Computers and Concrete, *Vol. 17, No. 6 (2016) 787-799*
DOI: http://dx.doi.org/10.12989/cac.2016.17.6.787

A study of the fresh properties of Recycled ready-mixed soil materials (RRMSM)

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(Received August 12, 2015, Revised December 23, 2015, Accepted March 15, 2016)

Abstract. Climate anomalies in recent years, numerous natural disasters caused by landslides and a large amount of entrained sands and stones in Taiwan have created significant disasters and greater difficulties in subsequent reconstruction. How to respond to these problems efficaciously is an important issue. In this study, the sands and stones were doped with recycled materials (waste LCD glass sand, slag powder), and material was mixed for recycled ready-mixed soil. The study is based on security and economic principles, using flowability test to determine the water-binder ratio (W/B=2.4, 2.6, and 2.8), a fixed soil: sand ratio of 6:4 and a soil: sand: glass ratio of 6:2:2 as fine aggregate. Slag (at concentrations of 0%, 20%, and 40%) replaced the cement. The following tests were conducted: flowability, initial setting time, unit weight, drop-weight and compressive strength. The results show that the slump values are 220 -290 mm, the slump flow values are 460 -1030 mm, and the tube flow values are 240-590 mm, all conforming to the objectives of the design. The initial setting times are 945-1695 min. The unit weight deviations are 0.1-0.6%. The three groups of mixtures conform to the specification, being below 7.6 cm in the drop-weight test. In the compressive strength test, the water-binder ratios for 2.4 are optimal (13.78-17.84 kgf/cm^2). The results show that Recycled ready-mixed soil materials (RRMSM) possesses excellent flowability. The other properties, applied to backfill engineering, can effectively save costs and are conducive to environmental protection.

Keywords: Recycled Ready-Mixed Soil Materials (RRMSM); waste LCD glass sand; waste-to-resource

1. Introduction

Backfilling is an important step during the construction process. The quality of backfilling affects the safety of engineering facilities both indirectly and directly. Due to the impact of many subjective and objective factors, backfilling cannot be effectively implemented and compacted in Taiwan. Moreover, riverbed sand resources are dwindling in Taiwan and the supply of good quality sand resources cannot meet the market demand, causing difficulty in controlling the quality of backfilling. Moreover, many earthworks produced by the excavation of large-scale construction projects and numerous natural disasters must be disposed of. Therefore, deciding how to

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http://www.techno-press.org/?journal=cac&subpage=8 ISSN: 1598-8198 (Print), 1598-818X (Online)

effectively control waste production, dispose of the waste properly, provide sufficient resources to meet the sandstone demand and solve the problem of poor quality backfilling materials are urgent issues (Tong 2007).

Conventional concrete is not the only option in modern construction. In response to a variety of demands, concretes of various properties have been developed (Nataraja and Nalanda 2008). CLSM (Controlled-Low Strength Materials) is an emerging backfilling material (Naik *et al*. 2001, Naik *et al*. 2003, Katz and Kovler 2004) that is designed to meet special needs, and it has the advantages of high density, self-flowability and low strength (Pierce and Blackwell 2003, Pierce *et al*. 2003). CLSM differs from conventional concretes because it uses a large amount of fine aggregates and its W/B ratio, within the range of 1.1-1.5, is far higher than that of conventional concrete, at 0.4-0.55 (Naik *et al*. 2006). According to the definition of ACI, the compressive strength of 28-day aged CLSM is lower than 8.3 MPa, and the design strength of general CLSM is lower than 1.4 MPa (American Concrete Institute 1999, Naganathan *et al*. 2012). For future re-excavation. CLSM is mainly used as a substitute material for backfilling compaction, and it can be automatically filled without any additional compaction device. Using the setting characteristics of the concrete materials, the base layer load-bearing requirements can be met, thus solving the problems faced in many backfilling projects (Rafat 2009). At present, CLSM is mainly used in backfilling, structural filling, conduit bedding, erosion control and void filling (Mejeoumov *et al*. 2010, Razak *et al*. 2009, Achtemichuk *et al*. 2009). Many previous studies have proposed to use of industrial byproducts such as hearthstone, fly ash, waste foundry sand, waste tires, cement kiln dust, and desulfurization slag in CLSM to address the problem of industrial wastes, to enhance certain properties of the material and to ensure the original engineering properties (Siddique 2009, Tikalsky *et al*. 2004, Turkel 2006, Turkel 2007, Lachemi, *et al*. 2007).

