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A COMPARATIVE STUDY ON THE CHARACTERISTIC COMPRESSIVE STRENGTH OF RECLAIMED RUBBER CONCRETE

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ABSTRACT

Disposal of waste tires is found to be one of the major problems faced by the local authorities throughout the world. A few countries recycle the waste tires which is called as Reclaimed rubber(RR) useful in concrete replacing conventional aggregates. This research work is focused on comparing the characteristic compressive strength test results of reclaimed rubber concrete used in M40 grade experimentally and analytically using genetic algorithm. A total of 105 cubes were cast and compressive strength tests were carried out using a Universal testing Machine.1000 sets were taken and 100 iterations were run during training of GA models. A base study was carried out in this research work partially replacing cement with three types of admixtures such as Plaster of Paris (POP), Fly Ash (FA), Reclaimed Rubber (RR) and Silica Fume (SF). It was found that SF produced maximum strength in concrete and was used in the main study with reclaimed rubber. All the admixtures used were replaced by cement at 2 percent increments in concrete. Tests were conducted on 21 cube samples with a combination of optimum SF percent and various proportions of RR replacing coarse aggregates in concrete mix. Characteristic compressive strength of concrete cubes reveal that the maximum strength is obtained at 12 percent replacement of cement and 8 percent replacement of coarse aggregates respectively. Moreover the GA results were found to be in line with the experimental results obtained.

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INTRODUCTION

There is a need to replace conventional materials because of the growing demand and increasing prices globally. The production of ordinary Portland cement has increased greatly during the last decades especially in emerging and developing countries. In the 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 problem of solid wastes in landfill to a greater extent. Mineral admixtures such as Plaster of Paris, fly ash, silica fume and reclaimed rubber were used partially replacing cement and coarse aggregates in this research 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 (Swapnil *et al.,* 2016). Silica fume is a by product 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 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 superplasticizers, it is relatively easier to obtain compressive strengths of order of 100–150 N/mm^2 in laboratory. An experimental study on waste rubber tire concrete and Silica fume replacing fine aggregate and cement for M25 grade concrete indicated that there is a reduction in compressive and split tensile strengths and an increase in flexural strength as the rubber content increases (Mansour and Saravanan, 2015). The aim of this study is to determine the concrete strength through experimental methods and compare the results with those obtained analytically using genetic programming. The basic concept of genetic algorithm is designed to simulate processes in natural system necessary for evolution (Vaishali *et al.,* 2012). Debabrata 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 compressive strength of 100mm cubes are higher than 150mm cubes at all age levels.

Rahul *et al.* (2015) in their study on the compressive strength of concrete have observed that as the fly ash content increases there was increase as well as decrease in the strength of concrete. Even though the strength decreased initially there was gradual improvement in the concrete strength for a further increase of fly ash content in concrete. Raj *et al.* (2016) have observed that as the proportion of POP coated rubber aggregate increases the concrete strength decreases. Moreover test results reveal that coated rubber aggregates and rubber aggregates slump value is very high compared to conventional concrete. Marta and Malgorzata (2007) in their investigation showed that addition of fly ash has a beneficial effect on compressive strength of all cements tested. The concretes containing fly ash are capable of developing a higher strength than portland cement concrete as well as the blast furnace cement concrete. Namyong *et al.* (2004) have clearly observed that predicted compressive strength values are very near to the 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 Jeena (2012) in their research confirmed that optimum silica fume replacement percentage for obtaining maximum 28- day's strength of concrete ranged from 10 to 20 percent. Cement replacement up to 10percent with silica fume leads to increase in compressive strength for M30 grade of concrete and improves the mechanical properties of concrete. In their study 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. Aman et al. (2014) in their research on compressive strength of silica fume concrete it was found that the compressive strength increased with increase in percentage replacement of silica fume with 5 and 10 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 compressive strength reduction. 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 (Yousff et al. 2014)

MATERIALS AND METHODS

The cementitious material used in concrete was Ordinary Portland cement (53 grade). Clean dry river sand and hard granite broken stones of 20mm size were used in the concrete mix. Reclaimed rubber replaced conventional coarse aggregates. POP, FA and SF replaced cement which was used as an admixture in the concrete mix to enhance the 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 binding material in the cement concrete which fills up voids existing in the fine aggregate and makes the concrete impermeable and provides strength to concrete on setting and hardening. Aggregate is commonly considered 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 aggregate affects the properties of fresh concrete more than hardened concrete.

