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ANALYTICAL STUDY OF MECHANICAL BEHAVIOR AND PREDICTION OF THE COMPRESSIVE STRENGTH OF RUBBER AGGREGATE CONCRETE

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ABSTRACT:
This study presents a comprehensive analytical investigation into the mechanical properties and compressive strength prediction of Rubber Aggregate Concrete (RAC), where waste tire rubber partially replaces conventional aggregates. Through systematic experimentation and mathematical modeling, the research examines the relationship between rubber content and mechanical behavior, focusing particularly on compressive strength characteristics. Multiple regression analysis models were developed to predict the compressive strength of RAC, incorporating variables such as rubber replacement percentage, aggregate properties. The experimental program involved testing specimens with varying rubber content (0-20% by volume) and different particle sizes. Results indicate that while increasing rubber content generally reduces compressive strength, it enhances ductility and energy absorption capacity. The developed prediction models achieved correlation R2 value is 0.96, demonstrating strong accuracy in estimating RAC compressive strength. Furthermore, the study establishes empirical equations that can effectively predict the mechanical behavior of RAC, These findings contribute significantly to understanding the performance characteristics of RAC and facilitate its practical implementation in sustainable construction.
Keywords: Rubber Aggregate Concrete (RAC), Compressive Strength Prediction, Mechanical Properties, Waste Tire Recycling, regration analysis and Sustainable Construction Materials.

INTRODUCTION:

General: - In recent years, waste handling and management is the primary issue faced by the countries all over the world. The waste problem is considered as one of the most crucial problems facing the world as a source of the environmental pollution. One of the critical wastes to be managed in today's scenario is 'waste tyre' because; modern development in transportation has produced large number of vehicles, which creates enormous amount of waste tyres. The disposal of waste tyres is becoming a major waste management problem in the world at the moment. It is estimated that 1.2 billions of waste tyre rubber has produced globally in a year, among that 275 millions of waste rubbers are produced by the United States, 180 millions of waste tyres are produced by European Countries, 170,000 tonnes of waste tyres are produced in Australia and 3 crores of waste tyres are produced in India per year. At present, it is estimated that 11% of postconsumer tyres are exported, 62% are reused, recycled or sent for energy recovery, among that only 4% of waste tyres are used for Civil Engineering projects and 27% are sent to landfill, stockpiled or dumped in illegal tyre dumps (Farcasiu 1993 and Brown 2002). Attention was not paid to identify the Civil Engineering applications of waste tyres.

Problem of Waste Tyre Rubber:

The use of rubber in so many applications results in a growing volume of rubber waste. With the increase in demand of automobiles, the manufacturing and use of tyres has been increased tremendously both in the developed and less developed countries. Since at least 65% of worldwide rubber production, and likely an even higher percentage of rubber disposals consists of automobile and truck tyres, this study has been chosen to focus on rubber waste from tyres. After finishing their working life, tyres wear out and have to be discarded and replaced. It is estimated that throughout the world an average of one used tyre per person per year is discarded. Used tyres are a challenging problem, since tyres have virtually unlimited life span.

Disposal of Waste Tyre Rubber:

Rubber materials are durable, flexible and elastic which are the basic properties required for manufacturing of tyre that itself engender critical problem of managing when it become waste. These waste tyres are source of environmental concern in developed countries, where land filling is still a common waste disposal strategy. Tyres decompose very slowly, at taking over a century to disintegrate at ambient temperatures. Tyres are bulky and trap air when disposed, which may make landfills unstable. Even worse, tyres do not stay buried, but float on the top of a landfill. Piled tyres trap water, and thus can become breeding grounds for mosquitoes and other water-incubating insects and bacteria.

Classification of Waste Tyres :

Waste tyre rubbers are categorized into three broad categories;

- **Crumb Rubber:** Crumb rubber refers to any material derived by reducing scrap tyres or other rubber into uniform granules with the inherent reinforcing materials such as steel and fiber removed along with any other type of inert contaminants such as dust, glass or rock.
- **Ground Rubber:** Ground rubber is also called crumb rubber and is produced by subjecting tyres to a series of high-powered machines that first shred the tyre, then reduced the product to ever decreasing particles size. Scrap Tyre: Tyre which cannot be used for the intended purpose it made for is known as Scrap Tyre.
- **Rubber Aggregate:** Reduction of scrap tyres to aggregate sizes by two processing technologies: mechanical grinding or cryogenic processing. Such rubber aggregate can be fine or coarse rubber aggregate. Fine rubber aggregate is sometimes referred to as crumb rubber aggregate while coarse rubber aggregate is sometimes referred to as tyre chips.