RMSM (Ready-Mixed Soil Material) uses earthworks to replace conventional river sand. RMSM is a new type of soil material with properties between those of CLSM (Controlled Low-Strength Material) and soil cement (Chen *et al*. 2003).

Taiwan's TFT-LCD panel manufacturing accounts for 43% of the global output, ranking top in the world (Tseng 2009). With rapid industrial development, many industrial wastes have been produced. The processing of waste glass produced in the TFT-LCD industry by landfill violates the principle of sustainable use of resources and has adverse impacts on the environmental protection image of the industry (Wang and Huang 2010, Wang and Chen 2008). Considering the slowdown of the exploitation of natural resources, the increasing awareness of the need for environmental protection and sustainable development (Terro 2006, Rahal 2005), and the excessively high cost of processing waste glass or other renewable aggregates in the past 10 years (Khatib 2005, Lee *et al*. 2005), it is important to consider a feasible method of waste-to-resource conversion using ground waste glass in concrete as the aggregate (Tu *et al*. 2006, Topcu and Canbaz 2004).

2. Test planning

2.1 Test materials

This study used a Type I brand cement with properties that meet the specifications of ASTM C150. The slag powder was the water-quenched high-grade slag powder produced by the CHC Resources Corp. With properties meeting the CNS 12549 specifications, the glass sand used in this

Table 1 physical properties of fine aggregate

Properties	Sand	LCD glass	Properties	Soil
Specific Gravity	2.63	2.42	-	2.74
Water Absorption (%)	1.47	0.45	OMC	13.7
Maximum size(in)	-	11.8	LL	16.4
Finesse Modulus (FM)	2.69	3.37	PL	11.9
Dry-rodded unit weight (kg/m^3)	1790	1680	PI	3.7

*OMC= Optimum Moisture Content, LL= Liquid Limit, PL=Plastic Limit, PI= Plastic Index

Table 2 the physical and chemical properties of cement, slag powder, and glass

Materials	cement	slag	LCD glass
Physical properties			
Specific gravity	3.15	2.89	2.45
Specific area(m^2/kg)	353	444	346
Chemical contents (%)			
SiO_2	20.22	33.79	64.28
Al_2O_3	4.96	13.59	16.67
Fe_2O_3	2.83	0.36	9.41
Ca0	64.51	41.33	2.70
MgO	2.33	7.26	-
SO_3	2.46	0.1	-
Alkalis	0.48	-	-
K_2O	-	-	0.20
Na_2O	-	-	0.64
TiO_2	-	-	0.01
P_2O_5	-	-	0.01
LOI	2.4	1.1	-

study was industrial waste LCD glass produced by high-tech electronic panel manufacturers after material quality control and classification processing. The fine aggregates, which met the specifications of ASTM C33, were taken from river sand in the Ligang region. The soil was waste soil excavated from construction sites. This study conducted basic soil property experiments, including soil classification and density experiments, the soil Proctor compaction test, and water absorption rate and sift analysis. Table 1 illustrates the basic properties of the fine aggregates. The mixing water meets the specifications of ASTM C1602. Table 2 illustrates the physical and chemical properties of the cement, hearthstone and the waste LCD glass sand.

2.2 Test variables and mix proportion

This study applied glass sand and slag powder in RRMSM with hearthstone content proportions of 0%, 20% and 40% to replace the general cement and soil to replace the coarse

Table 3 Mixture proportions of RRMSM (Unit: kg/m^3)