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.

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

Coarse Aggregate

Coarse aggregate is an ingredient of concrete mix 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 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

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 unit weight of rubberized concrete mixtures decreases as the percentage of rubber aggregate increases. Reclaimed rubber has been obtained from Inter City Enterprises, Chennai and cut to the required shape and size (Fig.1). Table 3. shows the test results of reclaimed rubber such as specific gravity, density, water absorption etc.,

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/cm2
4	Specific Gravity	1.25
5	Water Absorption	8.5%

Plaster of Paris

In this study Plaster of Paris replaces cement partially in the concrete mix.It is observed that 80percent of the target strength is achieved when cement is being replaced from 5 to 15 percent by POP in concrete (Kanthe, 2013). It is noted that 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).

Fly ash

Fly ash is most commonly used pozzolona in concrete. In presence of water, react 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 demand of mixing water and contributing to 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 (Carolyne and Rebecca, 2009)

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 beyond which the strength decreases (Pratik and Indrajit, 2013). The physical properties of silica fume is given in Table 4.

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%

Preparation and Testing of Concrete

In this study 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 150x150x150mm 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 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)

Fig. 2. Casting of Cube Samples

Fig.3. Curing of samples

In the main study reclaimed rubber replaces coarse aggregates in increments of 3 percent from zero up to 24 percent in concrete along with optimum SF percent obtained. Specimen of 81 cubes were cast and cured for 7, 14 and 28 days and tested for compressive strength in 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 strength and durability. The rate of loading on the test samples were monotonic in nature. The tests were conducted to find out the maximum load carrying capacity of the specimen. Table 4 shows the sample designation for each type of test conducted in the material lab with m i n e r a l admixtures and reclaimed rubber.

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
A	Plaster of Paris
B	Fly Ash
C	Silica Fume
D	Optimum SF with various proportion of RR

Genetic Algorithm

Genetic algorithm work with a set of individuals representing possible solutions of 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 single or multi-point figure. For the recombination a *bit Mask* is used (Fig.5). The equations describing the process are:

$C1 = Mask1 \& P1 + Mask2 \& P2$
$C2 = Mask2 \& P1 + Mask1 \& P2$
P*1*, P*2* – parent's chromosomes;
C*1*, C*2* – children's chromosomes (offspring individuals);

Mask1, Mask*2* – bit masks (Mask*2* = NOT (Mask1)) & - bit operation "AND".

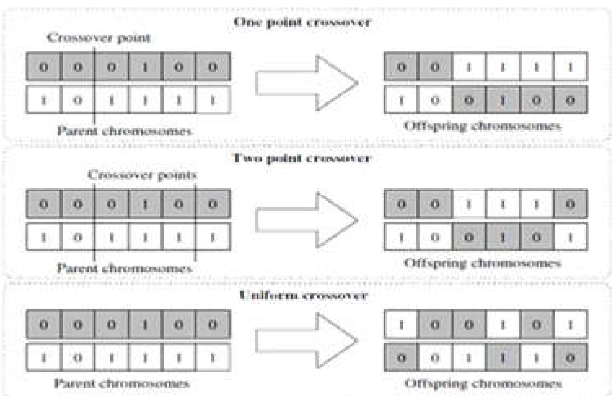

Fig. 5 Crossover with bit mask

The mathematic description of this crossover is:

$C1 = \gamma.P1 + (1-\gamma).P2$
$C2 = (1-\gamma).P1 + \gamma.P2$
$\gamma = (1+2.\alpha).r - \alpha$

P*1*, P*2* – chromosomes of the parents; C*1*, C*2* – chromosomes of the children (offspring individuals); α - exploration coefficient – user defined (α ≥ 0);

r – random number between 0 and 1;

