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An experimental and numerical approach in strength prediction of reclaimed rubber concrete

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Abstract. Utilization of waste tires may be considered as one of the solution to the problems faced by the local authorities in disposing them. Reclaimed rubber (RR) is being used in concrete for replacing conventional aggregates. This research work is focused on the strength prediction of reclaimed rubber concrete using a Genetic Algorithm (GA) for M40 grade of concrete and comparing it with experimental results. 1000 sets were taken and 100 iterations were run during training of GA models. A base study has been carried out in this research work partially replacing cement with three types of fillers such as Plaster of Paris (POP), Fly Ash (FA) and Silica Fume (SF). A total of 243 cubes were cast and tested for compression using a Universal Testing Machine. It was found that SF produced maximum strength in concrete and was used in the main study with reclaimed rubber. Tests were conducted on 81 cube samples with a combination of optimum SF percent and various proportions of RR replacing coarse aggregates in concrete mix. Compressive strength tests of concrete at 7, 14 and 28 days reveal that the maximum strength is obtained at 12 percent replacement of cement and 9 percent replacement of coarse aggregates respectively. Moreover the GA results were found to be in line with the experimental results obtained.

Keywords: Plaster of Paris; fly ash; silica fume; compressive strength; reclaimed rubber; genetic algorithm

1. Introduction

Constituents of concrete have a great demand all over the world. The production of ordinary Portland cement has increased greatly during the last decades especially in emerging and developing countries. There is a need to find an alternate material for the conventional materials used in concrete in order to reduce the price in the local markets. In recent years waste tires have been recycled and used in concrete as a replacement for aggregates thereby reducing the demand for natural aggregates and solving the problems related to disposal of solid waste materials in landfill to a greater extent. Fillers such as Plaster of Paris, fly ash and silica fume replaced cement partially whereas reclaimed rubber was used to partially replace coarse aggregates in this research

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work. POP reduces initial setting time and its incorporation improves the strength and water tightness of the product to some extent. Fly ash is a pozzolan when mixed with lime these pozzolans combine to form cementitious compounds. Concrete containing fly ash becomes stronger, durable and more resistant to chemical attack (Samrit *et al*. 2016).

Silica fume is a byproduct of the production of Ferro silicon alloy containing silicon. It is also known as micro silica, condensed silica fume, volatized silica or silica dust and it is fine non crystalline silica produced in electric arc furnaces as defined by the American Concrete Institute. It can exhibit both pozzolanic and cementitious properties. Silica fume has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. By using silica fume along with super plasticizers, it is relatively easier to obtain compressive strengths of order of 100-150 N/mm^2 in laboratory (Siddique and Iqbal 2011)

Mansour and Saravanan (2015) have done their research on concrete mixed with waste rubber tire and Silica fume replacing fine aggregate and cement for M25 grade concrete. Test results indicated a reduction in compressive and split tensile strength and an increase in flexural strength as the rubber content increases.

Ghorpade *et al*. (2012) in their study determined the concrete strength through experimental methods and compared it with the results obtained analytically using genetic programming. The basic concept of a genetic algorithm is designed to simulate processes in a natural system necessary for evolution.

2. Literature review

Pradhan and Dutta (2014) performed experiments with various percentages of Silica fume replacing cement with a water cement ratio of 0.5 which revealed that the optimum compressive strength was obtained at 20 percent replacement of cement by silica fume at all age levels (24 hours, 7 and 28 days). Test results showed that the compressive strength of 100mm cubes are higher than 150mm cubes at all age levels.

Bansal *et al*. (2015) in their study on the compressive strength of concrete have observed that as the fly ash content increases there was an increase as well as a decrease in the strength of concrete. Even though the strength decreased initially there was a gradual improvement in the concrete strength for a further increase of fly ash content in concrete.

Prasad *et al*. (2016) have observed that as the proportion of POP coated rubber aggregate increases the concrete strength decreases. Moreover test results reveal that the slump values of coated rubber aggregates and rubber aggregates are very high compared to conventional concrete.

Namyong *et al*. (2004) have clearly observed that predicted compressive strength values are very close to experimentally obtained values. To further test the efficacy and reliability of the models, the in situ compressive strength data at curing age of 28 days has been used in the study.

Amudhavalli and Mathew (2012) in their research confirmed that optimum silica fume replacement percentage for obtaining maximum 28 days strength of concrete ranged from 10 to 20 percent. 10 percent replacement of cement with silica fume leads to an increase in the compressive strength of M30 grade concrete leading to an improvement in the mechanical properties of concrete. In the above study the suitability of silica fume has been discussed by replacing cement with silica fume at varying percentage and the strength parameters were compared with conventional concrete.