Number		W/B	Cement	Slag	Water	Soil	Sand	Glass sand	Total weight
W24	0	2.4	150	-	360	941	602	-	2053
	20		120	30	360	940	601	-	2051
	40		90	60	360	938	600	-	2048
W26	0	2.6	150	-	390	892	571	-	2003
	20		120	30	390	890	570	-	2000
	40		90	60	390	889	569	-	1998
W28	0	2.8	150	-	420	842	539	-	1951
	20		120	30	420	841	538	-	1949
	40		90	60	420	840	537	-	1947
WG24	0	2.4	150	-	360	941	301	277	2029
	20		120	30	360	940	301	277	2028
	40		90	60	360	938	300	276	2024
WG26	0	2.6	150	-	390	892	285	263	1980
	20		120	30	390	890	285	262	1978
	40		90	60	390	889	284	262	1975
WG28	0	2.8	150	-	420	842	270	248	1930
	20		120	30	420	841	269	248	1928
	40		90	60	420	840	269	247	1926

aggregates. The sand/soil ratio was 4:6, and the ratio with the addition of glass sand was 2(glass):2(sand):6(soil). After a few pilot mixing adjustments, this study explored the fresh properties of concretes as shown in Table 3. The amount of cement was 150 kg/m^3; the W/B ratio was 2.4, 2.6, and 2.8; and the design workability was slump greater than 200 mm, slump flow greater than 400 mm and tube flow greater than 150 mm).

2.3 Testing items

The tests of fresh properties included the tests of slump (ASTM C143), slump flow and tube flow (ASTM D6103), the cumulative total secretion of water (ASTM C232), unit weight (ASTM D6023) and initial setting time (ASTM C403). In addition, this study produced concrete cylindrical specimens of ψ10 cm×20 cm to conduct compressive strength (ASTM C39) and drop-weight (ASTM D6024) tests of one-day-aged concrete.

3. Results and analysis

3.1 Properties of materials

As shown in Table 2, the major ingredients of the cement include SiO_2, Al_2O_3, Fe_2O_3, CaO and

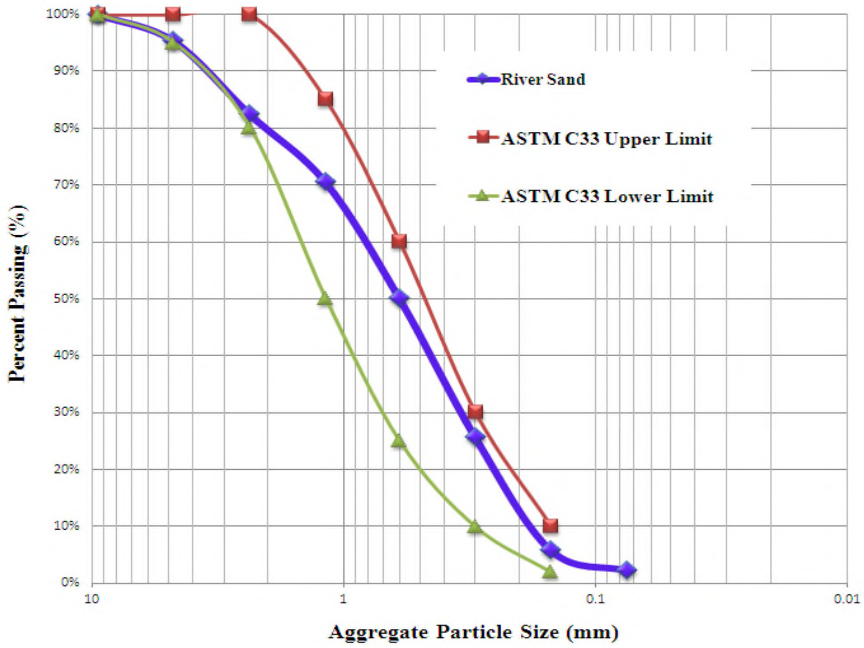

Fig. 1 River sand's particle size distribution

Table 4 Fresh proportions of RRMSM

Number		Slump (mm)	Slump Flow (mm)	Tube Flow (mm)	Unit Weight (kg/m^3)	Setting Time (mins)
W24	0	220	460	240	2062	945
	20	270	840	290	1956	1016
	40	270	850	300	1988	1043
W26	0	280	800	250	2002	1098
	20	290	890	500	1949	1138
	40	280	920	480	1969	1206
W28	0	290	830	340	2039	1261
	20	290	920	560	1943	1389
	40	290	960	590	1978	1411
WG24	0	270	700	250	1993	987
	20	270	900	320	2024	1041
	40	260	890	300	1939	1056
WG26	0	290	830	280	1995	1379
	20	280	930	400	2031	1488
	40	280	930	440	1926	1527
WG28	0	290	890	380	1996	1695
	20	290	1010	480	2036	1841
	40	290	1030	550	1916	1966

