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A Study on Self Compacting Concrete of M35 Grade

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Abstract*:- Due to the requirement of the durability of concrete, increase in efficiency and construction time of the project, self-compacting concrete (SCC) has gaining its popularity in modern construction. Self-compacting concrete is fresh concrete that flows under its own weight and does not require external vibration to undergo compaction. The objective of the research is to access the properties of M35 grade self-compacting concrete. The SCC having filling ability, passing ability and segregation resistance which are determined by the tests namely Slump-flow, L-Box and V-funnel as stated by the EFNARC guidelines, 2005. The samples of fine and coarse aggregate were taken from the Kotre crusher run source. The mix design is performed as per IS 10262:2009 and the conversion to SCC mix is done with trial method. With the increase of water paste ratio, the workability of concrete and properties of SCC gets improved but the compressive strength of concrete with age becomes harder to obtain. The study was carried out using Markplast Flow-30 as chemical admixture to obtain workability and also helps to reduce the water content in the mix and ultimately to increase strength. Also some portion of the cementitious material is replaced by fly ash which helps to improve and maintain the cohesion and segregation resistance. Different trials have been performed to identify the optimum mix. The optimum mix was obtained as trial FM2 where the fine and coarse aggregate were 60 and 40 percent of the total aggregate used, superplasticizer was 0.9% of cementitious material and water/cement ratio was 0.42. The 7 days and 28 days strength of the FM2 were obtained as 30.37 N/mm^2 and 43.63 N/mm^2.

Keywords: Compressive strength, Durability, Markplast Flow-30, Mix-Design and Workability.

1. INTRODUCTION

Concrete is the construction material consisting of cement, fine aggregate (sand) and coarse aggregate mixed with water which becomes harder with time. It is extensively used in modern construction for the construction of foundation, column, beams, slabs, roads, bridges and other load bearing elements. Water Cement ratio in concrete plays an important role in influencing various properties such as workability, strength and durability. Self-compacting concrete is a special condition of high performance concrete having high flow ability, segregation resistance and can reach every corner of formwork through its own self weight without the application of vibration during pouring process. The necessity of self-compacting concrete was proposed by Okamura at Ouchi University, Japan in 1986 to achieve durable concrete structure but it is first generated in North America which was characterized by high content of binder and high dosage of super plasticizer.

Self-compacting concrete (SCC) is fresh concrete which has capacity of compaction by its own weight. This concrete flows under its own weight and doesn't require vibration for compaction. Viscosity and low yield value of the concrete mix makes production of SCC possible (Sumit Ahlawat et al., 2015). So it requires good balance between deformability and stability. The main properties of SCC are filling ability, passing ability, segregation resistance and viscosity. Increasing the paste volume around the aggregate helps in the flow ability but decreases the strength of concrete. In construction industries, durability gets more priority than the strength requirement which can meet with the help of SCC as it generally requires high powder content (H. Okamura and K. Ozawa, 2003). The increase in water powder ratio increase the workability and flow property but increases the chances of segregation and bleeding in the mix. Use of small sized aggregate than the large sized aggregate helps to improve in the segregation resistance and checks bleeding. So the preparation of SCC requires intense quality control of ingredient materials used in it (Maria KASZYNSKA, 2003). Different types of mineral admixtures like fly ash, silica flumes, metakaolin, etc. are used as the partly replacement of cement which helps to increase cohesion and reduce sensitivity to change in water content. Mineral admixtures also helps to reduce the chemical requirement to get similar flow without altering the cement content (A. Kumar et al., 2018). The chemical admixture i.e. super plasticizer is an important ingredient for SCC to reduce the water demand in the concrete increasing strength and at the same time obtaining the fluidity and workability. The basic principle required for the production of self-compacting concrete is listed on EFNARC guideline, 2005 as

i) High volume of paste content and lower the water powder ratio (w/p);
ii) Lowering the value ratio of aggregate to cementitious material;
iii) Lowering volume of coarse aggregate to total volume ratio; and
iv) High dose of super-plasticizer and sometimes use of viscosity modifying agent (VMA).