Sharma *et al.* (2014) in their research on the compressive strength of silica fume concrete found that the compressive strength increased with an increase in percentage replacement of silica fume up to10 percent and then gradually decreased with 15 percent replacement. It also revealed that the compressive and tensile strength of concrete increased with age.

An analysis on strength prediction of crumb rubber concrete showed that there was a strong correlation between increasing rubber content and reduction in its compressive strength. The reduction in compressive strength reached 70 percent at 25 percent rubber content. The proposed model had the least scattering in its predictions compared to similar previous models (Youssf *et al.* 2014)

3. Experimental investigation

3.1 Materials used

The cementitious material used in concrete was Ordinary Portland cement (53 grade). Clean dry river sand and hard granite broken stones of 20 mm size were used in the concrete mix. Reclaimed rubber replaced conventional coarse aggregates. POP, FA and SF replaced cement and were used as fillers in the concrete mix to enhance its compressive strength.M40 grade of concrete was prepared with a water-cement ratio of 0.3. The concrete mix was designed as per IS 10262-2009. Cement is the binding material in concrete which fills up voids existing in fine aggregate and makes it impermeable by providing strength to concrete on setting and hardening.

Aggregate is commonly considered to be an inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete (Aginam *et al*. 2013). The shape, texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight along with the water/cement ratio determine the strength, workability, and durability of concrete. The shape and texture of the aggregate affects the properties of fresh concrete more than hardened concrete.

3.1.1 Fine aggregate

Fine aggregate is one of the ingredients of the concrete mix. The size of fine aggregate is less than 4.75 mm. Table 1 shows the properties of fine aggregates such as specific gravity, water absorption and fineness modulus.

3.1.2 Coarse aggregate

Coarse aggregate is the concrete mix ingredient which is being replaced partially by reclaimed rubber. Table 2 shows the test results of coarse aggregates such as specific gravity, water absorption and fineness modulus.

Table 1 Physical properties of fine aggregate

S. No	Description	Values
1	Specific Gravity	2.6
2	Water Absorption	2.4 %
3	Fineness modulus	3.5

Table 2 Test results of coarse aggregate

S. No	Description	Values
1	Specific Gravity	2.07
2	Water Absorption	0.5%
3	Fineness modulus	3.5

Fig. 1 Reclaimed rubber used for concrete

Table 3 Test results of reclaimed rubber

S. No	Description	Values
1	Ash Content	5.43%
2	Density	1.123g/cc
3	Tensile Strength	17.71kg/cm^2
4	Specific Gravity	1.25
5	Water Absorption	8.5%

3.1.3 Reclaimed rubber

The replacement of natural aggregates with rubber aggregates tends to reduce the density of the concrete. This reduction is attributable to the lower unit weight of rubber aggregate compared to ordinary aggregate. The unit weight of rubberized concrete mixtures decreases as the percentage of rubber aggregate increases. Fig. 1 shows reclaimed rubber which was obtained from Inter city Enterprises, Chennai and cut to the required shape and size. Table 3 shows the test results of reclaimed rubber such as its specific gravity, density, water absorption etc., which were obtained from the supplier.

3.1.4 Plaster of Paris

In this study Plaster of Paris replaces cement partially in the concrete mix. It is observed that 80 percent of the target strength is achieved when cement is being replaced by 5 to 15 percent of POP in concrete (Kanthe 2013). It is noted that the incorporation of plaster of Paris as an additive improves water tightness as well as the compressive strength of concrete. Moreover it reduces the initial setting time and is indifferent for its final setting up to a certain limit (Yadav 2008).

3.1.5 Fly ash

Fly ash is the most commonly used pozzolona in concrete. In the presence of water it reacts with calcium hydroxide at ordinary temperatures to produce cementitious compounds. The spherical shape and particle size distribution of fly ash improves the fluidity of flowable fill, thereby, reducing the amount of mixing water required and contributing to the long term strength of high strength concrete with fly ash. The compressive strength of concrete increased with an increase in the number of days that it was cured (Namagga and Atadero 2009)

3.1.6 Silica fume

Silica fume is a puzzalonic material which is used to strengthen the transition zone in concrete. In high performance concrete 7 percent of silica fume and 0.5 percent of cellulose fiber gives an optimum compressive strength but beyond these percentages the strength decreases (Patel and Patel 2013). It is seen that when cement is replaced with silica fume the compressive strength of concrete increases up to 10 percent replacement and further replacements tend to reduce the strength of concrete (Ghutke and Bhandari 2014) The physical properties of silica fume which are given in Table 4 were obtained from the supplier Astra Chemicals, Chennai.

