% rubber crumbs with 9% coal ash to produce safer critical flexural strength against rupture. It is concluded that flexural strength analysis also the optimal proportional combination of rubber crumbs should be limited to 9% with an equal 9% frozen combination of coal ash.

5. CONCLUSION

From the experimental results, the following conclusions are drawn.

1. Out of five dosages, 4GOCA gives better results for the concrete. 04% of Graphene oxide with coal ash (5%, 10% and 15%). It is a general rule of thumb that the other tests for flexural strength will also fall in line with the compressive strength as the best indicator if the compressive strength of the control or the improvised concrete mix reaches the maximum in the test period of 28 days. It is assumed that the strength criteria of flexural strength will closely follow the fluctuation trend shown by compressive strength. However, in this study, additional endorsements with divided tensile and flexural strength were tried for the additional anchorage of the optimistic results for the improved concrete mix.
2. The flexural strength validation also ended up with the same trend as observed with getting 6.25MPa by the addition of 9% rubber crumb with 9% coal ash against 5.7MPa registered for the control mix. Hence the flexural strength analysis also endorses the combination of 9% rubber crumb with 9% coal ash to produce safer critical flexural strength against rupture even though the percentage addition of rubber crumbs extended up to 12% economically.
3. The regression analysis to arrive at the prediction of different kinds of strengths at different proportional combinations of the substitution materials concerning different curing spells was tried. Simultaneously a family of curves would be developed depicting the influence of the curing spell lapses with respect to the material substitution treatments involving three replications.

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