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A study of the replacement of desulphurization slag for sand to ready-mixed soil materials (RMSM)

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Abstract. After the industrial of steelmaking by-products are processed properly, they can be used in civil engineering, not only as a substitute for natural resources and to reduce costs, but also to provide environmental protection. This study used different amounts (10%, 20%, 30%, 40%,and 50%) of desulphurization slag to replace natural fine aggregates in ready-mixed soil materials, and tested the physical and fresh properties (slump, slump flow, tube flow, initial setting time, and bleeding) and hardened properties (compressive strength, ball drop, ultrasonic pulse velocity) of the materials. The variations between the performances of the materials with different mix proportions were discussed. When desulphurization slag is used in RMSM, the workability can be enhanced obviously significantly. When the replacement of desulphurization slag is 50%, the slump flow is increased by 110mm compared with the control group, and the initial setting time increases as the replacement increases, because of bleeding. When the replacement is 10% and 20%, the compressive strength at various ages is higher than that of the control group. When the replacement is 10%, the compressive strength at 7 days is higher than that of the control group by 60%, and the ultrasonic pulse velocity is proportional to the compressive strength, which increases with age and decrease as the replacement increases. An appropriate replacement can effectively accelerate construction, and allow projects to be finished ahead of schedule; therefore, an appropriate replacement, is applicable for ready-mixed soil materials.

Keywords: industrial by-products; steelmaking slag; desulphurization slag; ready-mixed soil materials (RMSM).

1. Introduction

Environmental protection and sustainable development have received significant attention around the world in recent years. It is important to properly dispose industrial by-products, and effectively turn them into green materials. This study evaluated the feasibility of mixing steelmaking slag into ready-mixed soil materials, to explore its effects on engineering properties and to apply the new materials in engineering projects.

With technological advancements, communication and power wires, cables, natural gas transportation pipelines, and drain and sewer pipes are excessively used. Because these works are completed underground, road excavation and backfill construction operation are unavoidable,

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which often damages road pavement and affects traffic. Some backfilled roads often have cracks, or even collapse, due to the applicability of materials and the uncertain compaction after backfill. In some advanced countries, such as Japan, the U.S. and European countries, a new type of cement material has been used to replace traditional backfill material, called controlled low strength material (CLSM) (Zheng 2002). CLSM has a compressive strength of lower than 8.3 MPa, which is slightly higher than that of well-compacted soil (Wu 2009). CLSM is convenient to deliver, and possesses a self-leveling capacity. This material can reduce the labor for construction, and equipment cost, and it is more suitable for narrow spaces compared to conventional compacting backfills (Taha *et al.* 2007). Alternatively, guidelines derived from experience or trial and error (Bouzalakos *et al.* 2013) are usually employed. In this sense, Blanco *et al.* (2014) experimentally obtained the optimal CLSM mixture specifically for narrow trenches based on a deterministic procedure.

One drawbacks of CLSM is that its late strength is too high; thus, it is difficult to excavate again and consumes many coarse and fine aggregates. In addition, it has a very low strength requirement in comparison with normal concrete. If future re-excavation is desired for maintenance purposes, the long-term strength should be lower than 1.4 MPa (Lachemi *et al.* 2008). Consequently, a number of non-standard materials, of which the physical and chemical properties vary highly, have been successfully employed for making flowable fills. In previous research, industrial wastes and recycled materials have been considered as promising cement substitutes, such as blast furnace slag, cement kiln dust (Trejo *et al.* 2004) and fly ash. In response to global scarcity of resources, and considering the reuse of waste soil after excavation, the emerging backfill material-ready-mixed soil materials (RMSM) were developed. RMSM maintain the auto-flowability and self-comp actability of CLSM, solving problems associated with difficult excavation due to too high late strength and recycling resources. The recycled soil replaces excavated sandstone (coarse and fine aggregates) to reduce the consumption of natural sandstone resources and to solve the handling problem of waste soil after excavation, not only reducing the impact on environmental pollution, but also attaining the goals for resource economization and sustainable operation (Chen *et al.* 2012). Chen and Chang, (Chen *et al.*2006) developed a CLSM with fine ingredients that was, normalized from three primary soils, and indicated that the later-strength gain after 28 days could be limited and controllable, which is a key benefit for excavatable CLSM. With regards to soil type, ACI 229 (2005) indicates that fine clay soil have exhibited problems with incomplete mixing, and stickiness of the mixtures, and are unsuitable for CLSM applications. However, a previous study (Wu 2005) found that silly sand with less than 30% fine content (passing No. 200 sieve) and non-plastic soil (plastic index not in excess of 3.0), without organic impurities, could be considered for CLSM production. Finney *et al.* and Wu and Lee (Wu 2011) reported that on-site clay soil or reservoir salutation could be acceptable for the production of CLSM with careful mix design. The use of residual soil after excavation aims to provide great benefits in reducing the cost of the project and overcoming the shortage of natural resources (Green 1999).