Scope of The Study: The objective of the present investigation is to identify the potential use of tyre rubber in concrete. Henceforth extensive research has been carried out to study the mechanical properties and durability. The replacement of rubber aggregates with fine aggregate, coarse aggregate, both fine and coarse aggregate varied between 2% and 10% of aggregates in steps of 2% by weight fraction. Cylindrical specimens of 6% rubber aggregate replacement are cast to derive the impact resistance and ductility index, hollow block specimens with the rubber replacement of 5%, 10% and 15% by volume are cast to derive the mechanical properties and beams are cast with optimal percentage of rubber aggregate replacement for studying the flexural strength.

OBJECTIVES OF THE PRESENT STUDY:

1. Usage of angular rubber aggregate in the production of concrete.
2. To explore the physical properties of rounded rubber aggregate.
3. Prepare concrete aggregates from angular rubber aggregate.
4. To develop a mixed design process based on the selected parameters using the Using Indian Standard Code (IS Code),
5. Experimentation for testing the strength features of the concrete aggregate and conventional concrete; i.e. compressive strength.
6. Regration analysis done on compressive strength results

LITERATURE REVIEW:

GENERAL

India is a developing country; it proposes multipurpose development projects. Every budget proposal involves large construction of roads, bridges, dams, irrigation schemes, public health engineering schemes, educational buildings and residential buildings etc. all these construction schemes demand optimum and efficient use of construction resources. Most of the modern heavy constructions require huge quantity of cement concrete incurs depletion of natural resources such as river sand and rock strata. Cost of river sand and crushed rock particles is rapidly increasing because of inadequate raw materials and rise of transport cost due to the hike in fuel price and other inputs. Further mining of river sand causes severe environmental damage by lowering ground water table and disintegration of rock strata causes landslide and earthquake. This emerging problem obliges contemporary material usage to balance the ecology. In this essence the abundant availability of waste tyre rubber can be utilized as an effective replacement for natural aggregate which will be beneficial for both circumstances. Hence this research project investigates the use of waste tyres in various aspects of construction. There have been a few numbers of rubber based concrete projects developed in all the corners of Civil Engineering. A critical review of the existing literature on the utilization of waste rubber is presented in the following areas:

- Civil Engineering Applications of Scrap (Waste) Tyres
- Waste Tyres in Road Construction
- Waste Tyres in Concrete
- Waste Tyres in Hollow Blocks
- Applications and Advantages of Tyre Rubber Aggregate Concrete (TRAC)

Civil Engineering Applications of Scrap (Waste) Tyres:

Scrap tyre chips and their granular parts such as ground rubber and crumb rubber; have been used in a number of Civil Engineering applications. Tyre chips which is roughly shredded into 2.5 to 30 cm lengths have been researched extensively as lightweight fill for embankments and retaining walls, but it has also been used as drainage layers for roads and in septic tank leach fields (Humphrey 1999).

According to Humphrey (1999), some of the advantageous properties of tyre chips include low material density, high bulk permeability, high thermal insulation, high durability, and high bulk compressibility. In many cases, scrap tyre chips may also represent the least expensive alternative to other fill materials. Crumb rubber has been successfully used as an alternative aggregate source in both asphalt concrete and PCC. This waste material has been used in several engineering structures like highway base courses, embankments, etc

Sub grade Insulation for Roads:

Excess water is released when sub grade soils thaw in the spring. Placing a 15 to 30 cm thick tyre shred layer under the road cab prevents the sub grade soils from freezing in the first place. In addition, the high permeability of tyre shreds allows water to drain from beneath the roads, preventing damage to road surfaces (ASTM D6270-98).

Sub grade Fill and Embankments:

Tyre shreds can be used to construct embankments on weak, compressible foundation soils. Tyre shreds are viable in this application due to their light weight. For most projects, using tyre shreds as a lightweight fill material is significantly a cheaper alternative (Tyres Manufacture's Association 2003).

