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USING TAGUCHI METHOD TO PREDICT THESELF-COMPACTING RUBBERIZED CONCRETE MECHANICAL AND FRESH PROPERTIES

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Abstract

The effect and optimization of using self-compacting rubberized concrete was studied. Design of experiment using Taguchi method was performed via orthogonal array to accommodate four factors with four levels. These factors were the percentage of fine rubber, coarse rubber, fly ash and viscocrete in the concrete mix. The signaltonoise ratio was used as well as the analysis of variance (ANOVA) to evaluate the characteristics performance of self-compacting rubberized concrete (SCRC). Rubberized concrete can be improved using the concrete proportioned as self-compacting concrete. The results indicated that a reduction in compressive strength increasing rubber content but there was an increase in impact resistance. However, the replacement of 10% of coarse aggregate with coarserubber gave more strength than that of zero rubber mix by 124% at 90 days. Replacement of 20% of both fine and coarse aggregates with fine and coarse rubber respectively, increased impact resistance by 453% compared to the corresponding SCRC control mix.

Keywords: *Rubber; Recycling; Self-compacting; Taguchi Method; ANOVA.*

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1. INTRODUCTION

Self-Compacting Concrete (SCC) is a high performance developed concrete [1] described as a revolution in concrete manufacture in the last two decades.SCC has high impact on economic and environmental sustainability in the construction industry [2]. It has many advantages such as increased productivity rates, decreased manpower, and noise elimination [3]. SCC is able to fully self-compact under its own weight compared to plain concrete. It has high flowability and reduced blocking in reinforced areas and high segregation resistance as well as low permeability and high compressive strength [4].

The volume of polymeric solid waste like rubber tires is increasing. Rubber tires waste becomes an environmental problem due to its non-biodegradable nature. Up to now a small part is recycled and millions of tires are just stockpiled; land filled or buried and used as fuel in many industries. Recycling of vehicle tires as aggregate alternative to produce a new type of concrete is an innovative option with environmental and economic benefits [5].

Many researchers have therefore used rubber particles as aggregates in concrete production to eliminate poor deformation capacity, low tensile strength, and improve energy absorption capacity. Aggregate rubber particles enhanced deformation and energy absorption capacities while they decreased workability and mechanical properties [6]. Self-compacting rubberized concrete (SCRC) was produced to diminish the negative effect of rubber aggregate on the mechanical properties and workability of concrete [7].SCC has high powder content, so its microstructure is very compacted and dense. This compacted microstructure results in high compressive strength and brittle modes of failure. Therefore, (SCRC) composites are used in requiring deformable applications, which is difficult to reach in SCC application using environmental friendly aggregates.

2. AIM OF WORK

In the current research fresh and harden properties of (SCRC) were studied using Taguchi method. 16 concrete mixes were designed with the same water/powder ratio W/P (P= cement+ fly ash). Self-compacting properties and mechanical behavior are discussed.

3. DESIGN METHODOLOGY

Parameter design of Taguchi method is an optimizing powerful tool to enhance performance of the product. Optimization quality characteristic minimizes Sensitivity to Noise(S/N) (uncontrollable) factors. In this study, four control factors were chosen with four levels shown in table (1).

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Table 1: Control Factors of Experimental Work

Level	Factors			
	A	B	C	D
	Replacement of fine aggregates by fine rubber	**Replacement of coarse aggregates by coarse rubber**	**Fly-ash (cement %)**	**Viscocrete(cement %)**
1	0 %	0 %	20 %	2.00 %
2	10 %	10 %	25 %	2.25 %
3	15 %	15 %	30 %	2.50 %
4	20 %	20 %	35 %	2.75 %

3.1 Design of Experiment

Design of the experiment based on orthogonal array. The orthogonal array has a fractional design. It was obtained using selected factors with different levels of L16 array. It has 16 rows and 4 columns. Individual row represents an experimental trial condition.The column assists a product parameter. The main effects can be estimated. Each column has numbers, that indicate the levels of used factors (A, B, C and D). Taguchi Orthogonal Array Design is L16 (4**4). Factors are 4. Runs are 16 [9,10,11].