Table 4 Physical properties of silica fume

S.No	Description	Values
1	Physical state	Micronized powder
2	Odor	Odorless
3	Appearance	White Color powder
4	Pack density	0.76 gm./cc
5	Ph of 5% solution	6.9
6	Specific gravity	2.63
7	Moisture	0.058%

Fig. 2 Casting of cube samples

3.2 Preparation and testing of concrete

In this study the concrete mix was designed as per IS 10262-2009 and the mix ratio was found to be 1:1.09:1.75. The concrete mix was prepared based on the mix design in a mixer machine. Moulds of size 150×150×150 mm for cubes were used to cast the samples. The concrete batch is mixed on a water tight, non-absorbent steel platform with a shovel, trowel and similar suitable equipment using the following procedure. The ingredients of concrete are mixed in the required

Fig. 3 Curing of cube samples

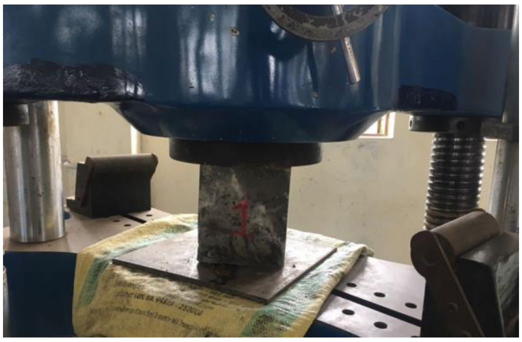

Fig. 4 Compressive strength test on cubes using universal testing machine

Table 5 Test sample designation (M40 Grade)

Sample Designation	Average Compressive strength of cubes (7,14 and 28days)
A	Plaster of Paris
B	Fly Ash
C	Silica Fume
D	Optimum SF with various proportion of RR

proportion in a concrete mixer machine after adding the required quantity of water. The mixing is continued until concrete appears to be homogenous and has the desired consistency. After mixing the cube moulds are filled in layers, compacted and allowed to harden for a period of 24 hours (Fig. 2) All the specimens are demoulded and immersed in a curing tank to attain the required strength (Fig. 3).

In the main study reclaimed rubber replaced coarse aggregates in increments of 3 percent from zero up to 24 percent in concrete along with the optimum SF percent obtained. 81 specimen cubes were cast and cured for 7, 14 and 28 days and tested for their compressive strength in a UTM which has a capacity of 50 tons (Fig. 4).

Testing of hardened concrete helps to achieve the required quality of concrete with respect to its strength and durability. The rate of loading on the test samples was monotonic in nature. The tests were conducted to find out the maximum load carrying capacity of the specimen. Table 5 shows the sample designation for each type of test conducted in the material lab with mineral admixtures and reclaimed rubber.

4. Numerical analysis

4.1 General

A Genetic Algorithm works with a set of individuals representing possible solutions to the task. The selection of individuals is performed by survival of the fittest. The selection principle is applied by using a criterion giving an evaluation for the individual with respect to the desired solution. The best suited individuals create the next generation. In this recombination type the parents exchange the corresponding genes to form a child. The cross over can be a single or a multi-point figure. For the recombination a bit Mask is used (Fig. 5). The equations describing the process are:

$$C_1 = Mask_1 \& P_1 + Mask_2 \& P_2$$
$$C_2 = Mask_2 \& P_1 + Mask_1 \& P_2$$

P_1, P_2-parent's chromosomes;
C_1, C_2-children's chromosomes (offspring individuals);
$Mask_1$, $Mask_2$-bit masks ($Mask_2$=NOT ($Mask_1$))&-bit operation "AND".

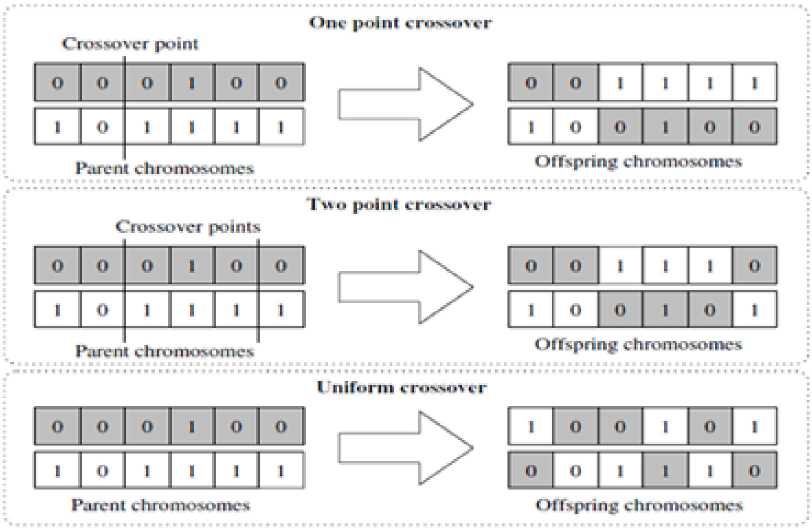

Fig. 5 Crossover with bit mask

The mathematical description of this crossover is:

$$C_1 = \gamma . P_1 + (1-\gamma) . P_2$$
$$C_2 = (1-\gamma) . P_1 + \gamma . P_2$$
$$\gamma = (1+2.\alpha).r - \alpha$$