Backfill for Walls and Bridge Abutments :

Tyre shreds can be useful as backfill for walls and bridge abutments. The weight of the tyre shreds reduces horizontal pressures and allows for construction of thinner, less expensive walls. Tyre shreds can also reduce problems with water and frost build-up behind walls because tyre shreds are free draining and provide good thermal insulation. Recent research has demonstrated the benefits of using tyre shreds in backfill for walls and bridge abutments. (Tyres Manufacture's Association 2003).

Landfills :

Landfill construction and operation is a growing market application for tyre shreds. Scrap tyre shreds can replace other construction materials that would have to be purchased. Scrap tyres may be used as a lightweight backfill in gas venting systems, in leachate collection systems, and in operational liners. They may also be used in landfill capping and closures, and as a material for daily cover. (Tyres Manufacture's Association 2003).

METHODOLOGY:

General:

Test examinations have been completed to decide the fresh concrete properties and hardened concrete properties for the structured M30 grade of concrete samples, and rubberised concrete samples.

Methodology:

In this examination, the new concrete properties and solidified concrete properties of Rubberised Concrete (RC) is done for a different level of replacement of coarse aggregate by rubber. Rubber having a size of 16mm to 20mm is utilized for making rubberised concrete. M30 grade concrete is utilized for making ordinary concrete with the water-cement proportion of 0.45.

Present investigation comprises of deciding the mechanical properties and cyclic stacking conduct of Rubberised Concrete (RC) in column beam joint and contrasting it with Conventional M30 grade concrete. M30 review having mix proportion with water-cement proportion of 0.45 is touched base by the strategy of IS-10262:2009. The level of replacement of rubber utilized is 0%, 5%, 10%, 15% and 20% for the coarse aggregate by volume of coarse aggregate. The separate concrete is assigned as CC, RC4, RC8, RC12 and RC15.

In M55 concrete utilized for railway sleeper compressive quality of the concrete with 0%, 5%, 10%, 15% and 20% rubber substance as coarse aggregate were discovered. The individual concrete was assigned as CC, R6, R8 and R12.

Details of the Specimen:

Specimens of size 150 mm x 150 mm x 150 mm which is utilized to locate the compressive quality. The factors of samples considered as Conventional Concrete (CC), Rubberised Concrete (RC) are named as RC4, RC8, RC10 and RC15. The level of replacement of rubber made is 0%, 5%, 10%, 15% and 20% for a volume of coarse aggregate.

Mixing and Casting of Concrete:

A sum of 5 fundamental mixes was cast. In that one control mix and four rubberised concrete mixes in particular CC, RC4, RC8, RC12, RC15 for every sample by utilizing M30 (1:1.62:2.764) grade concrete with the water-cement proportion of 0.45. At first, Ordinary Portland cement of 53 grade from Dalmia, river sand and a coarse aggregate of 20 mm maximum size were combined for making Conventional Concrete (CC). Polyvinyl alcohol (powder shape) was mixed with the above mix to create Rubberised Concrete samples. At first, the moulds were oil covered for simple expulsion of moulds. Presently cement, aggregates and Polyvinyl alcohol were mixed for 1 minute and water was included inside 2 minutes. Piece Rubbers mixed with coarse aggregate before including the coarse aggregate. Now concrete was permitted to mix for 3 minutes. The mixing was finished by the hand mixing process. In the wake of mixing, the moulds are filled promptly by pouring the concrete inside. Concrete is filled in three layers each layer is compacted well by utilizing a packing pole of standard size (16 mm), to keep away from entangled air inside the concrete solid shapes and honeycombing impacts on the sides. The samples were demoulded following 24 hours from the arrangement of sample. In the event that the concrete has not accomplished adequate strength to empower demoulding the samples, at that point the procedure must be postponed for an additional 24 hours consideration ought to be taken not to harm the sample amid the procedure in light of the fact that, if any harm is caused, the quality of the concrete may get diminished. Subsequent to demoulding, the sample was set apart with a readable distinguishing proof, on any of the countenances by utilizing paint. In the wake of demoulding the samples are set in a restoring tank with 90% relative dampness and 23°C for 28 days of curing. For 12 hours preceding the testing, the samples were permitted to air dry in the laboratory.