3.2 Taguchi's Orthogonal Array Approach of Experimental Design

Taguchi's target is developing products that achieve the target value on a consistent basis. The variation around the target value should be minimized. In other words, quality is achieved by minimizing the deviation from the target. Factors and levels are illustrated in Table (1); the mixes are given in Table (2). Factor A is replacement of fine aggregate by fine rubber (1mm) (replaced by 0, 10, 15 and 20%). Factor B is replacement of coarse aggregate by coarse rubber (5mm) (replaced by 0, 10, 15 and 20%). Factor C is addition of fly ash as a ratio of cement (added by 20, 25, 30,and 35%). Factor D is using super plasticizer (viscocrete) as a ratio of cement (2.00, 2.25, 2.50 and 2.75%) [11].

Table 2: Experimental Test Design of Control Factors with factor levels

Exp. No.	Factors			
	% Replacement by volume of aggregate		Addition(% wt of cement)	
	Fine rubber	Coarse rubber	Fly ash	viscocrete
1	0	0	20	2.00
2	0	10	25	2.25
3	0	15	30	2.50
4	0	20	35	2.75
5	10	0	25	2.50
6	10	10	20	2.75
7	10	15	35	2.00
8	10	20	30	2.25
9	15	0	30	2.75
10	15	10	35	2.50
11	15	15	20	2.25
12	15	20	25	2.00
13	20	0	35	2.25
14	20	10	30	2.00
15	20	15	25	2.75
16	20	20	20	2.50

4. MATERIALS AND METHODS

4.1 Materials

All test specimens were fabricated using locally available materials.

4.1.1. Cement:a locally produced ordinary Portland cement (42.5N) produced by Lafarge Company meeting the requirement of E.S. 373/2003 was used with constant content (400 kg/m3) for all mixes.

4.1.2. Fly ash:produced by SikaEgypt company fly ash type P (El Obour factory) was used as addition to cement.

4.1.3. Fine Aggregate: The sand was local siliceous sand with specific gravity 2.64.

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4.1.5. Coarse Aggregate: used was natural limestone with max size of 12 mm to achieve the requirement of self-compacting concrete.

4.1.6. Super plasticizer:a high range water reducer without retarding was used. (Sikaviscocrete 3425) was used as a demand for producing SCC. It meets the requirements for superplasticizers according to ASTM-C- 494 Types Gand F and BS EN 934 part 2: 2001.

4.1.7. Fine rubber aggregate:the fine crumb rubber used in this research is produced by MARSO factory at 10th Ramadan city-Egypt with size of (1mm) and was partially replaced (by volume) of fine aggregate.

4.1.8. Coarse rubber aggregate:the coarse rubber used in this research is produced by MARSO factory at 10th of Ramadan city-Egypt with one size of (5mms) and was used as a partial replacement (by volume) of coarse aggregate.

4.1.9. Water:fresh tap water was used with water /binder ratio w/b = 0.37.

Fine rubber (2 mm) coarse rubber (5mm)

Fig 1: Fine and coarse rubber

4.2 Mix Contents and Procedure

*4.2.1 Mix contents: T*he cement content was 400 kg/m^{3}for this study with water/binder* ratio of 0.37 and the mix proportion ratio (of weight) for cement: sand: dolomite was 1:2.125:2.125 respectively.
*binder = cement + fly ash

4.2.2 Mixing procedure was carried out in three stages; dry mix for 2 min, adding 75% of (water+S.P) and mixing for 2 min and a final mix for not less than 3 min after adding the remaining amount of (water+S.P). Subsequently, the fresh properties of SCRC mixes;Flowability and Passing-ability tests using slump flow, T50 test, V-Funnel and J-Ring) were determined. Concrete specimens were cast in standard steel molds. After 24 h from mixing, all the specimens were de-molded and cured in wet canvas for 7 days.

4.3 Tests

4.3.1 Fresh Tests

Fresh concrete tests were experimented according to EFNARC committee (European Federation for Specialist Construction Chemicals and ConcreteSystems) procedure recommendation [13]. See figure (2).

4.3.1.1 Slump Flow Test

Slump flow value represents the flow-ability of fresh concrete mix. It can specify self-compacting concretes, as a check of fresh concrete consistence that meet specification [8] as shown in figure (2).

4.3.1.2 V-Funnel

V-funnel test was performed in a shaped funnel filled with fresh concrete. Time taken for the concrete to flow out the funnel is recorded as the V-funnel flow time as shown in fig. (2).

4.3.2 Hardened SCRC

4.3.2.1 Compressive Strength Test

Compressive strength test was carried out on 15*15*15 cm cubes and according to ASTM C39-86. The capacity of the compression machine used is 2000 KN.

