Optimisation of Mix Proportioning of Self-Compacting Concrete using Heuristic Search

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***Abstract**: The quality of concrete construction mainly depends on the factors like concrete constituents, degree of supervision, method of curing, etc. Hitherto, one of the most influencing factors is the mix design or proportioning that contributes major parts directly to the quality of finished product. Unlike conventional concrete the mix proportion of Self-Compacting Concrete or Self-Consolidating Concrete (SCC) is complex since it incorporates special concrete chemicals such as Viscosity Modifying Agent (VMA), Air Entraining Agent (AEA), and so on, that tends to alter the workability and other properties of concrete and moreover it has no standard procedures and is generally carried out by trial and error method. This research seeks to develop a rational methodology for optimal mix proportion strategy for SCC based on the standard tests on SCC such as V-funnel and J-ring test conducted in the concrete laboratory in controlled environment as per EFNARC 2005 standard guidelines. The test results are incorporated for computer simulation and using a Heuristic Search Algorithms, the optimum mix proportioning of SCC for different admixtures are obtained.*

Keywords: Air- Entraining Admixture, self-compacting concrete, Viscosity Modifying Admixture, Heuristic Search Algorithms

I. INTRODUCTION

Self-compacting concrete is a highly flowable concrete that easily spreads into places and fills formworks without any consolidation or any significant segregation and yet it is a stable concrete. It does not requires any types of vibration to achieve full compaction. However, it has inherent demerits such as prone to high segregation and settlement of aggregates. The concrete's own weight is the reason for high fluidity, which results in consolidation.

A high degree of flow ability is created while maintaining low w/c ratio where the w/c<0.4 in the mix proportion of SCC. To maintain the moderate viscosity at low water/cement ratio, super plasticizers are used. The self-compacting concrete is mainly used in tunnel lining, ductile columns in seismic area, mat foundation, and deep beams etc. As SCC is self-compacting and easily flows and spreads into places where it cannot be reached manually or even by vibration. It will also reduce the time of construction and reduce the labor cost, as less labor is required for SCC structures but segregation, bleeding, settlement are to be reduced in self-compacting concrete. These risks can be eliminated by varying the properties of SCC both in fresh concrete state. The chemical admixtures such as plasticizers and super plasticizers are used to control the workability of the SCC with minimum water/cement ratio. It also reduce the bleeding, segregation and settlement of SCC. Other admixture used in modifying the properties of SCC is Air-Entraining Agent (AEA). These admixtures help to improve the strength, flow ability, self-compacting property and durability of the SCC.

II. REVIEW OF LITERATURE

Su et al (2001) proposed a new mix design method for preparation of SCC. The amount of aggregates required was determined initially. Then the aggregates were mixed with the paste of binders. These pastes of binder are to fill the holes or the voids between the aggregates. By this, the SCC will obtain it's the major properties such as flow ability, self-compacting property etc. the amount of aggregates, water/cement ratio, amount and type of super plasticizers used are also determined which is the most important parameter that gives the SCC its properties. The tests are carried out on SCC are Slump flow test, U-box, L-box, and V-funnel experiments. The performance of self-compacting concrete was determined from these tests. The results obtained from these experiments indicate that the SCC obtained from this mix design is of high quality. In addition, this method is simpler and it requires fewer amounts of binders etc. when compared to the method followed by JRMCA. Nabil and Lachemi (2001) investigated the SCC performance when fly ash is added. For the study, nine different mixtures of SCC and one mixture of control concrete was prepared.

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The amount of cement was 400 kg/m3 and the water/cement ratio was between from 0.35 to 0.45.Cement is replacement by 40%, 50%, and 60% by Class F fly ash in the experiment. Tests like compressive strength and drying shrinkage were carried out by the researchers to obtain the mechanical properties of hardened concrete. Compressive strength developed at 28 day ranging from 26 to 48 MPa. The test results show that the mixtures were economical.

Sahmaran and Yaman (2007) carried out an investigation on self-compacting mortars (SCM) using mineral additives and chemical admixtures. In this research, fly ash, brick powder, limestone powder and kaolinite were used. Fresh concrete properties like workability and hardened properties were determined by V-funnel and slump flow tests and ultrasonic pulse velocity and compressive strength at 28th and 56th days respectively. They reported that the workability of SCMs has been increased with fly ash and limestone powder among the mineral additives used.