Test and Properties of Self Compacting Concrete

Thera are mainly three property of Self-compacting concrete which requires different three test to verify.

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Filing ability: It is the ability to flow under its own weight reaching every corners without any vibration provided externally. Slump flow test, T_{500} slump flow and V-funnel test is done to identify the filling ability of the fresh concrete.

Passing ability: It is the ability of concrete to maintain its homogeneity and flow through the narrow opening. L-box test, J-ring test, U-box test, etc. are performed to identify passing ability of produced fresh SCC.

Segregation resistance: The resistance of the concrete not to undergo segregation when it flows during the transportation and placing process. V- Funnel at T_5 minutes is performed to identify segregation resistance test.

2. MATERIALS AND METHODS

2.1 Materials Required

The basic constituent of concrete are cement, fine aggregate, coarse aggregate and water. They have their own properties according to the requirement as per the use of concrete. The main properties of SCC are filling ability, passing ability and segregation resistance. So the ingredients thus required needs to fulfill these properties in SCC mix.

Cement: The fresh ordinary Portland cement of 43 or 53 grade which are available in the market can be used for the production of SCC. Shivhum Cement of 43 grade available locally was used in this study.

Additions: Additions are inert and pozzolanic/hydraulic additions to cement which are generally used to improve the rheological parameters and minimize the risk of cracking of concrete due to heat of hydration which ultimately increase durability (A. Kumar, 2018). Additions are used to replace certain percentage of cement in order to reduce the heat of hydration and thermal shrinkage. Some additions are mineral fillers, fly ash, silica fume, ground blast furnace slag, metakaolin, natural pozzolana, ground glass, air cooled slag and other fillers. Among these fly ash is an effective addition for SCC providing increased cohesion and reduced sensitivity to changes in water content. Fly ash was used 10% of the cementitious material in this study.

Fine Aggregate: Fine aggregate plays an important role than coarse aggregate in the fresh properties (flow ability) of SCC. Particles size fraction of less than 0.125 mm should be include the fines content of the paste. The high volume of paste in SCC mixes helps to reduce the internal friction between the sand particles but a good grain size distribution is still very important (EFNARC, 2005). Crusher run fine aggregate of Kotre source having gradation zone I was used in the study.

Coarse Aggregate: Coarse aggregate are important ingredients to obtain strength for the production of SCC. The reinforcement spacing is the main factor which determines the maximum size of aggregate. It can be varied according to the spacing of rebar on the structure. The maximum size of aggregate should generally be limited to 12 to 20 mm. As the particle size distribution and the shape of coarse aggregate directly influence the flow and passing ability of SCC and its paste demand (EFNARC, 2005). Coarse aggregate obtained from the crusher run and passes through 16mm sieve is used in the study.

Water: Water used in the production of the SCC is as same as of normal concrete. Portable fresh water was used for concrete production.

Admixtures: Superplasticizers or high water reducing admixtures are main and essential component of SCC. The use of superplasticizer helps to reduce the water content requirement up to 30% maintaining the flow ability and homogeneity. The chemical admixture should be chosen in such a way that it has the compatible to cement used (Maria KASZYNSKA, 2003). Viscosity modifying admixture (VMA) may also be used to reduce segregation and the sensitivity of the mix due to variations in other constituents, essential to moisture content. Markplast Flow-30 was used for the study.

2.2 Methods and Laboratory Procedure

A. Gradation of Fine and Coarse Aggregate

Gradation of sample was done to find out the distribution size of aggregate which was determined by sieve analysis of the required collected sample. The materials retained on each sieve were weighted and percentage retained and cumulative percentage retained were calculated. The values are then compared with the table 2 and table 4 of IS 383:1970 for the required gradation.