4.3.2.2 Impact Test

Beams 10*10*50 cm were prepared for this test. The impact resistance was assessed by measuring the ability of concrete

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specimens to withstand repeated blows of a free failing load (3kg) at a constant travelling height of 40 cm above the midpoint of the tested concrete beam which was supported on two ends. The load was then left to fall freely on the top side of the concrete beam and the number of impact blows to cause failure was recorded [14, 15, 16].

Figure (3) shows the hardened tests set up.

Slump flow test V-Funnel test
Fig 2: fresh tests

Compression test impact test
Fig 3: hardened tests

5. RESULTS

5.1 Fresh Properties

Experimental test results of fresh properties for SCRC are shown in table (3).

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Table 3: Experimental Test Results of Fresh Properties

Mix. No.	Slump (mm)	V-funnel(sec.)	Mix. No.	Slump (mm)	V-funnel (sec.)
1	723	3.65	9	675	13.94
2	735	3.79	10	690	7.2
3	755	3.56	11	550	18.25
4	720	6.47	12	585	14.97
5	710	7.81	13	665	6.16
6	740	5.89	14	630	11.03
7	715	6.71	15	605	17.53
8	645	5.72	16	560	9.22

5.2 Hardened Properties

Experimental test results of compressive strength for SCRC are shown in table (4). Table (5) shows test results for impact resistance which represented by numbers of blows.

Table 4: Compressive Strength Test Results (Hardened Properties)

Mix. No.	Compressive strength (Mpa)			Mix. No.	Compressive strength (Mpa)		
	7days	28days	90days		7days	28days	90days
1	33.2	47.7	52.0	9	22.1	31.6	44.5
2	40.3	53.3	64.4	10	21.3	32.9	37.3
3	27.6	37.7	44.4	11	20.4	24.8	32.2
4	21.6	347	456	12	19.0	24.3	29.0
5	28.4	421	483	13	23.0	38.4	32.2
6	23.9	35.8	43.9	14	23.9	25.7	33.6
7	21.9	33.2	41.2	15	20.8	24.8	30.2
8	20.2	26.0	38.3	16	18.3	20.2	29.8

Table 5: Impact Test Results.

Mix. No.	Impact (blows)	Mix. No.	Impact (blows)
	28 days		28 days
1	17	**9**	23
2	13	**10**	21
3	15	**11**	31
4	15	**12**	31
5	29	**13**	35
6	23	**14**	54
7	22	**15**	55
8	22	**16**	77

6. ANALYSIS AND DISCUSSION

Design of experiment data analysis was used to calculate the mean response function. The response variation in Taguchi technique is tested using an appropriately chosen S/N ratio. Signal to Noise ratio is the mean (signal) to the standard deviation (noise). Formula Ratio used to compute the S/N ratio adopted the objective function. Focusing on the strength characteristic, standard S/N equation used the objective function was 'larger the better'. Compressive strength and impact resistance are a 'larger is better' type of quality characteristic where the aim of this work is to maximize the strength. The standard S/N ratio computing formula for this type of response is:

$$\left(\frac{S}{N}\right)_i = -10log\left[\frac{1}{n}\sum_{j=1}^{n}\frac{1}{Y_{ij}^2}\right] \quad ....eq\ (1)$$

V-funnel is a 'smaller is better' function of quality characteristic since the goal is to minimize fresh properties values. The S/N ratio standard computing formula for this response is:

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$$\left(\frac{S}{N}\right)_i = -10log\left[\frac{1}{n}\sum_{j=1}^{n} Y^2\right] \quad ...eq(2)$$

Where 'i' is the trial number of a; 'Yij' is the value measured of quality characteristic for the i^{th}trial and j^{th}experiment; 'n' is the number of repetitions for the experimental test. Signal-to-noise ratios are calculated using Equation (1) for each condition of compressive strength and impact resistance. The factor can be affected separately in terms of S/N ratio.
The analysis of variance (ANOVA) is also performed to study the relative significance of the process parameters. The contributions of the various parameters are quantified.

6.1 Fresh Properties

The ability of SCRC to fill molds in the fresh state is defined by flowability, viscosity, passing ability, and segregation resistance. Each of them can be examined by a different test methods [13]. Flowabilityis measured using slump flow test, viscosity is measured using V-funnel flow time tests.