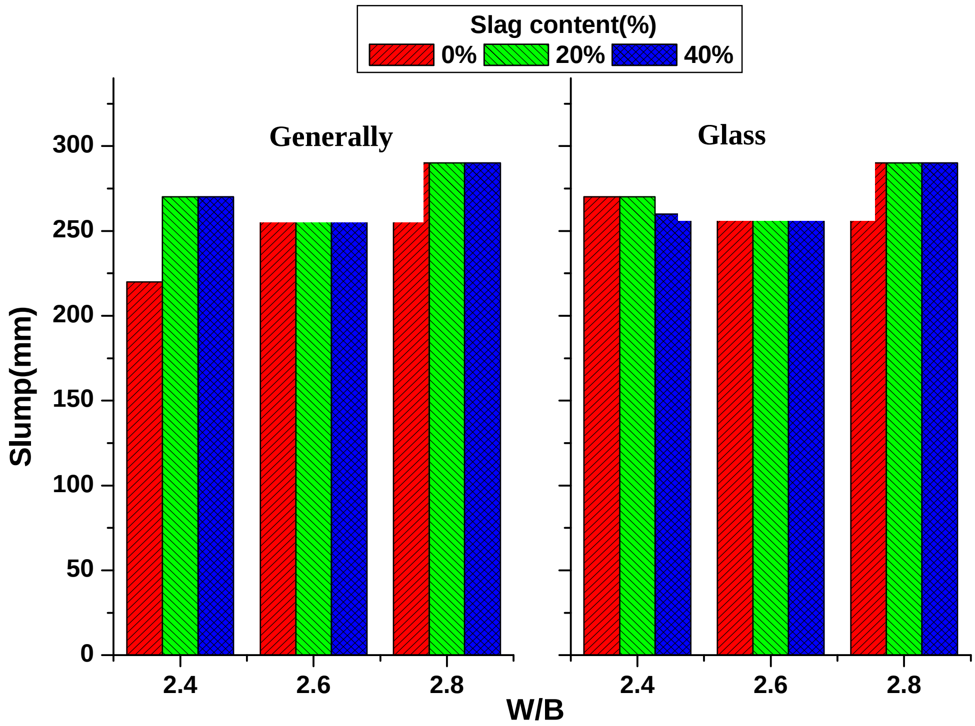

Fig. 2 Slump of RRMSM

MgO; the major ingredients of the slag powder are CaO and SiO_2, with the CaO content being relatively higher (greater than 40%). The glass sand is the waste LCD glass sand after the #8 sifts screening (2.38 mm) provided by CMO Corp. The surface of the waste LCD glass sand is smooth with edges and corners. The FM. of the waste LCD glass sand is 3.46, and its surface dry saturated density is 2.45. Regarding the chemical composition, the content of SiO_2 is highest at 62.48%, followed by other chemical ingredients in the order of Al_2O_3, Fe_2O_3, CaO, Na_2O and K_2O. The contents of Na_2O and K_2O are 0.64% and 0.20%, respectively. The TCLP is far lower than legal statutory principles. Therefore, the industrial waste meets the certification standards. Table 1 illustrates the basic properties of the dam's river sand and the waste soil. Fig.1 shows the distribution of the river sand particle sizes.

3.2 Slump

According to Table 4 and Fig. 2, the RRMSM slump value is within the range of 220-290 mm, and the slump value with the addition of glass sand is within the range of 270-290 mm, which meets the design objectives (greater than 200 mm). After the addition of glass sand, the slump slightly increases (10-50 mm), and when the W/B ratio increases, the slump value increases by 10-

