Study on Mix Design and Performance of Low Shrinkage Self compacting Concrete with Machine Made Sand

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Abstract. In order to prepare mechanism sand self-compacting concrete with good workability, this paper adjusted the dosage of cementitious materials, sand ratio, stone proportion, and admixture dosage through experiments. The T_{500} test, slump flow test, J-ring test, V-funnel test, U-box test, and L-box test were used to evaluate the workability of the mechanism sand self-compacting concrete and verify its 28-day compressive strength. A C35 mix proportion of mechanism sand self-compacting concrete with good workability was successfully prepared, and its workability and 28-day compressive strength were verified through various tests. These results provide a theoretical basis and reference for the application of mechanism sand self-compacting concrete in engineering.

Keywords: machine-made sand; Self-compacting concrete mix ratio; Working performance

1 Introduction

Self-compacting concrete (SCC) has been widely used in foreign countries such as Japan, Germany, the United Kingdom, the United States, and Canada. In China, research institutions have gradually carried out the preparation and performance studies of self-compacting concrete since 1993, and it has been applied in some projects. However, the technology of self-compacting concrete is not yet mature and its application is not widespread. Therefore, further research on the performance and application of self-compacting concrete is of great significance[1~4].

Self-compacting concrete (SCC) is a high-performance concrete that achieves uniform compaction without the need for mechanical vibration. This concrete demands high workability. In this study, limestone powder is incorporated to increase the volume of fines, and the sand ratio is adjusted accordingly. Previous research by Qiao Donghua, Ma Dongzhe, Wu Dinglue, and others has investigated SCC with manufactured sand. However, due to variations in origin and production processes, the performance of manufactured sand can differ significantly[5,6]. Therefore, the mix design for SCC with manufactured sand needs to be tailored according to the specific materials

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used[7~10].Building upon numerous studies on SCC with manufactured sand and considering the characteristics of the sand used, this paper, through laboratory experiments, formulates a mix design for C35 self-compacting concrete with manufactured sand that meets the required workability[11].

2 Experimental Raw Materials

The cement utilized is Guangdong Sea brand P·O42.5R cement, produced by Lechang City Zhongjian Building Materials Cement Co., Ltd. It has a specific surface area of 320 m^2/kg, a density of 3030 kg/m^3, a standard consistency water requirement of 27%, initial setting time of 142 minutes, final setting time of 241 minutes, compressive strength of 47.8 MPa at 28 days, and flexural strength of 7.8 MPa at 28 days. The fly ash employed is Grade I fly ash from Yuanyuan Jing Water Materials Factory in Gongyi City, with a fineness of 21.6%, and loss on ignition of 1.76%. Limestone powder is sourced from Yuanyuan Jing Water Materials Factory in Gongyi City, with a calcium carbonate content of 97.36%, fineness of 11.3%, flow ratio of 97%, and moisture content of 0.2%. The superplasticizer used is a high-performance polycarboxylate-based superplasticizer from Suzhou Fuke Technology Co., Ltd., with a water reduction rate of 25.6%, bleeding ratio of 29%, solid content of 17.53%, and slump flow change of 50 mm after 1 hour. Aggregates are produced from a local quarry using an E-type crusher, with particle size distribution inferior to that produced by impact crushers and poor angularity. The manufactured sand has an apparent density of 2720 kg/m^3, porosity of 41.4%, clay content of 0.1%, fineness modulus of 3.0, methylene blue value of 0.8 g/kg, limestone powder content of 12.6%, and maximum crush index of 12%, as shown in Table 1, the related experiments are shown in Fig. 1.

Table 1. Manufactured sand gradation

Sieve Opening Size/mm	4.75	2.36	1.18	0.6	0.3	0.15
II Zone Gradation Range/%	10~0	25~0	50~10	70~41	92~70	100~90
Cumulative Retained/%	0.8	25.6	48.8	65.2	77.6	83.7

For the crushed stone with particle size 10~20mm, the apparent density is 2710 kg/m^3, bulk density is 1490 kg/m^3, porosity is 45%, clay content is 2.6%, mud lump content is 0.3%, and needle-like particles account for 5.1% of the total. The gradation is shown in Table 2.

Table 2. Crushed stone gradation

nominal particle Size	sieve opening size/mm	2.36	4.75	9.5	16.0	19.0	26.5
5-10mm	gradation range/%	95~100	80~100	0~15	0	—	—
	cumulative retained/%	95.8	81	0.6	0	—	—

10-20mm	gradation range/%	—	95~100	85~100	—	0~15	0
	cumulative retained/%	98.9	98.8	90.0	20.2	0.7	0

Fig. 1. The related experiments picture

3 Experimental Testing and Results Discussion

3.1 Workability and Mechanical Properties Tests of the Mixtures

The testing parameters include T_{500}, slump flow, J-ring flow, V-funnel, U-box, L-box, and concrete compressive strength. Among these, slump flow and T500 are used to assess filling ability; J-ring flow is used to assess passing ability; U-box and L-box are used to assess passing ability and resistance to segregation; V-funnel is used to assess viscosity and resistance to segregation; and concrete compressive strength is used to assess mechanical properties.