Mutation means random change of the value of a gene in the population (Fig.6). The chromosome, which gene will be changed and the gene itself are chosen by random as well and Fig.7 shows the mutation process in genetic algorithm

Fig. 6. Mutation in a chromosome

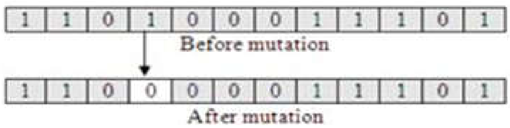

Fig. 7. Mutation in the genetic algorithm

Scheme of Evolutionary Algorithm

The Evolutionary Algorithm (EA) holds a population of individuals (chromosomes), which evolve my 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 schemes of GA is shown in flow chart as 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.
- Maximal number of iterations which is the most widely used stopping criteria.

- During crossover the individuals chosen by selection recombine with each other and new individuals will be created.
- Mutation is done by means of random change of some of the genes.
- The elite individuals chosen from the selection are combined with those who passed the crossover and mutation, and form the next generation.

RESULTS AND DISCUSSION

The maximum load is obtained with the aid of a UTM. Table 6 shows the compressive strength test results of M40 grade concrete replacing cement with different proportions of POP.

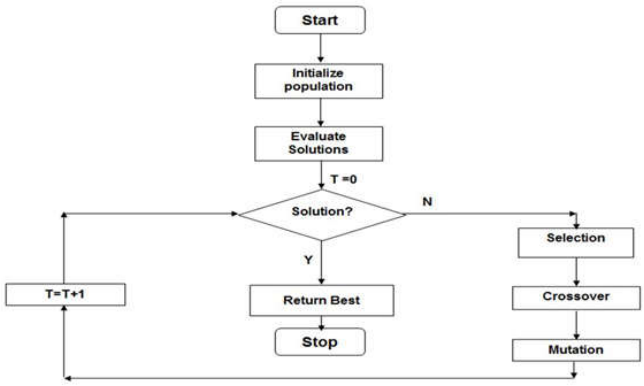

Fig. 8 Flow chart showing Scheme of EA

Fig.9 shows that for every 2 percent increase in POP 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 10 percent after 7 and 28 days of curing which gives appreciable result compared to conventional concrete since POP acts as a binder in concrete. Comparing the results of control mix with optimum results an increase of more than 25 percent is observed in the compressive strength due to replacement of cement with POP in concrete cubes after 7 and 28 days of curing.

Table 6. Test Results of M40 Grade Concrete

S. No.	Sample Designation	POP (%)	Average Compressive Strength (N/mm^2)	
			7 days	28 days
1	A1	0	27	40.3
2	A2	2	27.05	42.53
3	A3	4	27.65	45.82
4	A4	6	31.35	46.4
5	A5	8	31.5	48.2
6	A6	10	33.8	51.9
7	A7	12	33.3	49.3
8	A8	14	30.54	45.5
9	A9	16	28.31	43.75

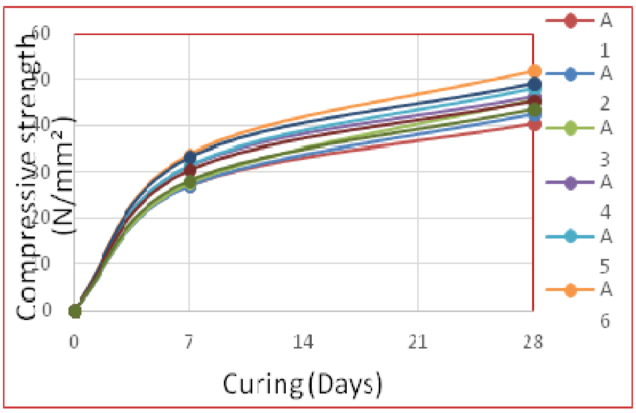

Fig. 9 Compressive Strength of Concrete Mix at various proportions of POP

Table 6 shows the test results of M40 grade concrete cubes replacing cement with fly ash at various proportions. It is observed from Fig.11 that for every 2 percent increase in fly ash the compressive strength of concrete increases up to 10 percent beyond which the strength decreases considerably due to increased calcium content in fly ash.