Felekoğlu et al (2007) performed experiments with different super plasticizer dosage levels and water/cement ratio on five self-compacting concrete mixtures. Optimum parameters for the self-compatibility of mixtures were determined. Hardened properties of concrete were studied by conducting tests like Compressive strength, modulus of elasticity and splitting tensile strength test. Optimum water/cement ratio concluded from the experiment was between 0.84–1.07 by volume.

Uysal and Yilmaz (2011) researched the self-compacting concrete with the partial replacement of cement by marble powder (MP), basalt powder (BP) and limestone powder (LP).The water binder ratio was taken as 0.33In this, they performed experiments to find the fresh and hardened properties of SCC. They reported that usage of LP, BP and MP helped in economic feasibility of SCC.

P. Dinakar et al (2013) investigated the properties of self-compacting concrete (SCC) with the replacement of cement by fly ash (10-70%). The water to binder ratio was taken as 0.30. Properties like self-compatibility properties, mechanical properties and durability properties were determined by slump flow, V-funnel time, L-box test, compressive strength, splitting tensile test, water absorption, water penetration depth and chloride permeability. Replacement of 30% of PPC with FA resulted in 100 MPa at 56 days. It founded that the SCC with fly ash can produce high strength high performance concretes. Replacement of cement with fly ash by 10% and 30% gives low water penetration depth whereas replacement at 30% and 50% gives high water penetration depth. By replacing of cement by 30%, they found a reduction in the chloride permeability.

Chockalingam (2014) conducted experimental investigation on SCC using marble powder and silica fumes. In this experiment, cement was replaced with different percentages of marble powder and silica fumes. To find the performance and the optimum properties of the self-compact ability of mixtures, several tests such as slump flow, V-funnel, L-box, U-box, Compressive strength &flexural strength are carried out. They plotted the load deflection curve and compared with the results of conventional concrete.

III. EXPERIMENTAL INVESTIGATION

The following section describes the material characteristics and method of experiments.

A. Constituent of the SCC

1. Cement

In this research, Ordinary Portland cement of characteristic strength 53 was used. The cement used was of specific gravity 3.15.

2. Air-Entraining Agent (AEA)

It increases the resistance towards freezing and thawing. It contains ultra-stable air bubbles. The technical details of AEA used for this research are given in Table 1.

Table 1 Properties of Air Entraining Agent

Density	1.0±0.01 kg/cm^3
pH value	10.5-12.5
Chloride content	<0.01%
Alkaline content	1.24%
Storage time	12 months between 5°C and 25°C BASF
Solids	11%+1%

Fig.1 Typical Air-Entraining Agent (AEA)

3. Viscosity Modifying Agent (VMA)

It modifies the viscosity of concrete. Even if the viscosity increases, the workability of the SCC can be increased by remixing the The technical features of the VMA used in this research are tabulated in Table 2.

Table 2: Properties of Viscosity Modifying Agent

Colour	Colorless free flowing liquid
Relative density	1.01+0.01 at 25°C
Ph	>6 at 25°C
Chloride iron content	<0.2%

Fig. 2. Typical Viscosity Modifying Agent (VMA)

4. Aggregates
They are basically sands from land or coastal area or from river banks. In this experiment, river sand was used. The fineness modulus is 2.65, specific gravity 2.68.
5. Polypropylene fibres
Polypropylene fibers are thermo plastics produced from Propylene gas which is a byproduct of petroleum. It was initially known as Stealth. 85% of this is propylene. It increases the strength of the Self compacting concrete. It is rough and flexible. The thermal expansion is very high.

Fig. 3. Typical Polypropylene fibres

6. Crumb Rubber
Crumb rubber is a material produced by shredding and commutating used tires. Tensile strength of rubber is very high as it's highly elastic. It is very flexible and has very good bonding property. It binds with other construction materials fast. They are good insulators of heat.

Fig. 4. Typical Crumb rubber

B. Experimentation Methodology
The purpose of conducting experiments on self-compacting tests is:
1) To check whether the concrete is self-compactable or not for the structure
2) If the compatibility is not sufficient, then adjust the mix proportion.

The following tests are carried out for studying fresh properties of SCC,

Table 3. Different tests for SCC

Test	Property	Acceptable Range of values
L-BOX	Passing ability	0.8-1.0
U-BOX	Passing ability	0-30mm
J-RING	Passing ability	0-10 mm
V-FUNNEL	Filling ability	Sec

1. L-Box Test
The L-box apparatus measures the passing ability of SCC. In this experiment, height difference was measured at the start and the end of the box and the ratio of these were taken. The range of H_2/H_1 should be between 0.8- 1.0.