P_1, P_2-chromosomes of the parents; C_1, C_2-chromosomes of the children (offspring individuals);
α-exploration coefficient - user defined ($\alpha \geq 0$);
r-random number between 0 and 1;
Mutation means random change of the value of a gene in the population (Fig. 6). The

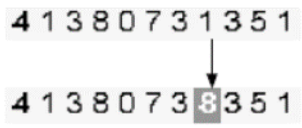

Fig. 6 Mutation in a chromosome

Fig. 7 Mutation places in the population

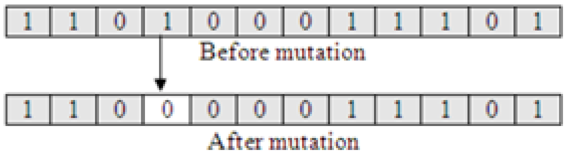

Fig. 8 Mutation in the genetic algorithm

chromosome, which gene will be changed and the gene itself are chosen by random as well. Fig. 7 shows the mutation places in the population and Fig. 8 shows the mutation process in genetic algorithm.

4.2 Scheme of evolutionary algorithm:

The Evolutionary Algorithm (EA) holds a population of individuals (chromosomes), which is evolved by means of selection and other operators like crossover and mutation. Every individual in the population gets an evaluation of its adaptation (fitness) to the environment. The selection chooses the best gene combinations (individuals), which through crossover and mutation should drive to better solutions in the next population. The most often used scheme of GA is shown in Fig. 9. In most of the algorithms the first generation is randomly generated by selecting the genes of the chromosomes among the allowed alphabet for the gene. It is possible to stop the genetic optimization by:

√ Identifying the value of the function of the best individual is within defined range around a set value.
√ Maximizing number of iterations which is the most widely used stopping criteria.
√ During crossover the individuals chosen by selection recombining with each other and new individuals being created.
√ Having the Mutation done by means of a random change of some of the genes.
√ The elite individuals chosen from the selection combining with those who passed the crossover and mutation, and forming the next generation.

5. Results and discussions

The maximum load is obtained with the aid of a UTM and compression test results are calculated based on the maximum force and the cross-sectional area for cubes. Table 6 shows the compressive strength test results of M40 grade concrete replacing cement with different proportions of POP.

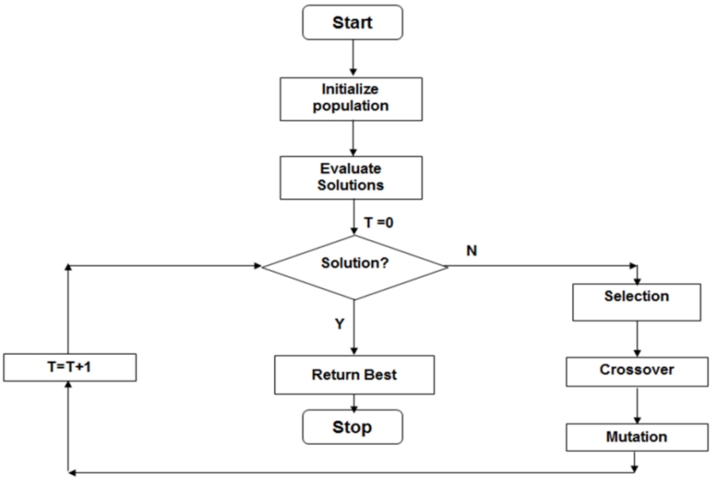

Fig. 9 Flow chart showing Scheme of EA

Table 6 Test results of M40 grade concrete mixed with POP

S. No.	Sample Designation	POP (%)	Average compressive strength (N/mm^2)		
			7th day	14th day	28th day
1	A1	0	27	33.75	40.3
2	A2	3	29.2	36.5	43.2
3	A3	6	31.35	39.2	46.4
4	A4	9	34.9	43.64	51.75
5	A5	12	33.3	41.6	49.3
6	A6	15	30	37.5	44.4
7	A7	18	27.4	34.6	41.2
8	A8	21	24.1	32.3	38.4
9	A9	24	21	29.2	35.0