A sum of 3 primary mixes were utilized to cast the T type Column-Beam joint samples. The samples were intended for seismic load as indicated by IS 1893 (Part-I): 2002 and IS 13920: 1998. The test sample is a sub gathering of the fortified concrete building. It is the outside Column-Beam joint at first floor. For experimentation, 33% scale outside column-beam section joint samples was developed for the 0%, 5%, 10%, 15% and 20% replacement of rubber.

RESULTS AND DISCUSSION:

Slump Value of Angular Flyash Aggregate in Concrete M-30:

Table 5.1: Slump Test Results rubber aggregate in Concrete M-30

Rubber aggregate	Slump Value	Slump Value %
0%	185	-
5%	172	-7.03
10%	165	-10.81
15%	120	-35.14
20%	95	-48.65

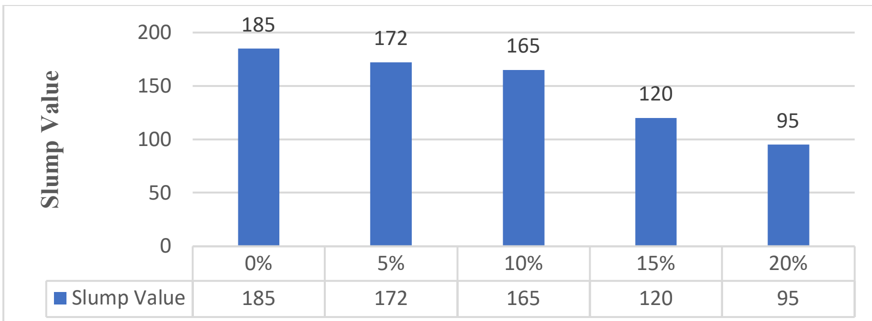

Fig 6.1: Slump Test Results angular rubber aggregate in Concrete M-30

5.2 All mix combinations' compressive strength at 3, 7, 14, 21, 28, 56 and 90 days

Figures 8(a) and (b), respectively, show the findings of the compressive strength of recycled concrete aggregate with samples A1, A2, A3, A4, and A5. Nearly all the mixes attain the desired value of compressive strength and demonstrate strength development with age.

Table 5.2: Compressive Strength of all mix combinations at 3, 7, 14, 21, and 28 days

S. No.	Compressive Strength								
	Natural aggregate	Rubber aggregate	3 days	7 days	14 days	21 days	28 days	56 days	90 days
1	100	0	20.30	29.33	34.81	37.19	39.41	40.74	43.26
2	95	5	19.85	28.59	28.59	34.81	38.52	39.56	40.89
3	90	10	18.37	26.96	30.81	33.04	35.70	37.33	38.22
4	85	15	16.59	24.15	26.96	29.93	31.56	32.44	35.85
5	80	20	14.96	22.52	23.41	27.85	29.93	31.26	34.81

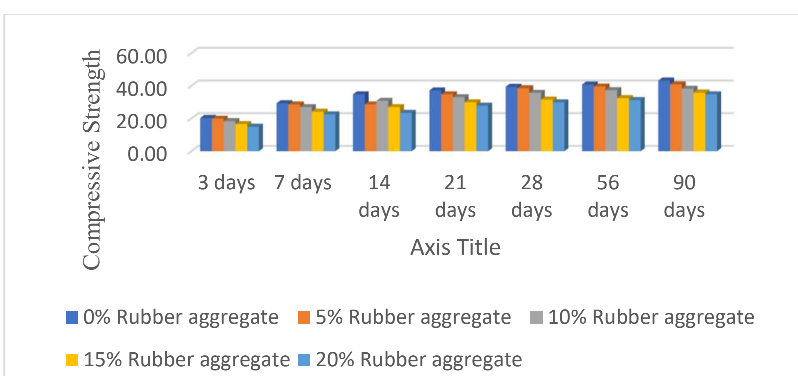

Figure 5.2 Compressive strength of concrete with various percentage combinations of rubber aggregate at different curing ages.

In the current work, a regression-based model is created for the estimation of the compressive strength of concrete containing various percentages of angular flyash aggregate at various ages (Fc(d)). The 28th-day compressive strength (Fc(28)) and normalized compressive strength calculated using the 28th-day strength [8] are used to produce the model equation. In order to derive equations for Fc(d)/Fc(28), which are based on experimental findings, regression analysis of the best-fitted curve is used.