3.2 Experimental Design and Mix Proportion

There are numerous factors influencing self-compacting concrete. Therefore, in the preliminary phase, it is essential to first determine the dosage of cementitious materials and explore the effects of aggregate-to-binder ratio and sand ratio on workability. Based on this foundation, adjustments are made gradually to parameters such as fly ash content and limestone powder content. The determination of water dosage for each mix is adjusted based on the performance of the concrete mix in the mixing drum, meaning that, while keeping other material dosages constant, the water dosage is adjusted according to the workability status of the concrete. The mix proportions for the experiments are provided in Table 3.

Table 3. Experimental mix proportions

ID	sand ratio/%	fly ash content/%	limestone powder content/%	fine aggregate dosage/kg/m³	coarse aggregate dosage/kg/m³
1	46	30	15	756	887
2	46	30	15	756	887

3	48	30	15	789	854
4	50	30	15	822	822
5	52	30	15	854	789
6	52	30	10	854	789
7	50	30	15	821.5	821.5
8	54	30	10	887	756
9	52	30	10	854	789
10	54	30	10	887	756
11	52	35	10	854	789
12	52	30	5	854	789
13	52	25	10	854	789
14	52	30	5	854	789
15	52	25	10	854	789
16	52	35	10	854	789
17	52	35	10	854	789

3.3 Experimental Testing Results and Discussion

The concrete mixture was subjected to testing including T_{500}, slump flow, J-ring flow, V-funnel, U-box, and L-box, and observations were made regarding workability, flowability, viscosity, and bleeding tendency. Specific testing data are presented in Table 4.

Table 4. Experimental testing data

ID	T_{500}/S	slump flow/mm	J-ring flow/mm	V-funnel/s	U-box/mm	L-box/mm
1	5	650	580	71	115	0.33
2	4	750	695	105	83	0.53
3	3	740	700	120	77	0.36
4	4	740	705	64	74	0.79
5	6	740	730	135	35	0.63
6	14	580	600	30	20	0.73
7	10	690	610	144	62	0.57
8	4	680	600	27	48	0.58
9	3	660	600	27	26	0.65
10	8	630	535	64	72	0.50
11	10	650	525	35	40	0.59
12	14	675	630	72	55	0.00
13	7	650	580	51	125	0.00
14	8	620	510	58	117	0.46
15	15	680	595	22	66	0.52
16	6	730	700	77	27	0.79
17	4	660	590	14	28	0.88

Based on the performance observations during the testing process, an analysis of the experimental data is conducted as follows:

By comparing trials 1 and 2, it is observed that a cementitious material dosage of 520 kg/m³ is more reasonable. When increased to 550 kg/m³, the concrete's passability improves, but it becomes excessively viscous, leading to rapid drying and significant slump loss over time. Considering cost factors, the subsequent mix design sets the cementitious material dosage at 520 kg/m³.

Comparing trials 1, 3, 4, 5, 6, 7, 8, 9, and 10, it is observed that higher sand ratios correspond to better workability. The peak performance is achieved at a sand ratio of 52%. However, when the sand ratio reaches 54%, workability rapidly declines, accompanied by reduced cohesiveness. Therefore, the sand ratio is selected as 52%. The results are illustrated in Fig. 1.

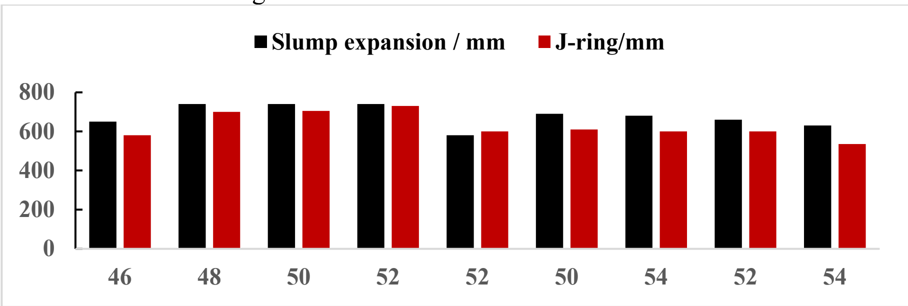

Fig. 2. The Influence of Sand Ratio Content on Workability

Comparing trials 5, 6, 9, 12, and 14, it is observed that as the limestone powder content increases, from 5% to 10%, the workability improves. However, as the content further increases from 10% to 15%, the workability deteriorates, resulting in excessively viscous concrete mixtures. The results are depicted in Fig. 2.