It is observed that the difference in test results at 12 and 14 percent replacement of fly ash is 2 to 3 percent which indicates the compressive strength may be constant for a further increase in fly ash beyond 16 percent. Table 7 below shows the compression test results of M 40 grade concrete cubes cast with various proportions of fly ash.

Table 7. Test Results of M40 Grade Concrete

S.N0.	Sample Designation	Fly ash (%)	Average Compressive Strength (N/mm^2)	
			7 days	28 days
1	B1	0	27	40.3
2	B2	2	27.45	40.82
3	B3	4	28.7	41.75
4	B4	6	29.6	43.8
5	B5	8	31.55	44.12
6	B6	10	31.2	43.86
7	B7	12	29.42	43.55
8	B8	14	28.45	42.64
9	B9	16	27.75	41.74

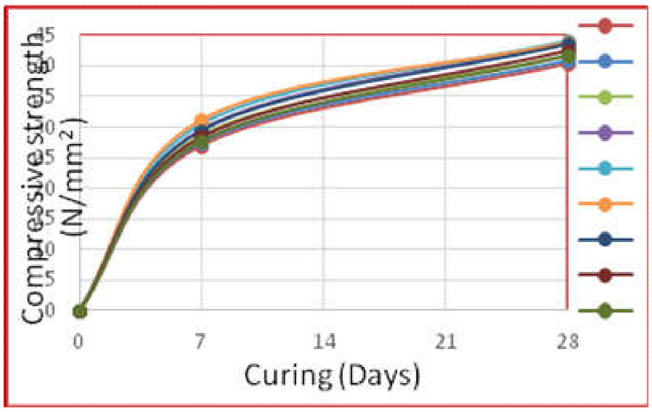

Fig. 10 Compressive Strength of Concrete Mix at various proportions of Fly ash

Table 8 below shows the compression test results of M 40 grade concrete cubes cast with various proportions of silica fume.

Table 8: Test Results of M40 Grade Concrete

S.N0.	Sample Designation	Silica Fume (%)	Average Compressive Strength (N/mm^2)	
			7 days	28 days
1	C1	0	27	40.3
2	C2	2	27.2	40.5
3	C3	4	27.6	40.9
4	C4	6	28.1	41.4
5	C5	8	29.2	44.3
6	C6	10	30.75	49.1
7	C7	12	35.5	54.8
8	C8	14	33.8	51.2
9	C9	16	32.6	46.4

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 addition of silica fume in concrete which acts as a filler in concrete mix (Fig. 11).

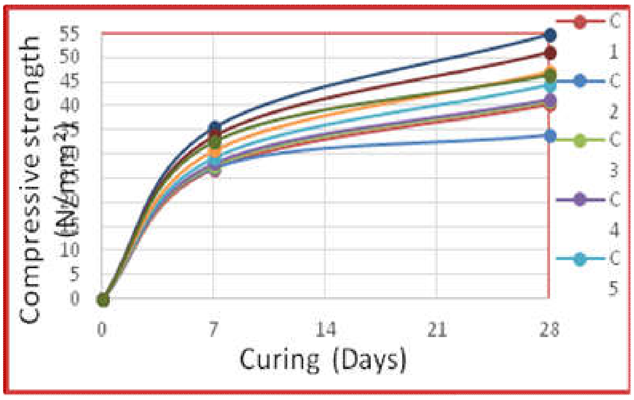

Fig. 11. Compressive Strength of Concrete Mix at various proportions of Silica fume

The strength of conventional concrete is found to be less than 30 to 35 percent of the strength achieved at optimum replacement which indicates that replacement of cement with SF in concrete mix enhances the concrete properties to a greater extent irrespective of the age of concrete.Table 9 below shows the compression test results of M 40 grade concrete cubes cast with combination of optimum SF and various proportions of reclaimed rubber. It is observed from Fig.12 for the same w/c ratio and silica fume content the compressive strength increased with rubber content increasing from 0 to 8 percent after 7 and 28days of curing. This is because of the adhesion between rubber and cement matrix due to the presence of SF. The maximum strength is achieved at optimum percent (12) replacement of cement with silica fume.