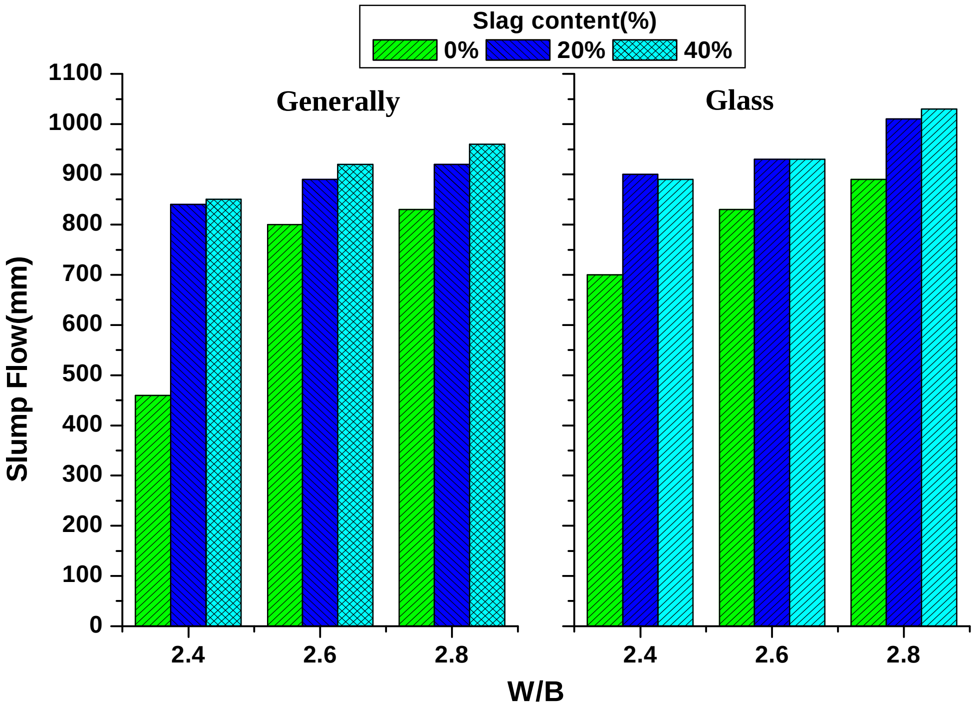

Fig. 3 Slump flow of RRMSM

70 mm; however, the slump value has no significant difference when the hearthstone replacement increases.

3.3 Slump flow

As shown in Table 4 and Fig. 3, the slump flow value of RRMSM is within the range of 460-960 mm, and it increases after the addition of glass sand (700-1030 mm), thus satisfying the design goals (greater than 400 mm). The waste glass sand consists of slab-like particles having irregular shapes with edges and corners. The impact of mutual friction between particles will result in impaired flowability when adding the glass sand. However, due to the water absorption difficulty, more water can be secreted to improve the slump flow. With the addition of slag power, the hydrophobic characteristics can improve slump flow by approximately 40% (90-390 mm).

3.4 Tube flow

According to Table 4 and Fig. 4, the RRMSM tube flow is within the range of 240-590 mm. After the addition of slag powder, the tube flow is within the range of 250-550 mm. The design goals are satisfied in both cases (greater than 150 mm). When the hearthstone replacement is 40%, the tube flow improves by 60-250 mm.