Fig. 5. Experimentation in .L-Box Test

2. U-Box Test
In U-box test, the passing ability of SCC is determined. The range of difference of height should be between 0-30 mm.
3. J-Ring Test
This test is to determine the passing ability of SCC. In this test, difference in the height of concrete inside and the outside of the j-ring is measured. The value should be between 0-10mm.

Fig. 6. Spread of SCC in the .J-Ring test

4. V-Funnel Test
The time taken for the flow of concrete through the apparatus is measured. This test gives account of the filling capacity.

Fig. 7. Experimentation in V-Funnel Test

IV. RESULTS AND DISCUSSION

This research focuses on optimization of mix proportioning of SCC using polypropylene fibres and crumb rubber.

Table5. Replacement Percentage of Polypropylne And Crumb Rubber

Control concrete	Polypropylene fibres	Crumb rubber
0%	Max. replacement 15%	Max. replacement 15%

In this experiment, the cement is replaced by 5%, 10% & 15% of polypropylene fibres and crumb rubber. Following table V shows the percentage variations of super plastizers (SP), viscosity modifying admixtures (VMA), air entraining agent (AEA) for doing the experiment.

Table 6 Percentage Variation of VMA, AEA and SP (Saranya and Kannan, 2015)

Sample no.	%of VMA	%of AEA	% of SP
1	0	0	1.1
2	0	0	0.3
3	0.1	0	1.1
4	0.2	0	1.1
5	0	0.5	1.1
6	0	1	1.1
7	0.1	0.5	0.3
8	0.2	1	1.1

Table 7 shows the mix proportions used in this experimental procedure.

Table 7 Mix Proportions Of SCC

Cement	530 kg/m3
Fine aggregate	836 kg/m3
Coarse aggregate	790 kg/m3
w/c ratio	0.36

Table 4. Test Results

(A) Results For 5% Replacement of Cement by Polypropylene Fibres

MIX.NO	EXPERIMENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
1	L-Box	0.78	0.8	0.82	0.8	0.77	0.79	0.83	0.85
2	U-Box(mm)	30	27	25	23	28	22	21	18
3	J ring(mm)	3.2	4.6	5.9	7.1	5.2	7.1	7.8	8
4	V funnel(sec)	10	9.7	8	8.2	7.5	6.4	6.1	5.55
5	V funnel-5 mints	3	2.5	2	1	2.8	2	1.2	1

(B)Results For 10% Replacement of Cement by Polypropylene Fibres

MIX.NO	EXPERIMENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
1	L-Box	0.77	0.79	0.8	0.8	0.75	0.78	0.81	0.83
2	U-Box(mm)	28	26	25	22	26	20	19	17
3	J ring(mm)	3	4.3	5.2	6.5	5.0	6.8	7.5	7.8
4	V funnel(sec)	9.8	9.2	7.72	7.9	7.39	6.2	5.9	5.5
5	V funnel-5 mints	2.8	2.3	1.58	1.1	2.52	2.1	1	0.85

(C) Results For 15% Replacement of Cement by Polypropylene Fibres

MIX.NO	EXPERIMENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
1	L-Box	0.77	0.78	0.8	0.79	0.74	0.78	0.8	0.82
2	U-Box(mm)	28	25	23	22	25	18	17	15
3	J ring(mm)	2.7	4.15	4.8	6.3	4.75	6.7	7.48	7.7
4	V funnel(sec)	9.65	9.25	7.6	7.82	7.3	6.1	5.6	5.4
5	V funnel-5 mints	2.5	2.22	1.67	1.02	2.34	1.88	0.8	0.7