B. Water Absorption and Specific Gravity

Water absorption and specific gravity is the physical properties of aggregates which are required in the mix design process. The water absorption and specific gravity of coarse aggregate were calculated as the average of two samples value using below formulas.
Here,

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Weight of sample = 2 kg
Weight of vessels + sample + water = A grams
Weight of vessel + water = B grams
Weight of saturated and surface dry sample = C grams
Weight of oven dry sample = D grams
Hence,

Specific Gravity = $\frac{D}{[C-(A-B)]}$ …………………………………………………………………..Equation 1.1

Apparent Specific Gravity = $\frac{D}{[D-(A-B)]}$ ………………………………………………………..Equation 1.2

Water Absorption = $\frac{C-D}{D} * 100$ …………………………………………………….…………Equation 1.3

For fine aggregate, the water absorption and specific gravity were calculated as the average of two samples value using below formulas.
Here,
Weight of sample = 2 kg
Weight of saturated and surface dry sample = C grams = 500 grams
Weight of vessels + sample + water = A grams
Weight of vessel + water = B grams
Weight of oven dry sample = D grams
Hence,

Specific Gravity = $\frac{D}{[C-(A-B)]}$ ………………………………………………………………….. Equation 1.4

Apparent Specific Gravity = $\frac{D}{[D-(A-B)]}$ ……………………………………………………….. Equation 1.5

Water Absorption = $\frac{C-D}{D} * 100$ ……………………………………………………….……… Equation 1.6

C. Mix Design

As there is no standard method for the mix design of the self-compacting concrete, institutions adopt their own method of preparation. Mix design should be done in such a way that meets the desired requirement of the consumer in function, durability and strength. In this study the mix design of M35 grade self-compacting concrete is done according to IS 10262:2009 and IS 456:2000. Although the mix design is not of self-compacting, this needs modification of the ingredient proportion in order to convert the mix design to SCC. EFNARC, 2005 gives the mix design principle compared to normal concrete and guidelines to convert into SCC which can be listed as:

i) Lower coarse aggregate content
ii) Increased paste content
iii) Low water/powder ratio
iv) Increased superplasticizer
v) Sometimes a viscosity modifying admixture

Table 1: Trials Performed in the Design Mix

Trial No	Cement Kg/m^3	Fly Ash Kg/m^3	FA Kg/m^3	CA Kg/m^3	Water Kg/m^3	SP Kg/m^3	W/C
Set X							
TRX1	431.06	47.90	912.24	912.24	163.80	3.35	0.38
TRX2	431.06	47.90	912.24	912.24	172.42	3.35	0.40
TRX3	431.06	47.90	907.65	907.65	181.04	3.35	0.42
TRX4	431.06	47.90	907.65	907.65	189.66	3.35	0.44
Set Y							
TRY1	431.06	47.90	1003.47	821.02	163.80	3.35	0.38
TRY2	431.06	47.90	1003.47	821.02	172.42	3.35	0.40
TRY3	431.06	47.90	1003.47	821.02	181.04	3.35	0.42
TRY4	431.06	47.90	1003.47	821.02	189.66	3.35	0.44
Set Z							
TRZ1	431.06	47.90	1089.19	726.12	163.80	3.35	0.38
TRZ2	431.06	47.90	1089.19	726.12	172.42	3.35	0.40
TRZ3	431.06	47.90	1089.19	726.12	181.04	3.35	0.42
TRZ4	431.06	47.90	1089.19	726.12	189.66	3.35	0.44
Final Mix							
FM1	452.62	50.29	1089.19	726.12	181.04	4.53	0.40
FM2	452.62	50.29	1089.19	726.12	190.10	4.53	0.42
FM3	452.62	50.29	1089.19	726.12	199.15	4.53	0.44

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Source: Lab Test, 2020

D. Slump Flow Test and T_{500} Time

The slump test is a test for the flow rate of the SCC so produced in the absence of obstruction. The result is an indication of the filling ability of SCC. The T_{500} time is the measure of the speed of flow and hence gives the viscosity of SCC.