Table 9. Test Results of M40 Grade Concrete

S.No	Sample Designation	Opt. SF	RR (%)	Average Compressive Strength (N/mm2)	
				7th day	28th day
1	D1	0	0	27	40.3
2	D2		2	29.5	44.52
3	D3	12	4	31.3	45.1
4	D4		6	33.64	46.4
5	D5		8	34.55	46.9
6	D6		10	33.4	44.15
7	D7		12	32.2	43.4
8	D8		14	31.6	42.8
9	D9		16	29.3	41.72

Fig.13 below represent 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 demonstrates a high correlation and low error values since the variation in compressive strength is negligible for different proportions of POP. A 2 percent variation is found while comparing the compressive strength of control mix of experimental and analytical results. The maximum variation in strength is found to be 8 percent at 10 percent replacement level of POP in concrete. It can also be observed that the target strength is achieved approximately at optimum replacement

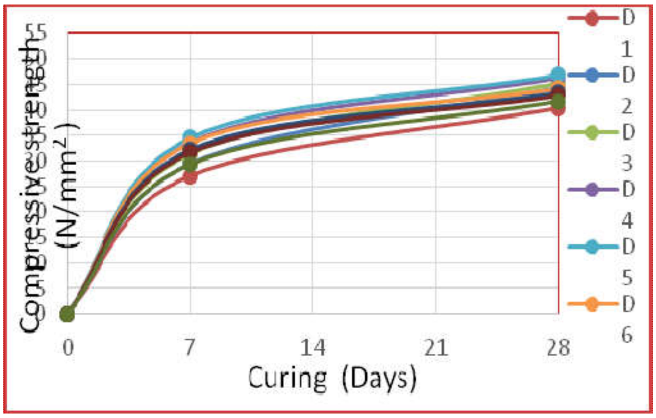

Fig. 12. Compressive Strength of Concrete Mix at various Proportions of RR and optimum SF

level while comparing both experimental and analytical results even though the maximum strength is obtained at 10 percent replacement of cement with POP in concrete.

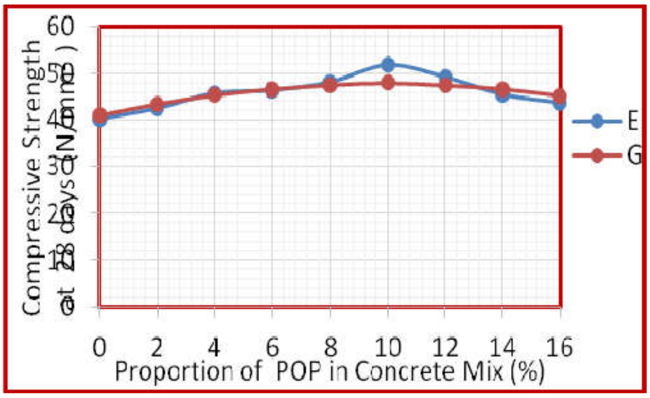

Fig. 13. Compressive Strength of Concrete Mix at various Proportions of POP

From Fig.14 it can be observed that the predicted and tested results are same for conventional concrete mix. Moreover the variation in strength is negligible after 28days for all proportions of FA in concrete mix except at 4 percent replacement of cement with FA in concrete. The maximum strength is achieved at 8 percent replacement level of fly ash in concrete mix.