(D) Results for 5% Replacement of Cement by Crumb Rubber

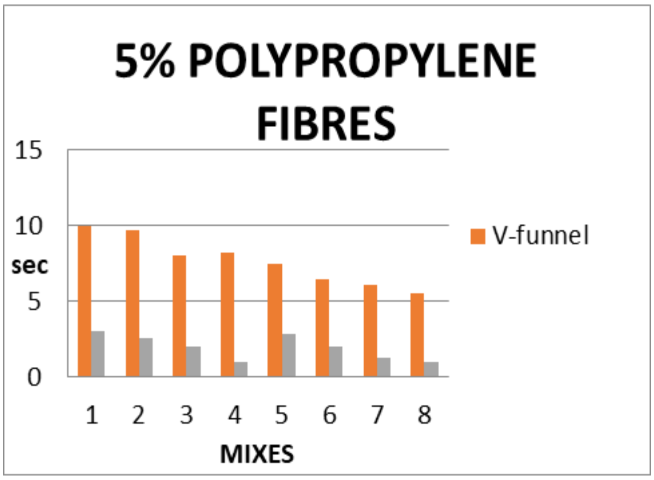
MIX.NO	EXPERIMENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
1	L-Box	0.69	0.75	0.78	0.80	0.75	0.82	0.82	0.85
2	U-Box(mm)	28	25	23	20	28	20	20	16
3	J ring(mm)	3	4.5	5.7	7	5.6	6.9	7.5	8.3
4	V funnel(sec)	9.7	8.35	7.59	6.6	5.8	6.55	6	5.7
5	V funnel-5 mints	2.67	2.2	1.5	1	2.53	2.5	1.5	1

(E) Results for 10% Replacement of Cement by Crumb Rubber

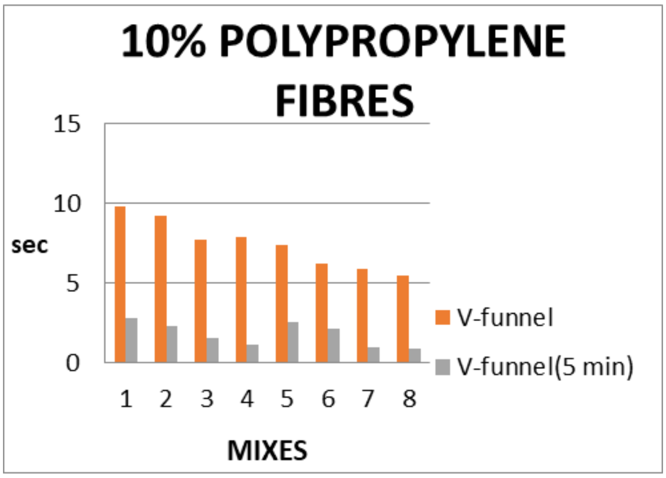
MIX.NO	EXPERIMENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
1	L-Box	0.68	0.73	0.75	0.78	0.75	0.8	0.82	0.83
2	U-Box(mm)	26	23	22	17	26	18	17	16
3	J ring(mm)	2.9	4.3	5.3	6.5	5.5	6.3	7.15	8
4	V funnel(sec)	9.5	8.2	7.4	6.5	5.7	6.4	5.85	5.6
5	V funnel-5 mints	2.55	2.15	1.4	1	2.49	2.45	1.4	1

(F) Results for 15% Replacement of Cement by Crumb Rubber

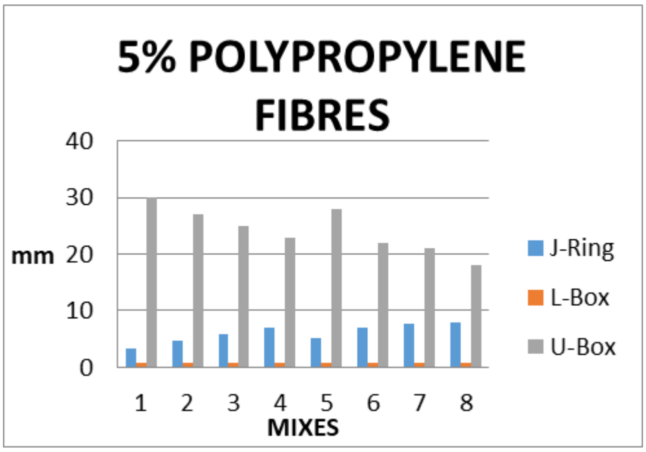
MIX.NO	EXPERIMENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
1	L-Box	0.66	0.7	0.73	0.76	0.7	0.77	0.79	0.8
2	U-Box(mm)	24	21	20	15	24	14	16	15
3	J ring(mm)	2.75	4.2	5.2	6.3	4.9	6.2	7	7.3
4	V funnel(sec)	9.4	8.09	7.25	6.4	5.55	6.2	5.73	5.24
5	V funnel-5 mints	2.50	2.1	1.54	1.2	2.42	2.38	1.25	1