Self-compacting concrete requirements in fresh phase should be selected from one of the above mentioned characteristics and specified in a known value. To define the flowability, viscosity, passing ability, and segregation resistance of the produced SCRC, slump flow diameter and V-funnel flow time of the all produced concretes were measured and presented.

6.1.1 Slump Flow Test

Signal to noise ratios values for slump flow test are shown in table (6) and fig. (4). Table (7) shows the analysis of variance for this test. Increasing rubber content decreased slump flow diameter but increasing fly ash and/or viscocrete increased slump flow diameter. Added fly ash to the mix increased cement paste volume, which made the mix more flowable. Viscocrete increased the viscosity of concrete which increased the slump flow diameter.

Table 6: Response of Signal to Noise Ratios for slump flow (larger is better)

Level	Fine rubber (A)	Course rubber (B)	Fly ash (C)	Viscocrete (D)
1	57.30	56.81	56.08	56.40
2	56.92	56.87	56.33	56.20
3	55.88	56.27	56.58	56.58
4	55.76	55.91	56.87	56.69
Delta	1.54	0.96	0.78	0.49
Rank	1	2	3	4

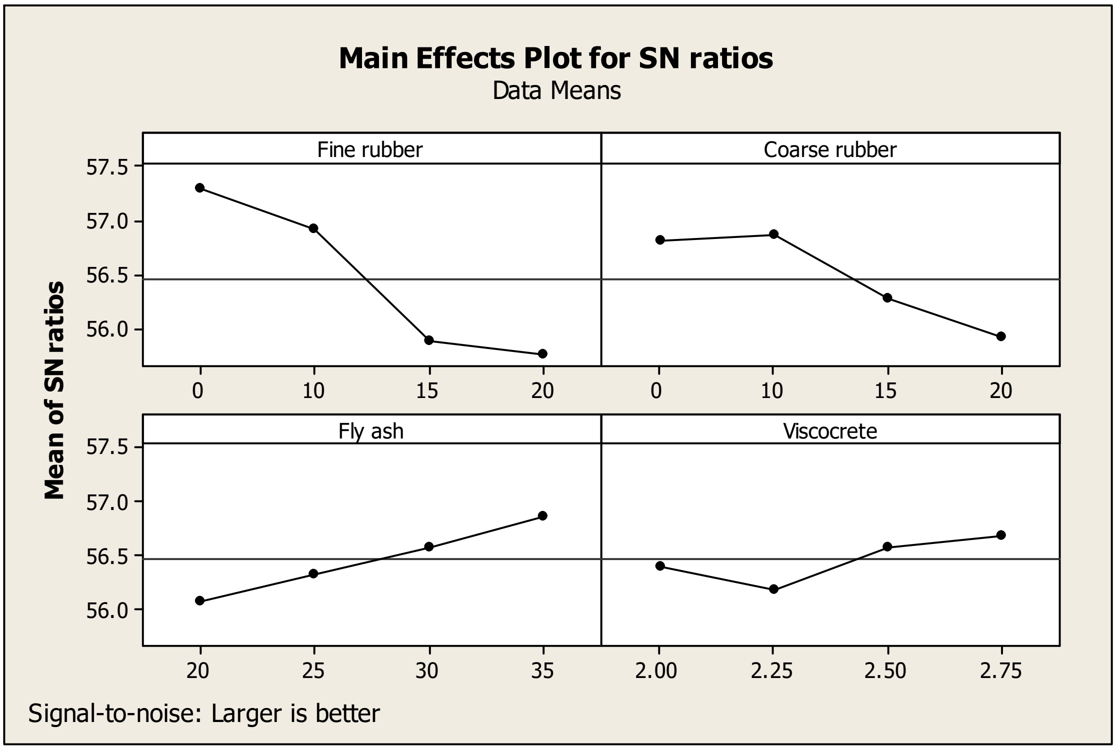

Fig 4: Main Effect Plot for Signal to Noise Ratio of slump flow (larger is Better)

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Table 7: Analysis of Variance for slump flow test, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	Contribution %
Fine rubber	3	40344.9	40344.9	13448.3	61.27
Coarse rubber	3	13407.4	13407.4	4469.1	20.36
Fly ash	3	6557.4	6557.4	2185.8	9.96
Viscocrete	3	3182.4	3182.4	1060.8	4.83
Error	3	2344.9	2344.9	781.6	3.56
Total	15	65837.1			100

6.1.2 V-Funnel Test

As mentioned above, V-Funnel test is measuring the viscosity like T50 test. But here, viscocrete has 2nd rank in S/N analysis which mean that it has a big effect on V-Funnel test. However, using the highest content of viscocrete (2.75%) increased the time of this test as shown in fig. (5). like T50, increasing rubber content increased V-Funnel time. Signal to noise ratio values of the control factors for this test are shown in table (8) and fig. (5). Table (9) shows the analysis of variance for this test.