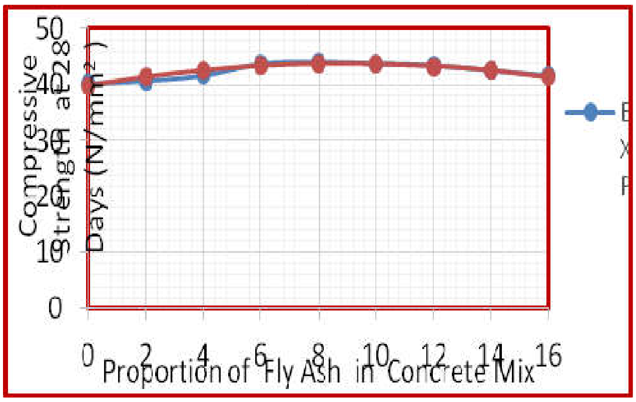

Fig. 14 Compressive Strength of Concrete Mix at various Proportions of Fly ash

The combined test results (Exp. + GA) for concrete cubes mixed with SF after 28days of curing is shown in Fig.15. The following figure indicates that the curve is non linear up to 8 percent replacement of cement with silica fume in concrete comparing 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 8 percent replacement level. At the same replacement level (12%) the experimental results exhibit higher compressive strength than the target strength when compared with analytical results.

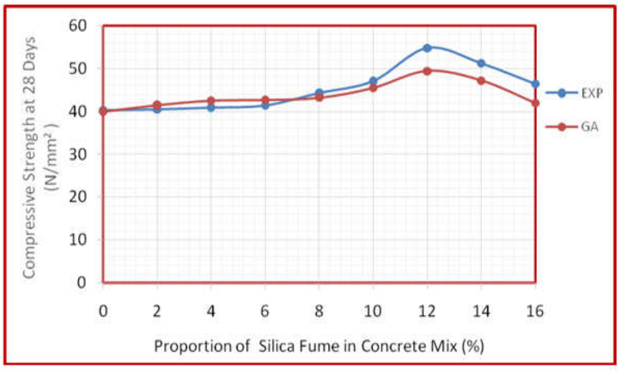

Fig. 15 Compressive Strength of Concrete Mix at various proportions of SF

The 28 days strength is shown in Fig.16 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 8 percent replacement of RR in concrete for both values obtained experimentally and using genetic algorithm. From 2 to 8 percent there is an increase in strength and beyond 8 percent RR replacement the compressive strength starts to decrease gradually in both results.

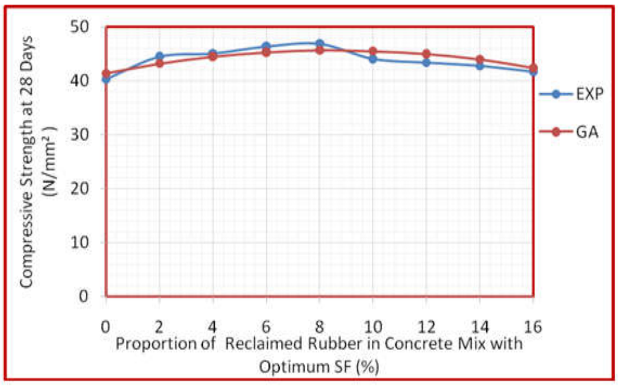

Fig. 16 Compressive Strength of Concrete at various proportions of RR and optimum Silica Fume

Conclusion

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

- From the base study it is observed that maximum compressive strength was obtained in concrete mix in which cement was replaced with silica fume when compared to strength produced with fly ash and POP mixed concrete.
- The optimum replacement level of cement with silica fume is found to be 12 percent in M40 grade concrete at which the target strength is achieved.
- Combination of optimum SF (12 %) and 8 percent replacement of coarse aggregates with reclaimed rubber produces better results compared to control mix irrespective of the age of concrete.
- Beyond the optimum replacement level of rubber in concrete a further increase in rubber content reduces the compressive strength since the specific gravity of rubber is less than that of conventional aggregates.
- In the main study it was observed that both experimental and analytical results obtained were similar in magnitude with minor variation irrespective of the mineral admixtures used in concrete mix.
- It is found that genetic algorithm can be used as an alternative approach for the evaluation of compressive strength of concrete.
- It is evident from this research that reclaimed rubber may be used as an alternate material replacing conventional aggregates in concrete.
- It can be concluded that the use of additives influence the properties of concrete to a greater extent irrespective of the concrete grade used in this study.

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