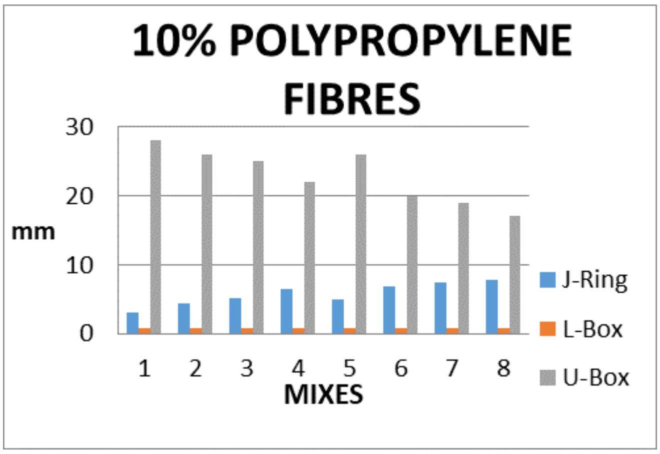
(a)For 5% replacement of cement by polypropylene fibres in v-funnel and v-funnel (5 mints)



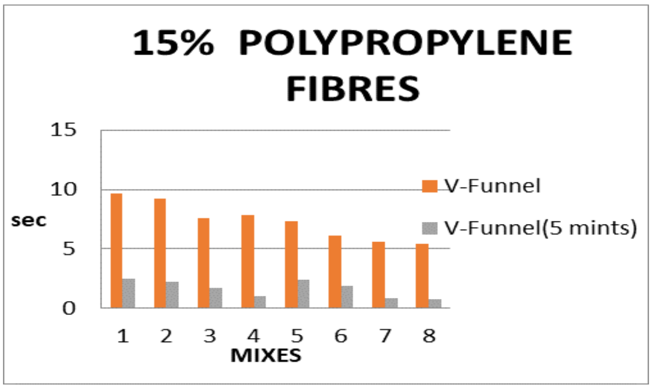
(c)For 10% replacement of cement by polypropylene fibres in v-funnel and v-funnel (5 mints)



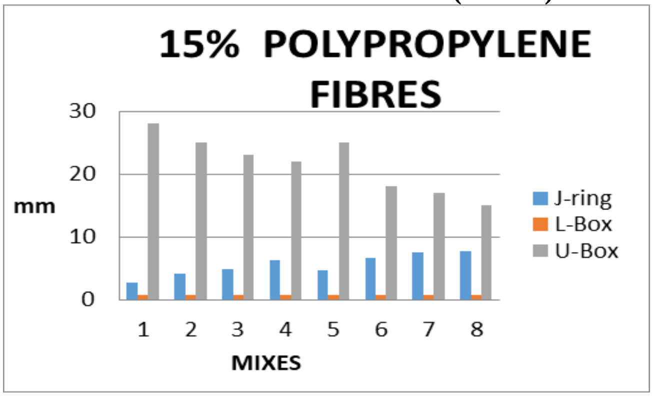
(b)For 5% replacement of cement by polypropylene fibres in L-box,U-box and J-ring



(d)For 10% replacement of cement by polypropylene fibres in L-box,U-box and J-ring

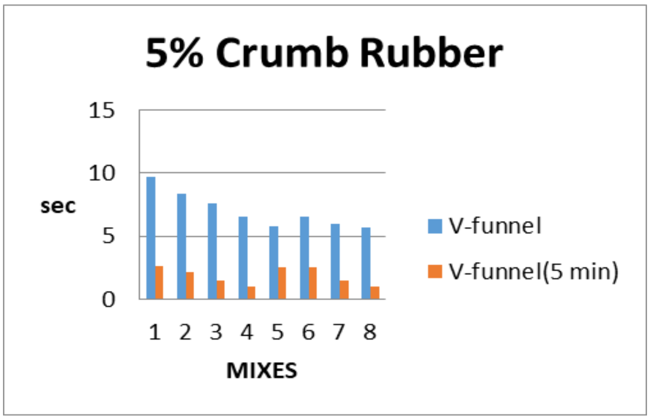


(e)For 15% replacement of cement by polypropylene fibres in v-funnel and v-funnel (5 mints)