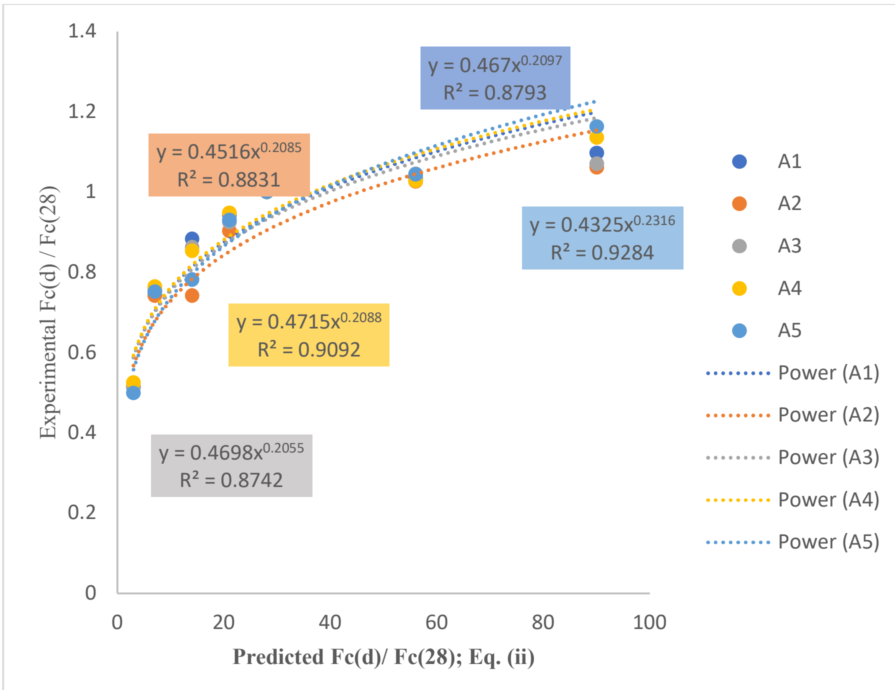

Figure 5.3 Compressive strength normalizes at 28days as a function of curing age in days for A_1, A_2, A_3, A_4, & A_5

A relationship between the ratio of compressive strength experimental data at any age, d (in days, Fc(d)), to 28th days compressive strength Fc (28), versus curing time (in days), is plotted as shown in Figure8 to derive the strength evaluation model for various samples. Five well-fitted curve power curve were generated by regression to formulated the generalized equation in terms of compressive strength evaluation as;

$F_{c(d)}/F_{c(28)}=a_1t^{b1}$ (i)

where, t is the curing time, a_1 and b_1 are constants.

Because of higher R^2 values, we can say constants a_1 and b_1 are proposing the compressive strength evaluation and they are rewritten as Eqs. for different samples A_1, A_2, A_3, A_4, and A_5, respectively.

$F_{c(d)}/F_{c(28)} = 0.265d^{0.395}$ $R^2 = 0.948$ (ii)

$F_{c(d)}/F_{c(28)} = 0.226d^{0.446}$ $R^2 = 0.992$ (iii)

$F_{c(d)}/F_{c(28)} = 0.263d^{0.403}$ $R^2 = 0.932$ (iv)

$F_{c(d)}/F_{c(28)} = 0.264d^{0.400}$ $R^2 = 0.914$ (v)

$F_{c(d)}/F_{c(28)} = 0.218d^{0.444}$ $R^2 = 0.991$ (vi)

The estimation models for compressive strength evaluation based on curing time and 28th-day compressive strength provided in various standard codes around the world are listed in Table 7. The graph in Figure 10 (a), (b), (c), (d), and (e) compares the outcomes of suggested estimated models to current estimated equations. A higher R2 value indicates that geopolymer concrete behaves similarly to concrete in terms of strength development with curing time.