Figure 1: Slump Flow Test with Apparatus

E. V-Funnel Test

V- Funnel test is used to access the viscosity and filling ability of SCC. A V-funnel is filled with fresh concrete and time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time.

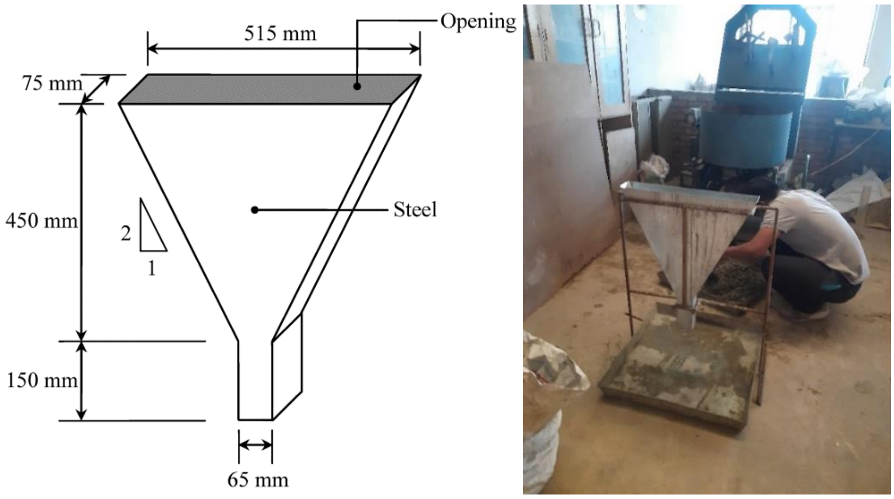

Figure 2: V-Funnel Test with Apparatus

F. L-Box Test

The L- Box test is a method used to assess the passing ability of self-compacting concrete to flow easily through narrow openings and obstructions without segregation or bleeding.

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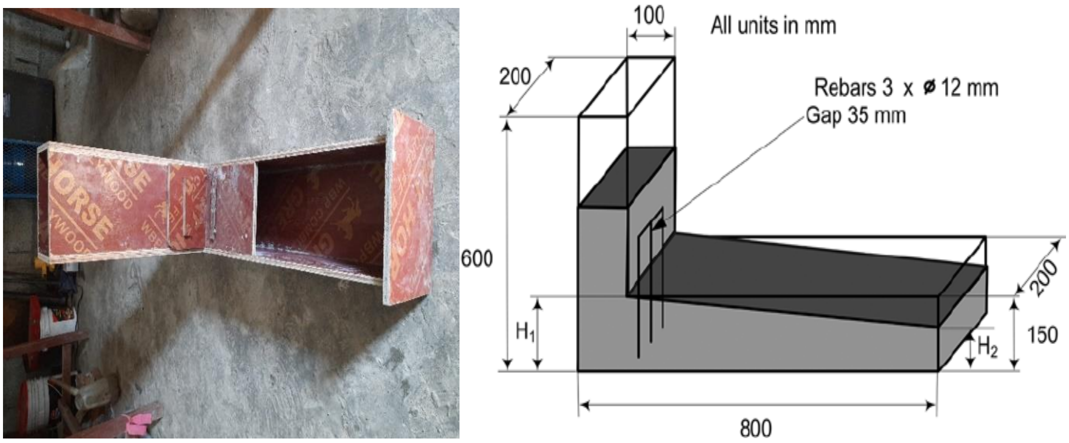

Figure 3: L-Box Test with Apparatus

Table 2: Conformity Criteria for Fresh Concrete Test

Test on Fresh Concrete	**Recommended Limits**
Slump Flow	550-850 mm
T_{500}	3-7 secs
L-Box Test	0.8 - 1.0
V-Funnel Test	7 - 27secs

Source: EFNARC, 2005

G. Test on Hardened Concrete

Normally concretes are tested on hardened state to find out the strength criteria. Compressive strength is one of the relevant criteria of strength which is extensively used in the normal concrete. Compression testing machine provides the breaking load of the cube and dividing that value by the surface area of the cube gives the compressive strength of the concrete.
Therefore, Compressive Strength = Breaking Load / Surface Area of Cube