Note: POP-Plaster of Paris

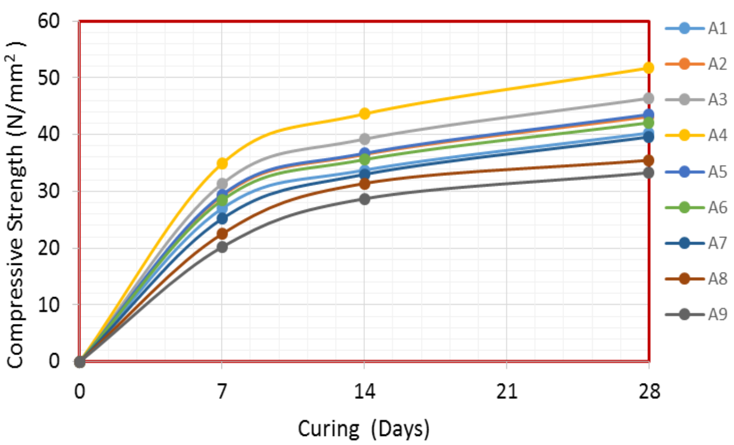

Fig. 10 Compressive strength of concrete mix at various proportions of POP

Fig. 10 shows that for every 3 percent increase in silica fume there is a gradual increase in the concrete strength irrespective of the replacement percentage. Moreover the optimum percent replacement of cement with POP is found to be 9 percent after 7,14 and 28 days of curing which gives an appreciable result compared with results of conventional concrete since POP acts as a binder in the concrete. Comparing the control mix with optimum results there is an appreciable increase in the concrete compressive strength due to the replacement of cement with POP.

Table 7 shows the test results for M40 grade concrete cubes replacing where cement is replaced with fly ash in various proportions. It is observed from Fig. 11 that for every 3percent increase in fly ash up to 9 percent the compressive strength of concrete increases but beyond 9 percent the strength decreases considerably due to the increased calcium content in fly ash. It is observed that the difference in test results at 15 and 18 percent replacement of fly ash is 5 to 10 percent which indicates the compressive strength may be constant for a further increase of fly ash in the concrete mix.

Table 8 below shows the compression test results of M40 grade concrete cubes cast with various proportions of silica fume. The optimum replacement of SF is found to be 12 percent and this increase in the compressive strength is due to the adhesion of cement paste developed because of the addition of silica fume in concrete which acts as a filler in the concrete mix (Fig. 12). The

Table 7 Test results of M40 grade concrete mixed with fly ash

S. No.	Sample Designation	Fly ash (%)	Average compressive strength (N/mm^2)		
			7th day	14th day	28th day
1	B1	0	27	33.75	40.3
2	B2	3	27.5	34.4	41.4
3	B3	6	29.59	36.9	43.8
4	B4	9	30.4	38	45
5	B5	12	29.42	36.7	43.55
6	B6	15	28.45	35.6	42.1
7	B7	18	25.2	33.0	39.6
8	B8	21	22.5	31.4	35.5
9	B9	24	20.2	28.7	33.3

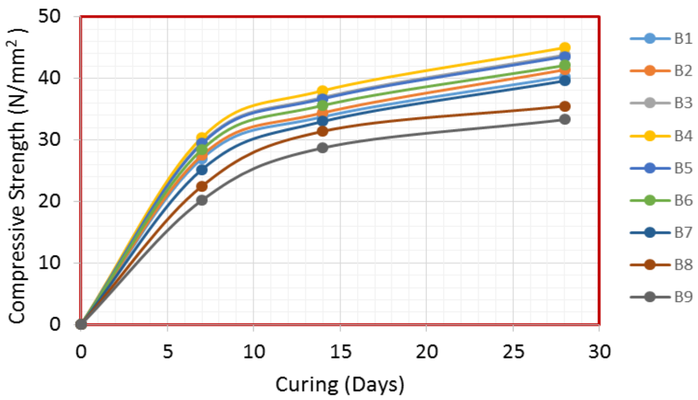

Fig. 11 Compressive strength of concrete at various proportions of fly ash

Table 8 Test results of M40 grade concrete mixed with silica fume

S. No.	Sample Designation	Silica fume (%)	Average compressive strength N/mm^2		
			7th day	14th day	28th day
1	C1	0	27	33.75	40.3
2	C2	3	27.2	34	40.5
3	C3	6	27.5	34.4	41.2
4	C4	9	30	37.5	45
5	C5	12	35.5	44.5	54.8
6	C6	15	33	41.25	49.5
7	C7	18	31.6	39.5	47.7
8	C8	21	28.7	37.2	45.4
9	C9	24	26.1	35.3	42.6