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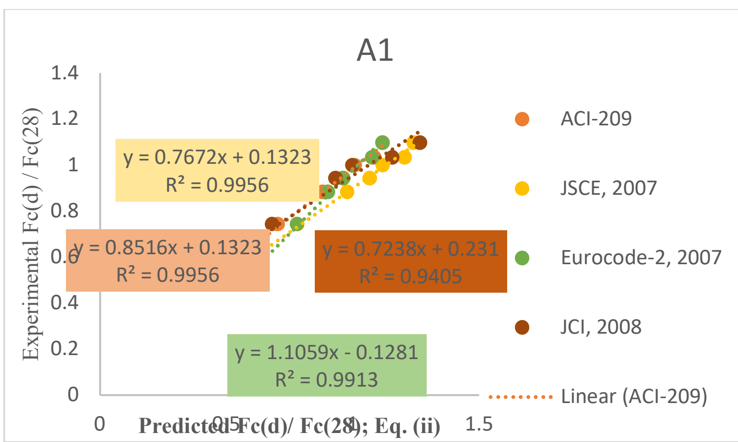
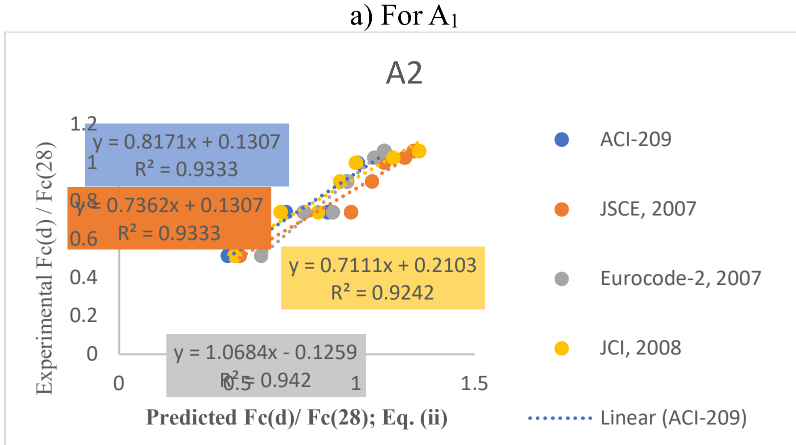
Table 7. Compressive strength estimation models based on curing age that are currently available

S.No.	Estimating model	Reference
(a)	$\frac{F_c(d)}{Fc(28)} = \frac{d}{4 + 0.85d}$	ACI-209, 1992 [27]
(b)	$\frac{F_c(d)}{F_c(28)} = 1 \cdot 11 \frac{d}{4 \cdot 5 + 0.85d}$	JSCE, 2007 [28]
(c)	$\frac{F_c(d)}{F_c(28)} = \exp\left(0.25\left(1 - \sqrt{\frac{28}{d}}\right)\right)$	Eurocode-2, 2007 [29]
(d)	$\frac{F_c(d)}{F_c(28)} = 0 \cdot 2289Ln(d) + 0 \cdot 235$	JCI, 2008 [30]