Table 8: Response of Signal to Noise Ratios for V-funnel (smaller is better)

Level	Fine rubber (A)	Course rubber (B)	Fly ash (C)	Viscocrete (D)
1	-12.52	-16.94	-17.79	-18.03
2	-16.23	-16.24	-19.45	-16.93
3	-22.19	-19.42	-17.48	-16.33
4	-20.20	-18.54	-16.42	-19.85
Delta	9.67	3.17	3.03	3.51
Rank	1	3	4	2

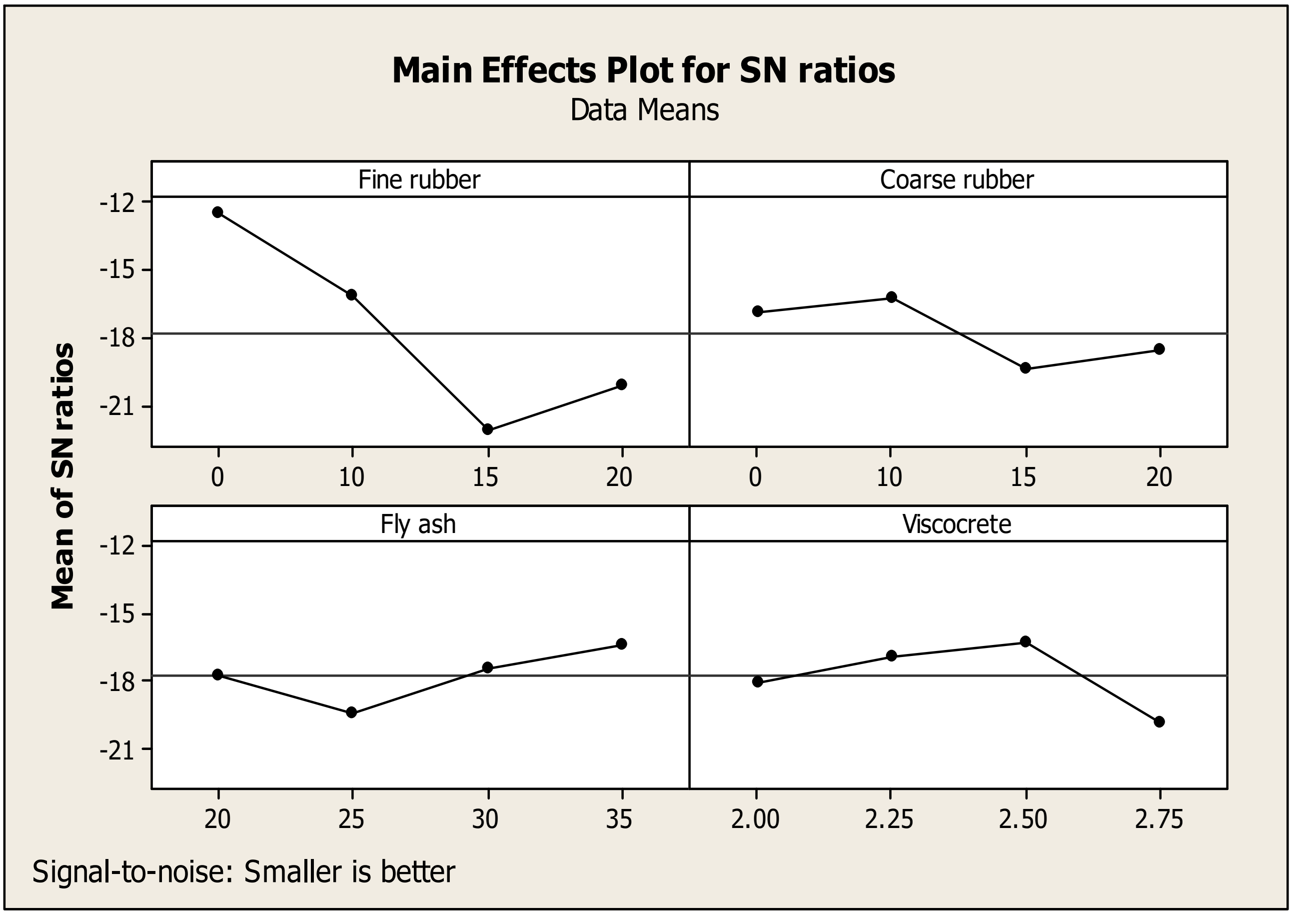

Fig 5: Main Effect Plot for Signal to Noise Ratio of V-funnel results (smaller is Better)