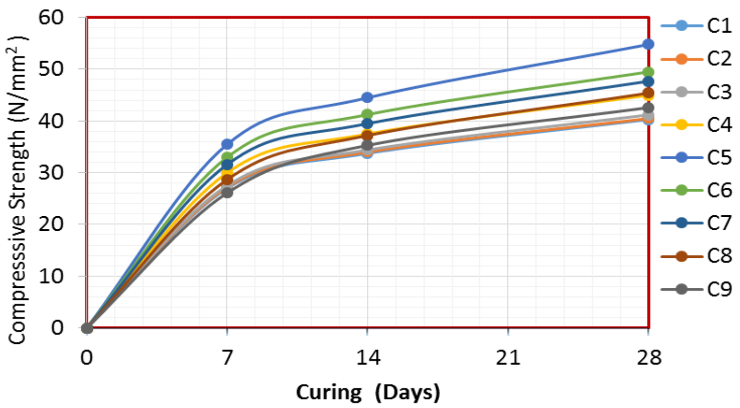

Fig. 12 Compressive strength of concrete at various proportions of silica fume

strength of conventional concrete is found to be less than 25 percent of the strength achieved at optimum replacement which indicates that the replacement of cement with SF in concrete mix enhances the concrete properties to a certain extent.

Table 9 below shows the compression test results of M40 grade concrete cubes cast with various proportions of reclaimed rubber. It is observed from Fig. 13 that for the same w/c ratio and silica fume content the compressive strength increased as the rubber content increases from 0 to 9 percent after 7, 14 and 28days of curing. This is because of the adhesion between the rubber and cement matrix due to the presence of SF. The maximum strength is achieved at the optimum percent (12%) replacement of cement with silica fume and 9percent replacement of coarse aggregates with reclaimed rubber in concrete. The strength reduction in rubberized concrete beyond the optimum level is due to the rubber particles being soft than the surrounding cement matrix which leads to the failure of concrete mix through the development of cracks.

Table 10 below shows the compression test results of M40 grade concrete cubes cast with various proportions of fly ash. Fig. 14 represents the combined test results (Exp.+GA) for cubes after 28 days of curing. Comparing the predicted values with experimental results for training and testing stages it demonstrates a high correlation and low error values since the variation in compressive strength is negligible for different proportions of fly ash.

Table 9 Test results of M40 grade concrete

S. No.	Sample Designation	Optimum Silica fume (%)	Reclaimed Rubber (%)	Average compressive strength (N/mm^2)		
				7th day	14th day	28th day
1	D1	0	0	27	33.75	40.3
2	D2	12	3	29.3	36.6	45.1
3	D3		6	33.64	42.5	46.4
4	D4		9	35.2	43.5	47.5
5	D5		12	32.22	40.27	43.4
6	D6		15	29	38.1	42.05
7	D7		18	27.35	35.5	39.4
8	D8		21	25.2	33	36.7
9	D9		24	22	30.3	32.26

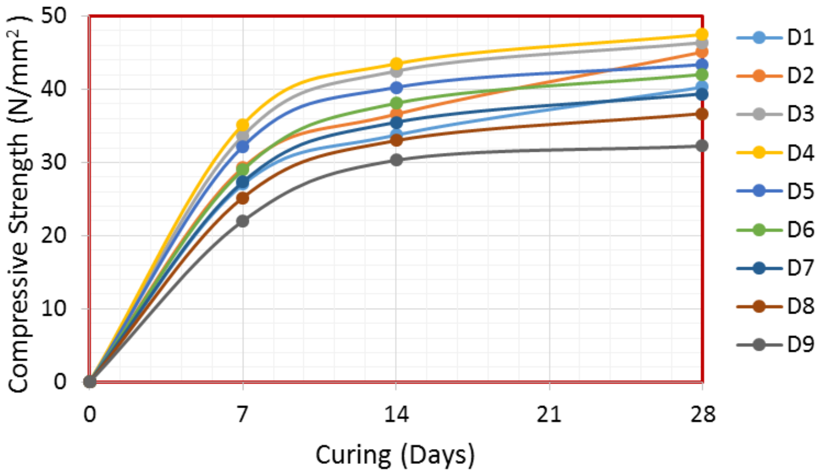

Fig. 13 Compressive strength of concrete with combination of optimum SF and various proportions of RR

Table 10 Test results of M40 grade concrete mixed with fly ash (Exp. & GA)