a) For A_1



b) For A_2

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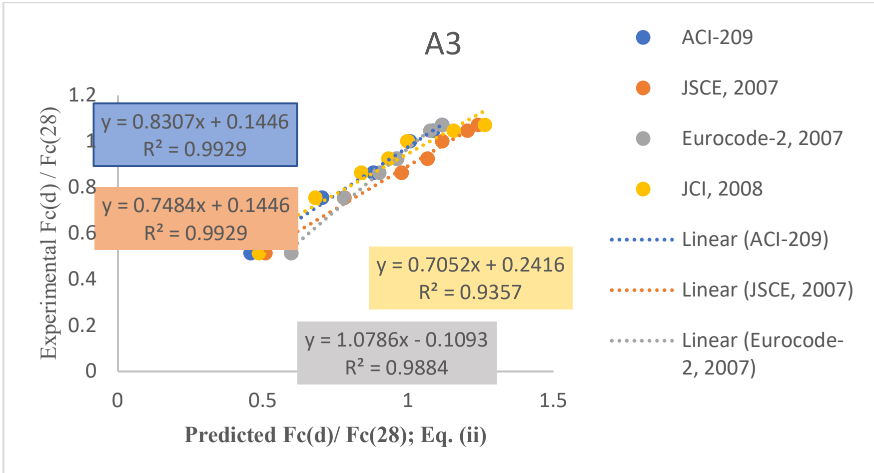
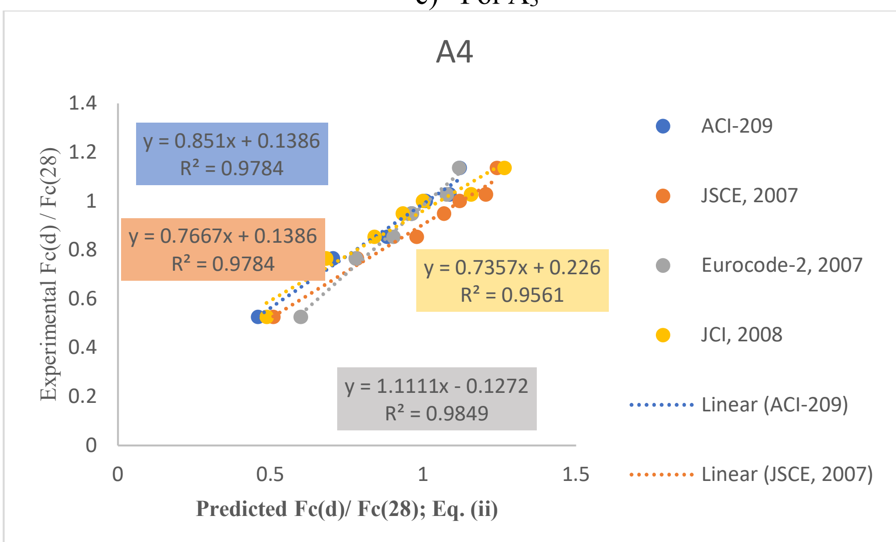
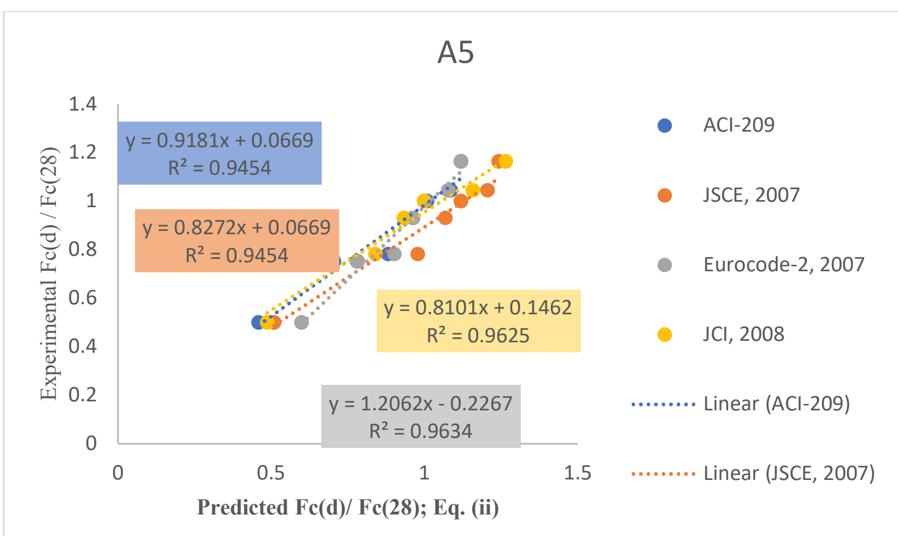