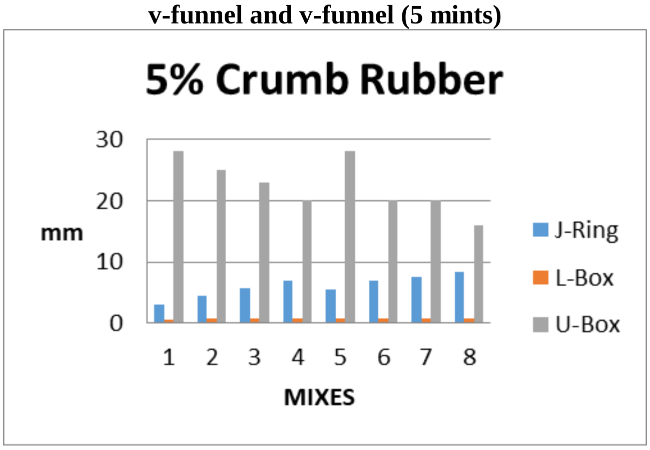


(f) For 15% replacement of cement by polypropylene fibres in L-box,U-box and J-ring

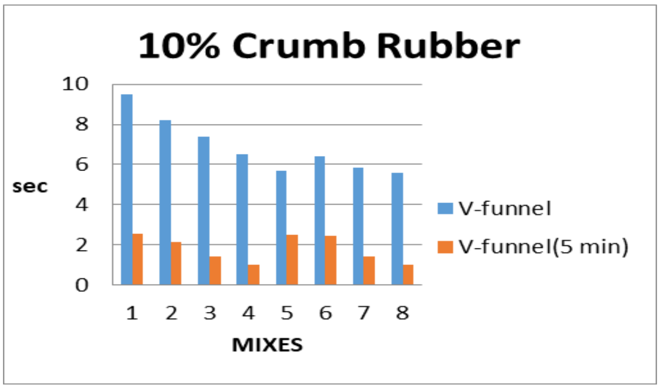
Fig 8. Variation of Values of Different Mixes (Poly Propylene Fibres)



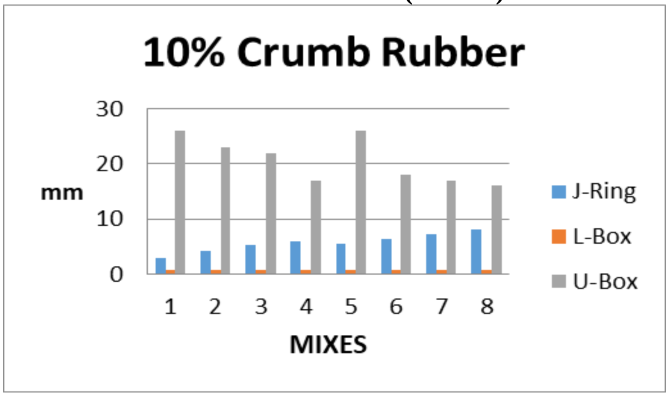
(a)For 5% replacement of cement by crumb rubber in v-funnel and v-funnel (5 mints)



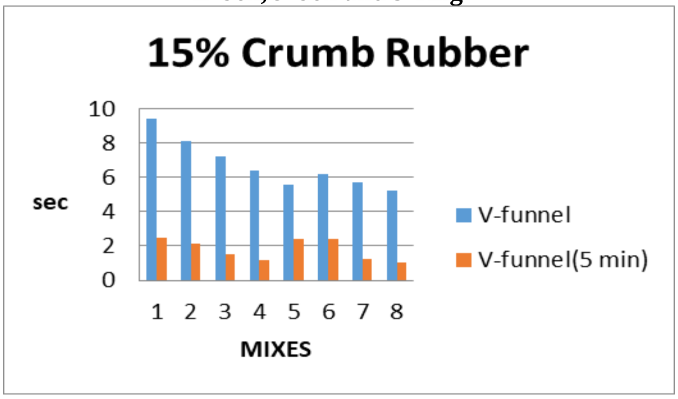
(b) For 5% replacement of cement by crumb rubber in L-box,U-box and J-ring