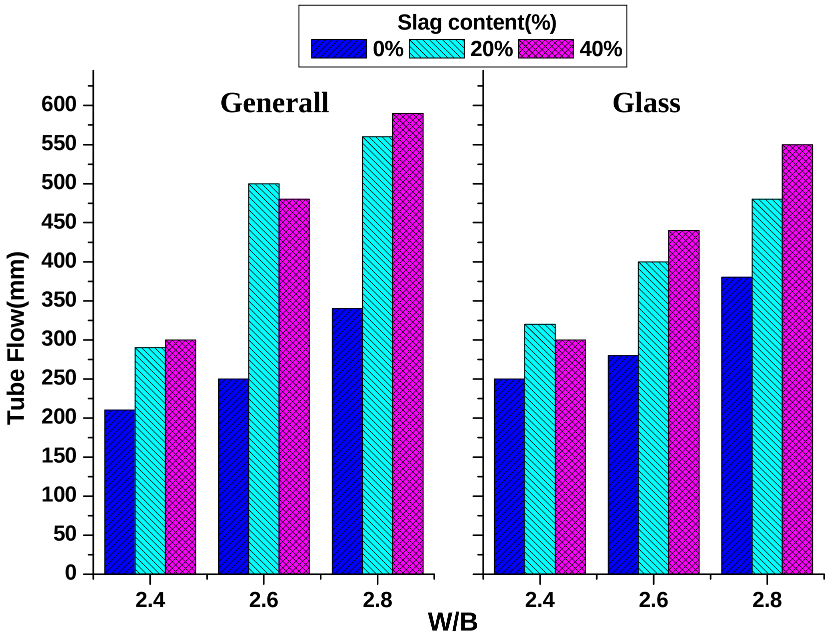

Fig. 4 Modified tube flow of RRMSM

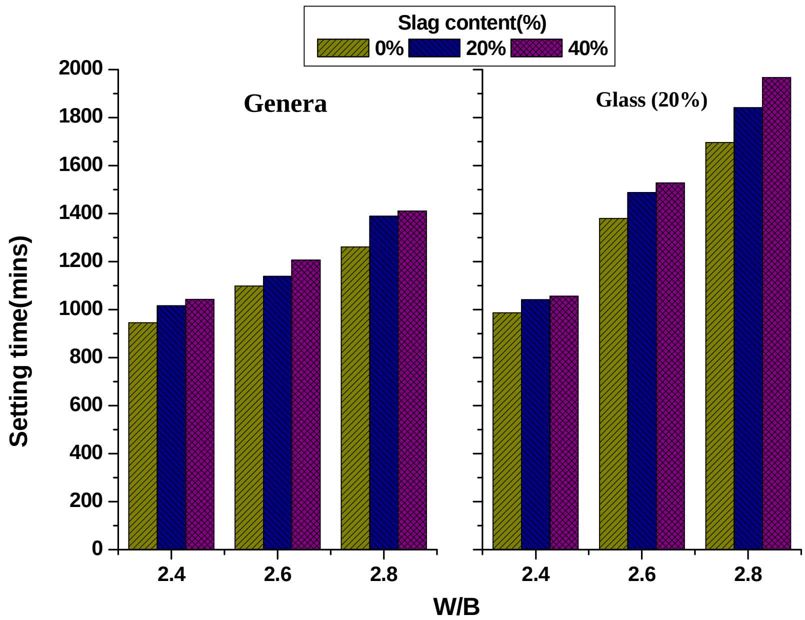

Fig. 5 Initial setting time of RRMSM

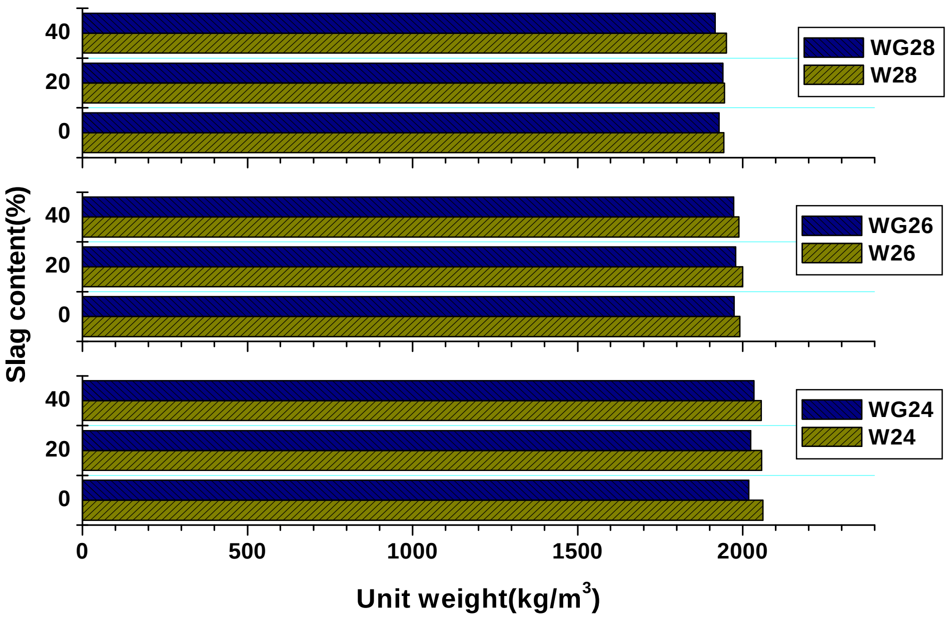

Fig. 6 Relationships of RRMSM's hearthstone replacement and unit weight

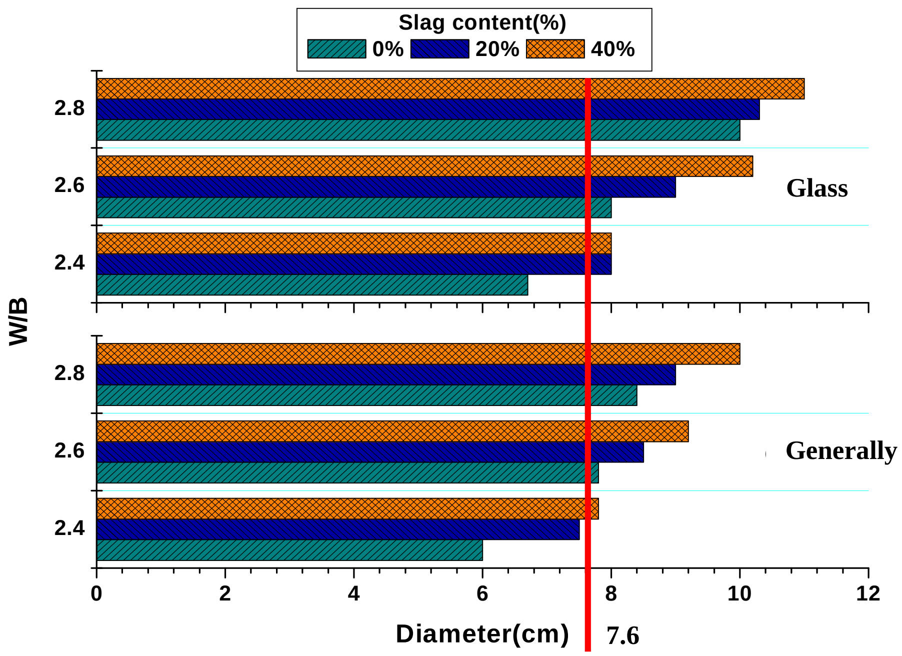

Fig. 7 Drop-weight value of RRMSM

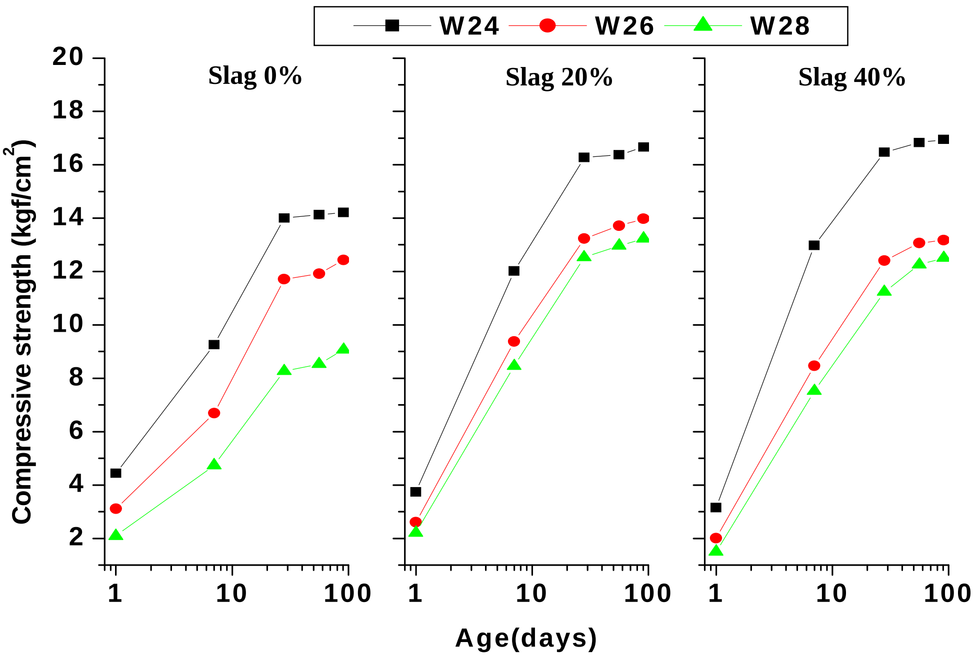

Fig. 8 Compressive strength of RRMSM

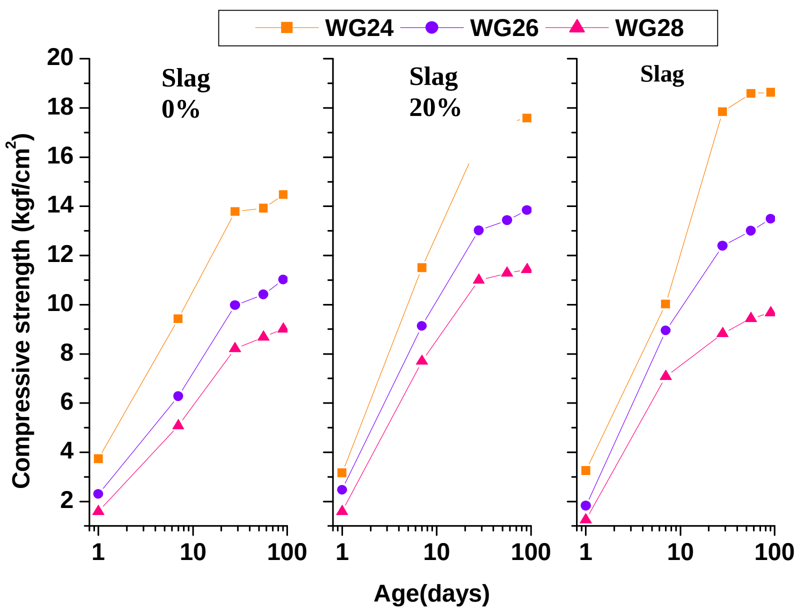

Fig. 9 The developmental trends of the compressive strength of RRMSM with 20% glass sand

3.5 Initial setting time

According to Table 4 and Fig. 5, the RRMSM initial setting time is within the range of 945-1966 min. The setting time will be prolonged with a rising W/B ratio and with the amount of slag powder replacement. When the W/B ratio is 2.4, the setting time of the hearthstone replacement at 0% and 40% is 945 min and 1043 min, respectively. In addition, the RRMSM with the addition of glass sand will delay the setting time.

3.6 Unit weight

As shown in Table 4 and Fig. 6, the unit weights of RRMSMs for the three W/B ratios are close. At the same W/B ratio, the unit weight will be lower without a great difference when the content level of hearthstone is higher.