Figure 4: Compression Test on Hardened Concrete

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3. RESULTS AND DISCUSSION

3.1 Specific Gravity and Water Absorption

The obtained results of specific gravity and water absorption on the laboratory are tabulated on table 3 and 4. Specific gravity are within the standard range (>2.5) as per Standard Specification for Road and Bridges 2073 of Nepal. Water absorption of aggregate was within the standard range (<2%) as per Standard Specification for Road and Bridges DOR 2073 of Nepal.

Table 3: Specific Gravity of Coarse and Fine Aggregate

Ingredients	Specific Gravity	Name of Source
Coarse Aggregate	2.70	Kotre crusher run
Fine Aggregate	2.65	Kotre crusher run

Source: Lab Test, 2020

Table 4: Water Absorption of Coarse and Fine Aggregate

Ingredients	Water Absorption	Standard Value
Coarse Aggregate	0.29 %	< 2 %
Fine Aggregate	1.43 %	< 2 %

Source: Lab Test, 2020

3.2 Gradation of Aggregate

Data's obtained from the sieve analysis of fine and coarse aggregate is presented in table. From the table fine aggregate falls under gradation zone I as compared with the table 4 of IS 383:1970. Table 5 also shows the percentage passing for graded aggregate of nominal size 16mm as per table 2 of IS 383:1970. This shows that the fine aggregate used in the study was coarser as the sample was taken from crusher run source.

Table 5: Gradation of Fine Aggregate

Sieve size (mm)	Avg. retained wt.	Passing wt.	Passing %	Zone I from IS 383:1970 (%)
10	0	2702.7	100	100
4.75	253.56	2449.14	90.62	90-100
2.36	860.72	1588.42	58.77	60-95
1.18	610.3	978.12	36.19	30-70
0.6	569.1	409.01	15.13	15-34
0.3	153.86	255.15	9.44	5-20
0.15	141.8	113.36	4.19	0-10
Pan	113.36			
Total	2702.7			

Source: Lab Test, 2020

Table 6: Gradation of Coarse Aggregate

Sieve size (mm)	Avg. retained wt.	Passing wt.	Passing %	From Table 2 of IS 383:1970 (%) 16mm
20	0.00	3888.00	100.00	100
16	0.00	3888.00	100.00	90-100
10	1414.00	1794.00	46.14	30-70
4.75	1794.00	0.00	0.00	0-10
Pan	0.00			
	3888.00			

Source: Lab Test, 2020

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3.3 Fresh Property of Trials Mix for SCC of M35 Grade Concrete

Fresh property is the property of concrete immediately after the preparation of concrete. This was observed through Slump flow, L-Box and V-Funnel in this research. The obtained fresh property of the different trial mix of M35 grade concrete are tabulated on the table below.

Table 7: Fresh Properties of Different Trials for M35 Grade Concrete

Trial No.	Slump Flow (mm)	T_{500} Sec.	L-Box (H2/H1)	V-funnel Sec.	Remarks
TRX1	320	-	-	-	
TRX2	360	-	-	-	
TRX3	380	-	-	40	
TRX4	390	-	-	35	
TRY1	400	-	-	37	
TRY2	480	-	-	35	
TRY3	520	18	0.2	30	
TRY4	570	15	0.34	28	
TRZ1	540	16	0.5	21	
TRZ2	580	9	0.78	15	
TRZ3	680	5	0.84	9	SCC
TRZ4	720	4	0.9	8	SCC
FM1	710	4	0.87	8	SCC
FM2	730	3	0.89	7	SCC
FM3	740	3	0.91	7	SCC
Recommended Limit	550-850 mm	3-7 secs.	0.8 – 1.0	7-27 secs.	EFNARC, 2005

Source: Lab Test, 2020 and EFNARC 2005.