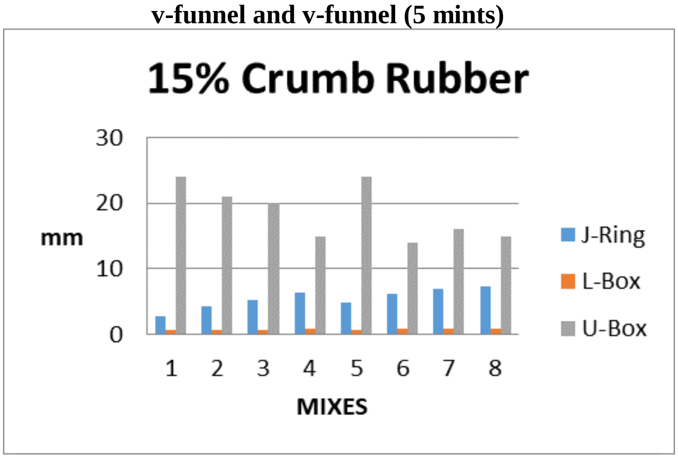
(c)For 10% replacement of cement by crumb rubber in v-funnel and v-funnel (5 mints)



(d) For 10% replacement of cement by crumb rubber in L-box,U-box and J-ring



(e)For 15% replacement of cement by crumb rubber in v-funnel and v-funnel (5 mints)



(f) For 15% replacement of cement by rubber crumb in L-box,U-box and J-ring

Fig. 9..Variation of Values of Different Mixes (Crumb Rubber)

For numerical optimization using Heuristic Search, the values in tables are converted into PERSP 3-D graph and contour plot by R software. The graphs obtained are:

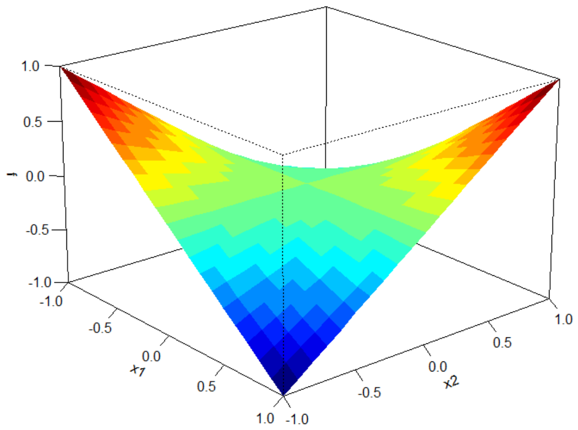


Fig. 10. Persp 3-D Graph of L-Box

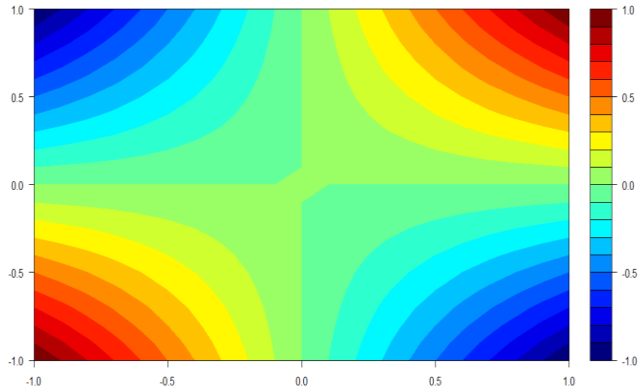


Fig. 11.Contour Plot of L-Box

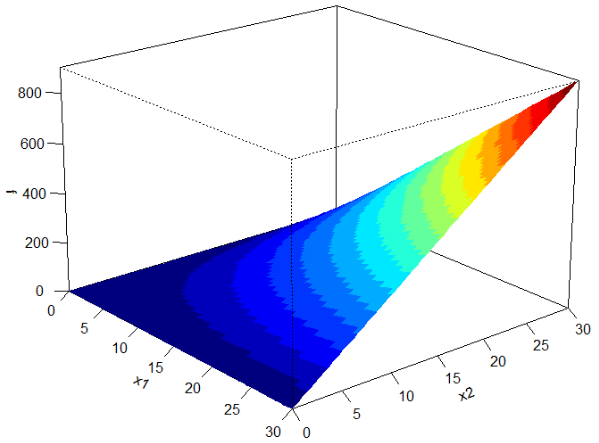


Fig. 12.Persp 3-D Graph of U-Box

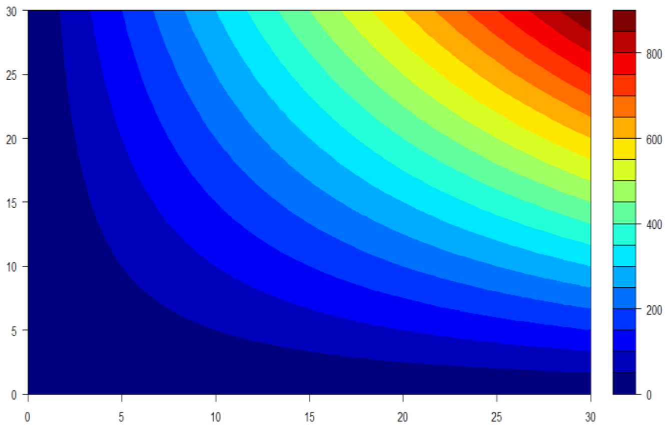


Fig. 13. Contour Plot of U-Box

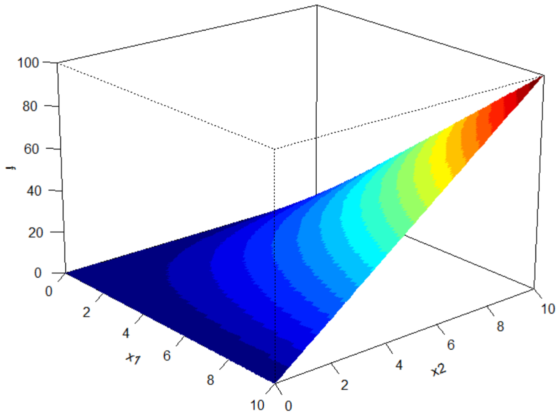


Fig. 14. Persp 3-D Graph of J-Ring

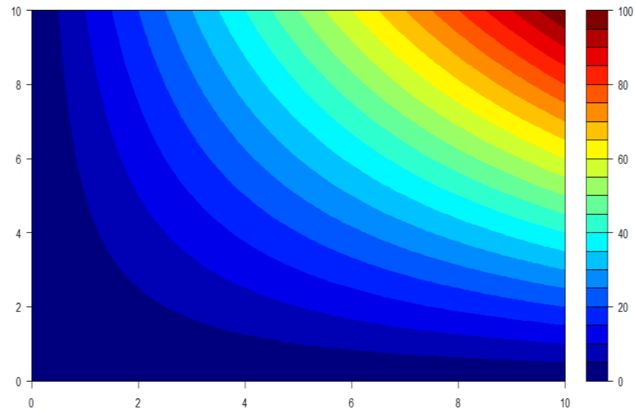


Fig. 15. Contour Plot of J-Ring

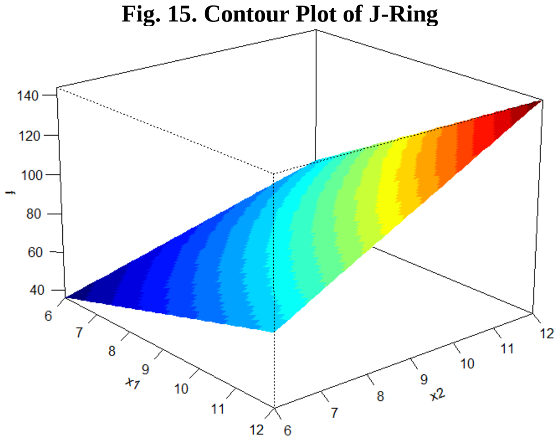


Fig. 16. Persp 3-D Graph of V-Funnel

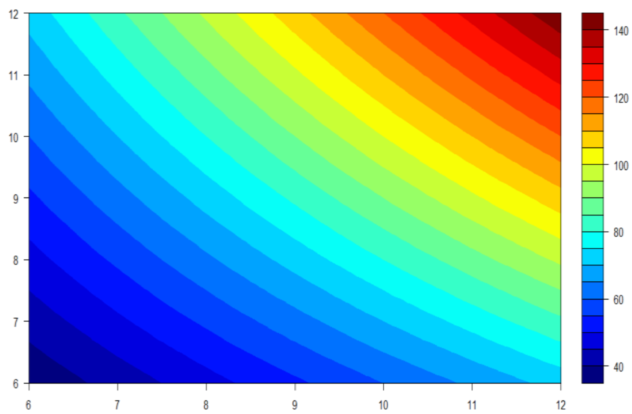


Fig. 17. Contour Plot of V-Funnel

V. CONCLUSION

From the results obtained from the experiments conducted, the replacement of cement by 5% of polypropylene fibres and crumb rubber shows good passing and filling ability compared to other percentage of replacements. By using Heuristic Algorithm, we found that the optimum mix for the replacement of cement by polypropylene fibres is MIX 6 and for the crumb rubber is MIX 7 from the aforementioned sections.

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