3.7 Drop-weight test

As shown in Fig. 7, the three groups of RRMSM compositions meet the drop-weight value in the ASTM D6024-96 specifications (1 day less than 7.6 cm), and the produced crack is smaller than 0.3 cm without water in the dent. The three groups of mixtures are as follows: when the W/B ratio is at 2.4, the hearthstone replacement is 0 and 20% (the drop-weight values are 6 cm and 7.5 cm, respectively); when the glass sand control group of the W/B ratio is at 2.4, the hearthstone replacement is at 0% (the drop-weight value is 6.7 cm). The drop-weight value increases after adding the glass sand or increasing the hearthstone replacement.

3.8 Compressive Strength

As shown in Fig. 8 and Fig. 9, the RRMSM compressive strength increases with age and reduced W/B ratio. When the hearthstone replacement is 20%, the compressive strength is relatively higher. When the W/B ratios are 2.4, 2.6 and 2.8, the RRMSM compressive strength is 13.78-17.84 kgf/cm^2, 9.98-13.24 kgf/cm^2 and 8.21-12.53 kgf/cm^2, respectively. The effectiveness in the improvement of the compressive strength is ranked by W/B ratio of 2.8, 2.6 and 2.4.

4. Conclusions

1. The RRMSM slump values within the range of 220-290 mm, the slump flow values within the range of 460-1030 mm, and the modified slump flows within the range of 240-590 mm all meet the design goals, suggesting good workability. RRMSM can effectively save time and labor costs when applied in backfilling projects.

2. The setting time will be prolonged by a greater W/B ratio and increased hearthstone replacement. The setting time will increase by 30-40% after adding the glass sand and increasing the W/B ratio.

3. The RRMSM unit weights show no significant differences.

4. RRMSM's compressive strength is relatively higher when the W/B ratio is 2.4. The result is better when the hearthstone replacement is 20% than 40%. In the drop-weight test, the three

groups of concretes meet the drop-weight value of the specifications (1 day less than 7.6 cm).

5. The recycled RRMSM has a high potential for re-excavation and can be reused, making it cost-effective, beneficial to environmental protection, and with considerable potential for development.

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ASTM C150, American Society for Testing and Materials, Standard Specification for Portland cement.

ASTM C1602, Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.

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