S. No.	Replacement percent of Fly Ash	Experimental Results: Average Compressive Strength at 28 days (N/mm^2)	Genetic Algorithm Results: Average Compressive Strength at 28 days (N/mm^2)
1	0	40.3	40.0
2	3	41.4	42.1
3	6	43.8	43.4
4	9	45	43.8
5	12	43.55	43.3
6	15	42.1	42.06
7	18	39.6	39.9
8	21	35.5	36.9
9	24	33.3	33.1

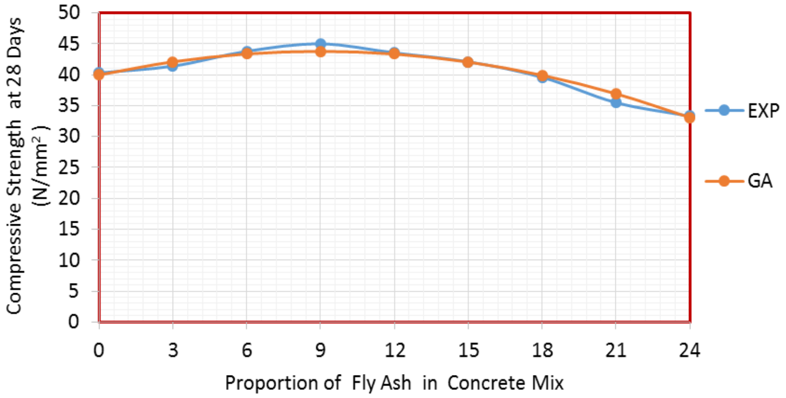

Fig. 14 Compressive strength of concrete mix at various proportions of FA

Table 11 Test results of M40 grade concrete mixed with POP (Exp. & GA)

S. No.	Replacement percentage of plaster of Paris	Experimental Results	GA Results
		Average Compressive Strength at 28 days (N/mm^2)	Average Compressive Strength at 28 days (N/mm^2)
1	0	40.3	41.0
2	3	43.2	44.5
3	6	46.4	46.7
4	9	51.7	47.7
5	12	49.3	47.5
6	15	44.4	46.0
7	18	41.2	43.3
8	21	38.4	39.4
9	24	35	34.2

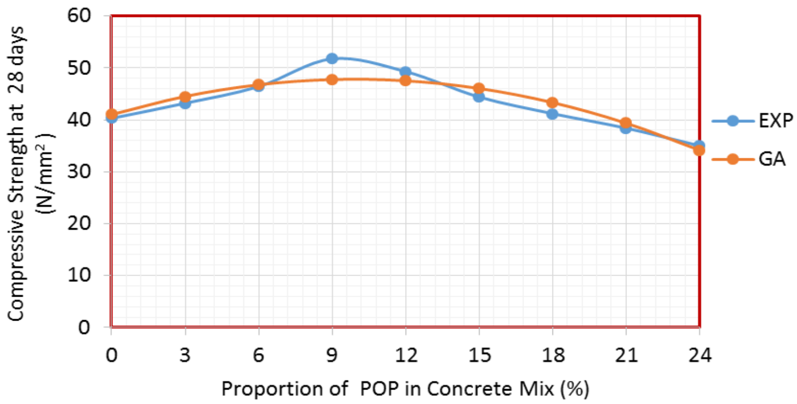

Fig. 15 Compressive strength of concrete mix at various proportions of POP

Table 11 shows the results of M40 grade concrete with various proportions of fly ash obtained through a genetic algorithm. Fig. 15 represent the curves for experimental and analytical results

Table 12 Test results of M40 grade concrete mixed with Silica Fume (Exp. & GA)

S. No.	Replacement percent of Silica Fume	Experimental Results	GA Results
		Average Compressive Strength at 28 days (N/mm^2)	Average Compressive Strength at 28 days (N/mm^2)
1	0	40.3	38.1
2	3	40.5	40.8
3	6	41.2	42.6
4	9	45	43.4
5	12	54.8	54.3
6	15	49.5	42.4
7	18	47.7	40.5
8	21	45.4	37.7
9	24	42.6	34.1

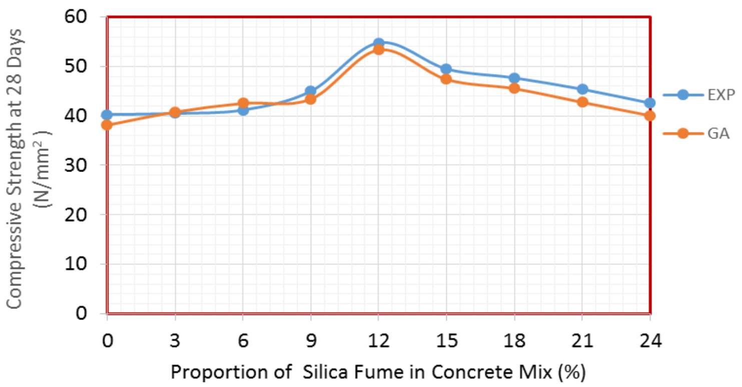

Fig. 16 Compressive strength of concrete mix at various proportions of SF

after 28 days of curing. It can be observed that the predictions and testing results are same for the conventional concrete mix. Moreover the variation in strength is negligible after 28 days for all proportions of POP in the concrete mix except at 9 percent replacement of cement with POP in concrete.