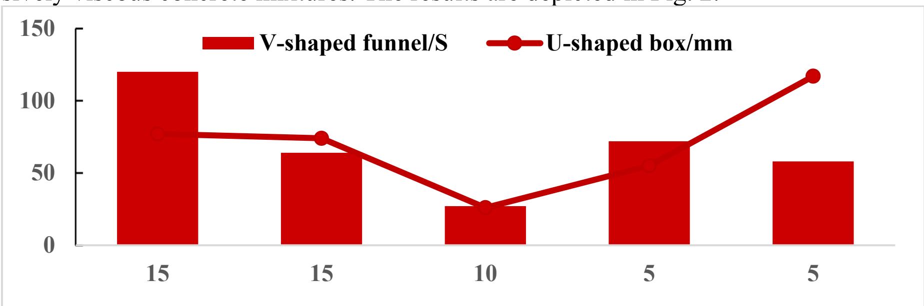

Fig. 3. The Influence of Limestone Powder Content on Workability

Comparing trials 6, 9, 11, 13, 15, 16, and 17, it is observed that as the fly ash content increases from low to high, the workability of the concrete improves, reaching its peak at 35%. However, some indicators start to decline slightly, accompanied by minor bleeding, and there is fluctuation in various properties. Therefore, the fly ash content is selected to be between 30% and 35%. The results are illustrated in Fig. 3.

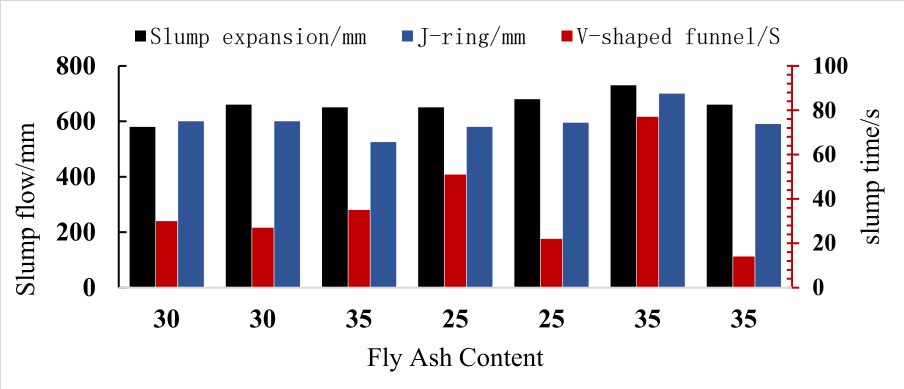

Fig. 4. The Influence of Fly Ash Content on Workability

From Fig. 4 shown, based on the results of the mix proportion experiment, Trial No. 17 is tentatively selected as the reference mix proportion for the construction mix design used in tunnel lining casting on-site. Performance testing is conducted at the casting site, yielding the following results: T_{500} of 4 seconds, slump flow of 630mm, J-ring flow of 565mm, V-funnel time of 15 seconds, U-box spread of 30mm, L-box height H1 of 93mm, H_2 of 76mm, and H_2/H_1 ratio of 0.81. Samples are taken for standard compressive strength testing at 28 days, resulting in a compressive strength of 45.7 MPa, meeting all requirements. The slight decrease in performance compared to laboratory mixing is attributed to time factors; from completion of concrete mixing to casting, it takes 30 minutes, and casting begins after 45 minutes, leading to rapid loss of concrete flowability due to a higher content of cementitious materials. The casting process proceeds smoothly, with the concrete self-leveling without the need for vibration, significantly improving casting efficiency. Although there is more bleeding compared to ordinary concrete, the appearance after formwork removal is satisfactory, and the rebound strength measured after 28 days is 43.3 MPa.

Self-compacting concrete needs precise mold setup and robust pressure and support systems. It reduces worker errors and improves casting efficiency. The concrete has great flowing and filling abilities, preventing issues like honeycombing and providing a smooth surface. It's a great choice for both performance and ease of use.

4 Conclusion

Self-compacting concrete requires higher workability compared to conventional concrete due to the absence of vibration during placement. Therefore, the mix design must comprehensively consider the characteristics of materials and gradation. Various factors can have both favorable and unfavorable effects on the mix design. When other factors remain relatively constant, exceeding the peak value of a certain parameter can lead to a decrease in the workability of the concrete.

C35 self-compacting concrete with manufactured sand was developed using a mix design consisting of 520 kg/m^3 of cementitious materials, 52% sand ratio, 35% fly ash content, 10% limestone powder content, and 1.0% admixture dosage. The workability meets the requirements, but due to high cement content, slump loss over time is significant and the superplasticizer experiences rapid loss of slump within 1 hour. Therefore, measures should be taken during transportation to maintain slump and casting should be done promptly.

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