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Table 9: Analysis of Variance for V-Funnel test, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	Contribution %
Fine rubber	3	209.952	209.952	69.984	59.57
Coarse rubber	3	46.302	46.302	15.434	13.13
Fly ash	3	39.520	39.520	13.173	11.21
Viscocrete	3	33.017	33.017	11.006	9.36
Error	3	23.628	23.628	7.876	6.70
Total	15	352.419			100

6.2 Hardened Properties

Three tested values average at 28 days was recorded to determine the compressive and impact resistance for all mixtures.

6.2.1 Compressive Strength

Increasing rubber content decreased the compressive strength. The decrease in compressive strength is attributed to low rubber modulus of elasticity (E), increased porosity due to air entrainment from rubber particles, and weak bond in the transition zone between cement paste and rubber particles. This weakness may be due to crack initiation from the voids generated between crumb rubber particles and cement paste. Aggregate is capable of pullout resulting in particle perimeter voids and crack initiation under compressive load. For fly ash, increasing fly ash content increased compressive strength as it works as a filler which fills the voids on concrete. Using 35% of fly ash as addition to the mix gave highest compressive strength. Viscocrete has small effect on compressive strength. It had the 4th rank in S/N analysis. Superplasticizer added in SCC gives high strength in early age. The average values of Signal to noise ratios of compressive strength for control factors test are shown in table (10) and fig. (6). Table (11) shows the analysis of variance for this test.

Table 10: Response of Signal to Noise Ratios for Compressive Strength of 28 days (larger is better)

Level	Fine rubber (A)	Coarse rubber (B)	Fly ash (C)	Viscocrete (D)
1	52.62	51.93	49.66	49.98
2	50.57	51.04	50.65	50.60
3	48.98	49.43	49.50	50.12
4	48.46	48.23	50.82	49.94
Delta	4.15	3.70	1.32	0.66
Rank	1	2	3	4