c) For A_3



d) For A_4



e) For A_5

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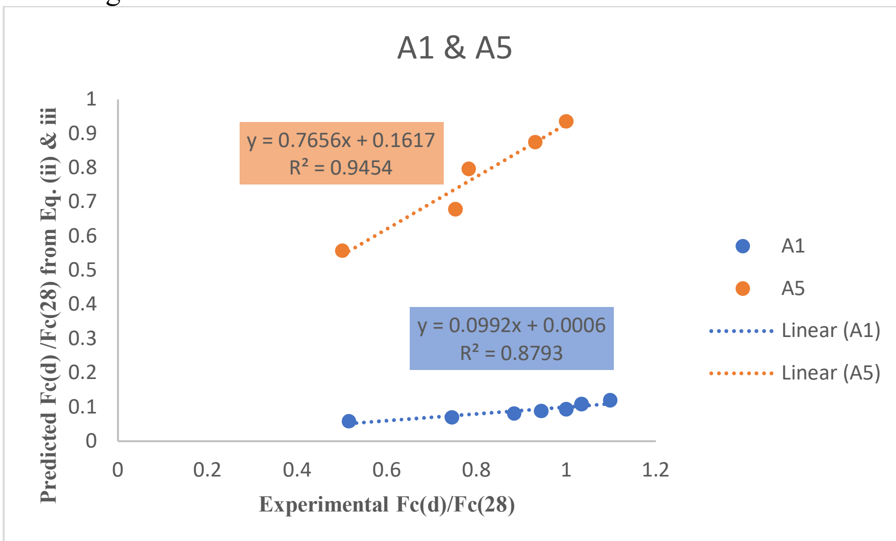
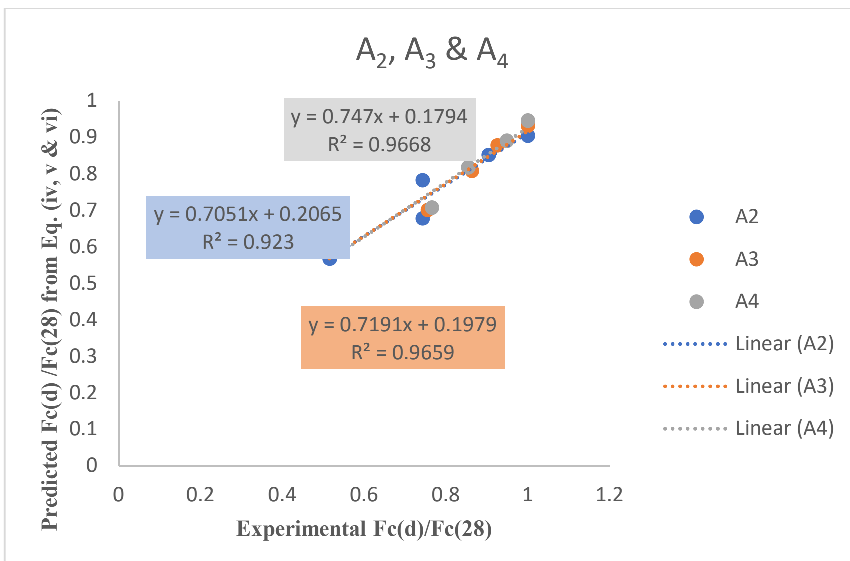
Figure 6.4. Evaluation of Fc(d)/Fc(28) findings using proposed regression-based model and existing estimation methodologies.



a) A_1 & A_5(Unitary)



b) A_2, A_3 & A_4 (Binary)

Comparison of experimental Fc(d)/Fc(28) values for various angular flyash aggregates of coarse aggregate in concrete with values from proposed models is shown in Figure 6.5.

Equations (ii), (iii), (iv), and (v) are plotted in Figure 11 (a) and (b) in relation to experimental compressive strength for various blends of angular flyash aggregate concrete, including unitary (A1 and A5) and binary (A2, A3, and A4 blends. In relation to the variable Angular Flyash Aggregate, the higher values of R2 demonstrate the applicability of regression-based compressive strength evaluation equations on concrete.

CONCLUSIONS:

In this study, the feasibility of using rubber aggregate as a substitute for natural coarse aggregate in concrete was investigated. The influence of various particle sizes of rubber aggregate was also examined. Experimental data on compressive strength at different curing durations were utilized to develop a regression-based model. Additionally, the empirical model's outcomes for concrete were compared with existing predictive models to evaluate compressive strength at different ages of curing. Based on the analysis of the experimental findings, the following conclusions can be drawn:

- As the content of rubber aggregate increased, the slump value decreased.
- An increase in rubber aggregate content resulted in a decrease in compressive strength.
- Optimum strength for the M-30 mix design was achieved with a 15% replacement of rubber aggregate.
- Utilizing 15% rubber aggregate as coarse aggregate in concrete demonstrated favorable results in terms of compressive strength. Sample A4, which combined natural aggregate (85%) and rubber aggregate (15%), achieved the target compressive strength within 28 days.
- R^2 value high in 15 % of natural aggregate with rubber aggregate.
- The proposed model proved to be reliable for predicting compressive strength in rubber aggregate concrete.

Future Scope of the Study:

The following recommendations are proposed for further research:

- If further investigations support the use of concrete buildings, it is suggested to revise existing specifications to permit and encourage the utilization of other waste materials.
- Conduct additional trials with varying percentages of steel fiber, jute fiber, and coir fiber replacements.
- Further explore the durability, creep, and shrinkage characteristics of steel fiber, jute fiber, and coir fiber materials in new concrete through comprehensive laboratory tests.

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