Table 12 below shows the results of M40 grade concrete with various proportions of Silica Fume. The combined test results (Exp. + GA) for concrete cubes after 28 days of curing is shown in Fig. 16. The following figures indicate that the curve is non-linear up to 9 percent replacement of cement with silica fume in concrete in both experimental and analytical results. Moreover it can be observed that the results obtained through tests and training of data is linear in nature for various proportions of SF beyond 9 percent replacement level.

Table 13 below shows the results of M 40 grade concrete with optimum SF and various proportions of reclaimed rubber. The 28 days strength is shown in Fig. 17 which represents the combined test results of cubes. It is seen that the maximum compressive strength is achieved for a combination of optimum SF and 9 percent replacement of RR in concrete for both values obtained experimentally and using a genetic algorithm. From 3 to 9 percent there is an increase in strength and beyond 9 percent RR replacement the compressive strength starts to decrease gradually in both results.

Table 13 Test results of M40 grade concrete mixed with optimum SF & RR (Exp. & GA)

S. No.	Optimum Silica Fume percent	Replacement percent Reclaimed Rubber	Experimental Results	GA Results
			Average Compressive Strength at 28 days (N/mm^2)	Average Compressive Strength at 28 days (N/mm^2)
1	12	0	40.3	41.4
2		3	45.1	43.9
3		6	46.4	45.3
4		9	47.5	45.7
5		12	43.4	45.0
6		15	42.0	43.3
7		18	39.4	40.4
8		21	36.7	36.5
9		24	32.3	31.6

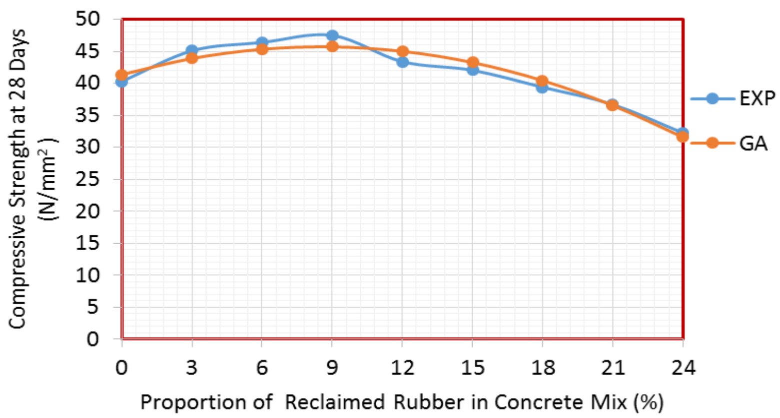

Fig. 17 Compressive strength of concrete at various proportions of RR and Opt. SF
Note: RR - Reclaimed Rubber, SF - Silica Fume

4. Conclusions

Based on the experimental and analytical results the following conclusions are drawn:

• Twelve percent replacement of cement with silica fume is taken as the optimum level since it produces the maximum compressive strength in concrete compared to the increase in strength increments due to a partial replacement of fly ash and plaster of Paris.

• Combination of optimum SF (12%) and 9 percent replacement of reclaimed rubber achieves higher results compared to conventional mix irrespective of the age of concrete.

• The optimum replacement level of fly ash and plaster of Paris in concrete is found to be 9 percent for compression tests conducted after a period of 7, 14 and 28 days of curing.

• For an increasing percentage of rubber the strength parameter is reduced due to the difference in specific gravity of rubber with respect to conventional coarse aggregates.

• Comparing the experimental and predicted values in the base study the variation in compressive strength is found to be less.

• In the main study it was observed that both experimental and analytical results obtained were similar in magnitude with minor variation.

• Genetic programming can be used to validate the experimental results and also as an alternate method to predict the strength of concrete compared to conventional testing methods.

• It is evident from this research that reclaimed rubber may be used as an alternate material to replace conventional aggregates along with fillers such as silica fume in concrete.

• It can be concluded that the use of fillers in concrete influence its properties to a greater extent compared to the strength obtained by replacing coarse aggregates with reclaimed rubber.

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