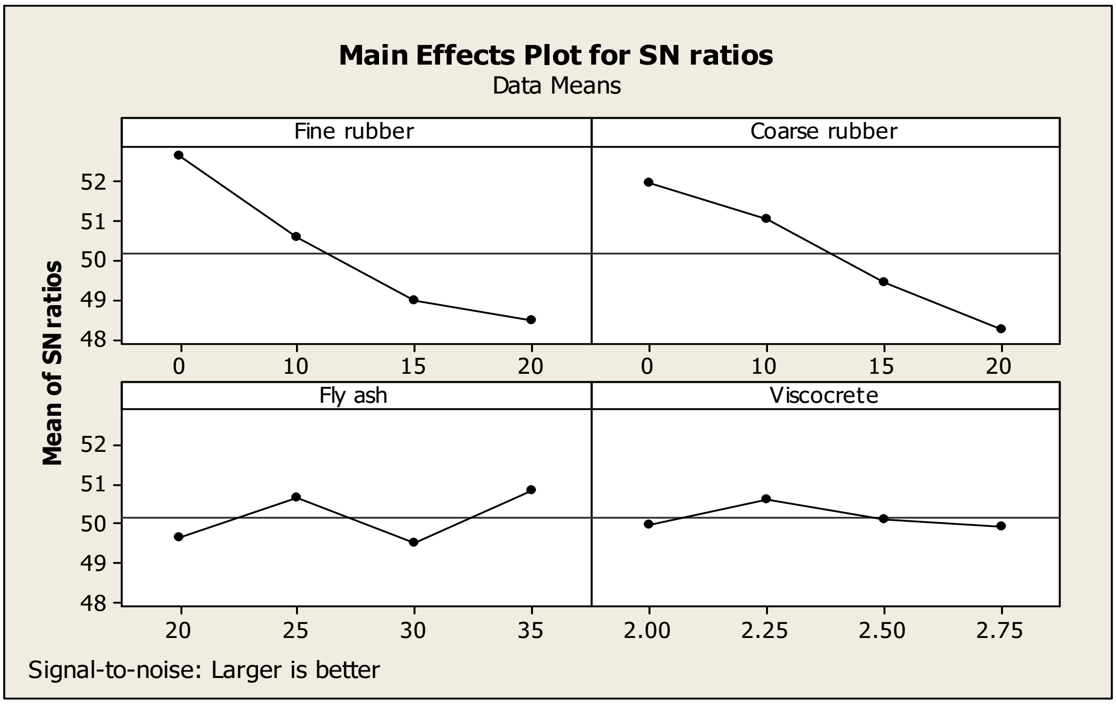

Fig 6: Main Effect Plot for Signal to Noise Ratio of Compressive Strength after 28 days (Larger is Better)

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Table 11: Analysis of Variance for 28 days Compressive Strength, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	Contribution %
Fine rubber	3	65266	65266	21755	52.098
Coarse rubber	3	46506	46506	15502	37.12
Fly ash	3	8413	8413	2804	6.71
Viscocrete	3	3273	3273	1091	2.61
Error	3	1818	1818	606	1.45
Total	15	125275			100

6.2.2 Impact Resistance

Increasing rubber content led to increase impact resistance. The impact resistance, as a number of blows, increased from 17 blows for mix No.1 (no rubber replacement) to 77 blows for mix No.16 (20% fine rubber and 20% coarse rubber). This gain of impact resistance of SCRC is due to the ability of rubber to absorb the plastic energy, which was generated from the falling of a mass from a certain height. In addition, the high deflection of the rubberized concrete increases the ability to withstand more energy. Table (12) and fig. (7) Show the average values of S/N ratios of the control factors for T50 test. Analysis of variance (ANOVA) for experimental test is shown in table (13).The percentage of fine rubber replacement was the most significant parameter influencing the impact resistance. The percentage contribution was 75.14%.

Table 12: Response of Signal to Noise Ratios for Impact Resistance after 28 days (Larger is better)

Level	Fine rubber (A)	Coarse rubber (B)	Fly ash (C)	Viscocrete (D)
1	23.06	27.01	29.99	29.09
2	28.24	28.11	28.82	27.70
3	28.57	28.96	28.45	28.69
4	34.35	30.15	26.97	28.75
Delta	11.29	3.14	3.03	1.39
Rank	1	2	3	4