From above table, three test i.e. slump flow, L-box and V-funnel doesn't have any influence on first set X of trials which has the proportion of fine and coarse aggregate as 50-50%. The next trial set Y were performed taking fine aggregate as 55% and coarse aggregate as 45% of the total aggregate used in the mix. This gets improved on the flow ability with the increase in water cement ratio. The trail TRY4 reached the slump flow criteria but L-Box and V-funnel criteria was not satisfied. Then the next set of trial as set Z was performed having 60% fine and 40% coarse aggregate of the total aggregate in the mix. The trial TRZ2, TRZ3 and TRZ4 of set Z shows improved property on fresh concrete satisfying the nearly all three test. These trials further tested on 7th and 28th days but the compressive strength doesn't meet the target strength. Thus the final mix trials were carried out increasing the cementitious materials by 5% and superplasticizer to 0.9%. This further increase of cement and superplasticizer on mix helps to meet the strength criteria on hardened concrete as well as the fresh property. The SCC property started to show its results when the water cement ratio becomes 0.4. The slump flow obtained between 660-750mm which falls under SF2 criteria of EFNARC guideline which shows that the concrete can be used in the normal applications like walls, columns, etc. Five trials performed during the study meets SCC property as per table 4. Among these trials FM3 was considered the best mix for the fresh property of M35 grade self-compacting concrete.

3.4 Compressive Strength of Trial Mix Concrete

Table 8: Compressive Strength of Different Trials at 7 and 28 days

S.N.	Trial Specimen	Compressive Strength (N/mm^2)	
		7 days	28 days
1	TRZ3	19.48 < 28.11	34.22 < 43.25
2	TRZ4	22.15 < 28.11	37.26 < 43.25
3	FM1	25.78 < 28.11	38.67 < 43.25
4	FM2	30.37 > 28.11	43.63 > 43.25
5	FM3	31.04 > 28.11	42.44 < 43.25

Source: Lab Test, 2020

From the above table it can be seen that the trials which passes the fresh property of SCC were casted and tested at 7 days and 28 days. The density of the cube was obtained above 2400 kg/m^3 which is as per IS standard. But the strength of the cube at 7 days needs to be 65% of the total target value of character strength. Here the 7 days strength of TRZ3, TRZ4 and FM1 was obtained less than the target strength (<28.11N/mm^2). But trial FM2 and FM3 was obtained to be more than target strength (>28.11N/mm^2). For the economical it was taken trial FM2 as the best mix from the 7 days result.

Similarly for the 28th days result, all trials except FM2, fails to obtain the target strength (43.25 N/mm^2). It may be because of higher water cement ratio and paste flows away. Thus trial FM2 can be considered as the best mix for the M35 self-compacting concrete from the ingredients used for the study.