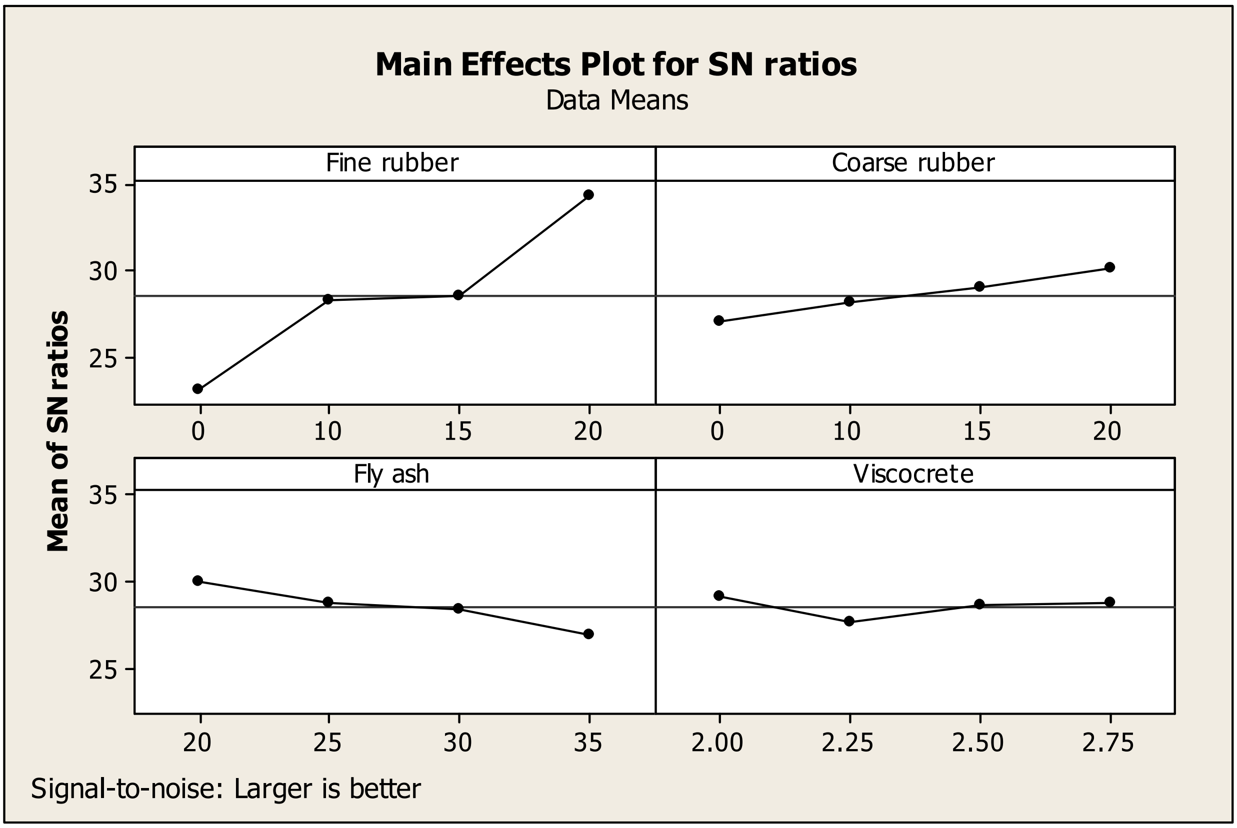

Fig 7: Main Effect Plot for Signal to Noise Ratio of impact resistance after 28 days (Larger is better)

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Table 13: Analysis of Variance for 28 days impact resistance, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	Contribution %
Fine rubber	3	3514.35	3514.35	1171.45	75.14
Coarse rubber	3	467.47	467.47	155.82	10
Fly ash	3	443.13	443.13	147.71	9.47
Viscocrete	3	146.41	146.41	48.80	3.13
Error	3	105.24	105.24	35.08	2.25
Total	15	4676.60			100

7. PREDICTION OF PROPERTIES CHARACTERISTIC

The predicted mean of the quality characteristic for slump flow, V-Funnel, compressive strength and impact resistance is computed using the following equation:

$$S_{mp} = \bar{Y} + (\bar{A}_0 - \bar{Y}) + (\bar{B}_0 - \bar{Y}) + (\bar{C}_0 - \bar{Y}) + (\bar{D}_0 - \bar{Y}) + (\bar{E}_0 - \bar{Y})$$

It is the grand average of performance characteristic.

$(\bar{A}_0 - \bar{Y}), (\bar{B}_0 - \bar{Y}), (\bar{C}_0 - \bar{Y}), (\bar{D}_0 - \bar{Y})$ and $(\bar{E}_0 - \bar{Y})$

The following values of factors were chosen: A=20%, B=20%, C=35%, D=2.75%

From the analysis of S/N ratio and the mean response characteristic, the mean values for SCRC have been predicted as shown in table (14).

Table 14: Taguchi predicted values and actual values for SCRC.

Test	Experimental results of the confirmation mix	Taguchi predicted value	Ratio of predicted value and actual value
Slump flow	645 mm	618.28 mm	95.85 %
V-funnel	10.224 seconds	11.0663 seconds	108.31 %
Compression	19.34 MPa	20.1 MPa	96.23%
Impact	51 blows	55 blows	107.85%

A confirmation mix was performed with the selected factors (A=20%, B=20%, C=35%, D=2.75%) and the results were recorded in table (14). These results were compared with the predicted values, illustrated in table (14), which obtained from Minitab program. The ratio between the actual values and the predicted values are also illustrated in table (14) which is in range of 10% difference so experimental results could be confirmed.

8. CONCLUSION

Taguchi Method achieved a good prediction of mechanical properties of self-compacting rubberized concrete in terms of compressive strength and impact resistance and fresh properties in terms of slump flow diameter and V-Funnel time. The analysis shows that the proposed Taguchi technique was adequate to predict the above properties.

The study also considered examining the influence of different concrete mix proportioning parameters that included fine rubber, coarse rubber, fly ash and viscocrete contentson the studied mechanical and fresh properties.

The analysis of variance (ANOVA) showed that the percentage of fine rubber replacement was the most significant parameter influencing the studied mechanical and fresh properties. The percentage contribution was 61.3%, 59.6%,52.1% and 75.14% for slump flow diameter, V-Funnel, compressive strength and impact resistance respectively.

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