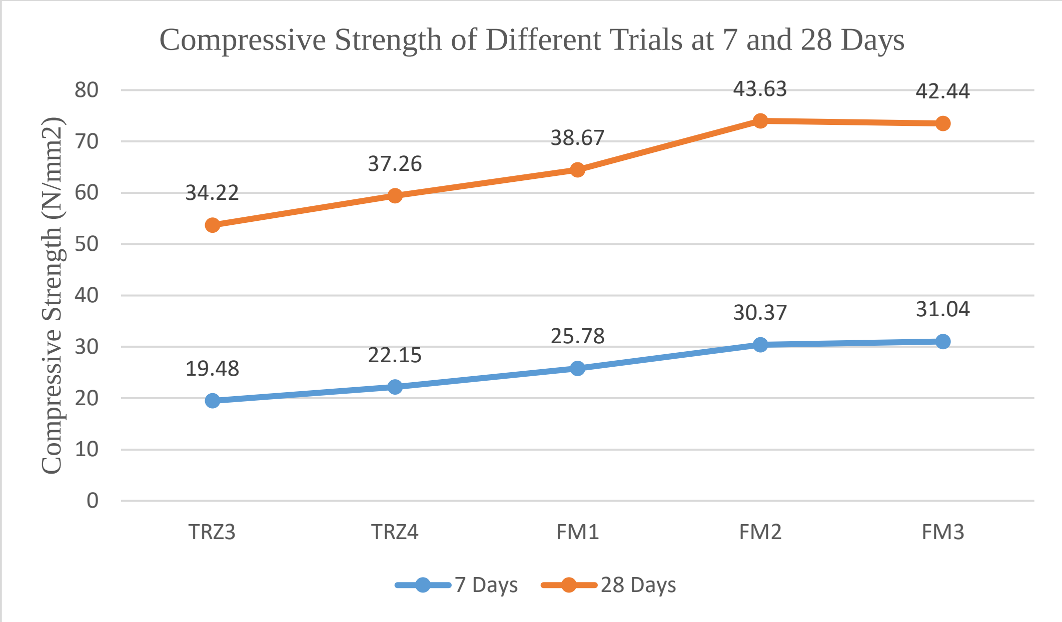

Figure 9: Compressive Strength at 7 and 28 days for different trials

3.5 Recommended Mix for M35 Grade Self-Compacting Concrete

According to IS 10262:2009, the target strength of M35 concrete is 43.25 N/mm^2, so the target is fulfilled by the trial FM2 which contains following ingredients.

Table 9: Ingredient and Proportions Recommended for M35 Mix Grade of SCC

Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Water	Superplasticizer
452.61 kg/m^3	50.29kg/m^3	1094.69 kg/m^3	729.80 kg/m^3	192.1 kg/m^3	4.53 kg/m^3
1	0.11	2.42	1.61	0.42	0.01

Table 10: Recommendation for Mix Design of M35 Grade of SCC

Quantity of Ingredients per m^3	Cement	452.61 kg
	Fly Ash	50.29 kg
	Fine Aggregate	1094.69 kg
	Coarse Aggregate	729.80 kg
	Water	192.10 kg
	Superplasticizer	4.53 kg
Workability Test Result	Slump Flow	730 mm
	T_{500} Time	3 secs
	V-Funnel Time	7 sec
	L- Box Ratio	0.89
7 Days Compressive Strength (N/mm^2)		30.37
28 Days Compressive Strength (N/mm^2)		43.63

4. CONCLUSIONS AND RECOMMENDATIONS

From the test performed in the laboratory, this study concludes that the mix design of M35 grade of self-compacting concrete can be done according to the IS 10262:2009 and IS 456:2000 with some modifications and trials. Conclusions drawn from the study may be listed as:

a) Superplasticizer is the major ingredient for the SCC which helps in the flowing ability decreasing the water cement ratio and influence to the compressive strength.

b) Paste volume needs to be increase to satisfy the fresh property of SCC.
c) Increase in water cement ratio increase the workability and flow ability but the compressive strength decreases. So the optimum ratio of water cement for the used superplasticizer need to be taken more care for different trials.
d) Fly ash is very useful ingredient as it enhance the paste quality requirement for the self-compacting concrete.
e) Self compacting concrete can be produced without the use of viscosity modifying agent. If it needs to be used, more care should be taken during mixing time and compatibility with other admixtures. If care isn't taken, the property of cement may be effected and takes some more days to bind the materials.
f) The chemical admixture needs to be added after the addition of 60-70% water to the mix.
g) The Markplast flow 30 superplasticizer is compatible with Shivhum cement of Nepal and can be used in preparation of concrete with higher grade.

Hence self-compacting concrete of high grades can be produced using the ingredients available in Pokhara valley. For the further study, it is recommend that:

a) The use of different types of mineral admixture to produce higher grade concrete.
b) The crushed aggregate can be replaced by the recycled aggregate and observe the behaviour.
c) The optimization of the fly ash or superplasticizer in the mix can be done.
d) It is also recommended to study the behaviour of SCC use viscosity modifying agent.
e) The study can be done on SCC using different types of cement for the same other ingredients.

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