Desulphurization slag comes from integrated steel plants using iron sand as the main raw material and is a byproduct of blast furnace molten iron desulfurized by a desulfurizer. The annual output of desulfurized slag in Taiwan is approximately 340,000MT (Chen 2004) EPA. Because desulphurization slag is a product of high melt, it is resistant to high temperature, free from climate change, and free of organic matter, polychlorinated biphenyl, peroxide, cyanide, inflammables and halogen solvent. It has little heavy metal leaching and high safety, and its pH value ranges from 11.8-12.2. Therefore, when it is treated properly, its properties are applicable for fertilizer, road

Table 1 Physical properties of materials

N.O. Material	Specific gravity	Unit weight (kg/m^3)	Water absorption (%)	Fineness modulus
Soil	2.68	1818 (Maximum unit weight)	10.3 (Optimum water content)	1.94
Sand	2.632	1872	1.6	3.05
Desulfurization slag	2.38	1011	38	2.4

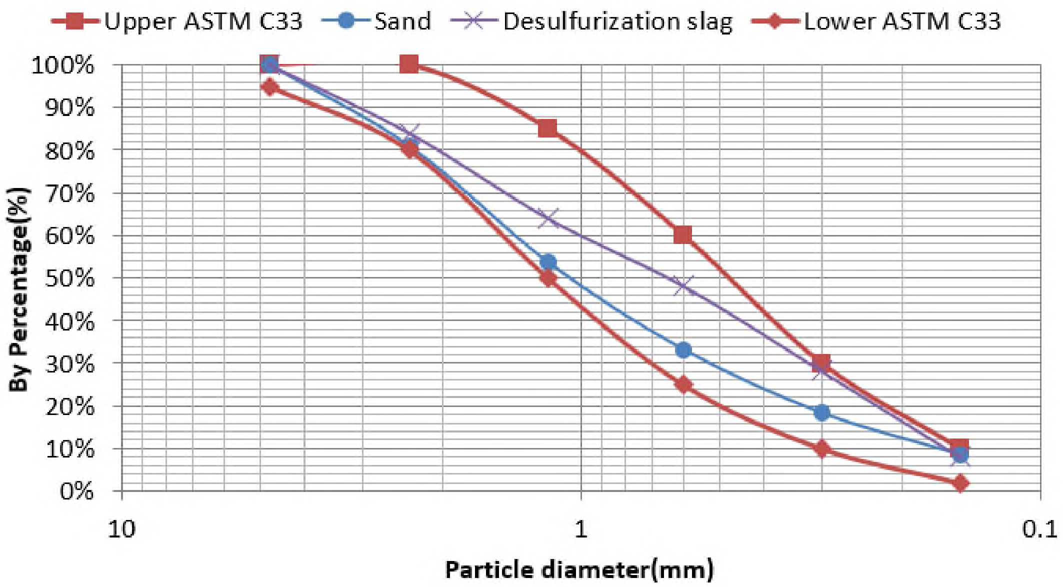

Fig. 1 Size distribution of natural fine aggregate and desulphurization slag

gradation, filling material, acid soil amendment, recovery by sintering plants or blast furnaces, as a cement raw material (Kuo *et al.* 2006).

2. Experimental programming

2.1 Test materials

This study used desulphurization slag treated by a crusher and sifted through a Screen mesh #4 sieves. The fineness was similar to that of a natural aggregate. The soil was from earthwork excavated in Phase I of the Kaohsiung City Light Rail Transit Project, and was classified by unified soil classification as poorly-graded sandy soil SP. The cement was Type I Portland cement produced by a cement company in Taiwan. The quality conformed to ASTM C150 specifications. The natural sandstone was tested by sieve analysis. The particle size distribution curve conformed to ASTM C33 specifications. The basic properties of the specific gravity and water absorption were tested, as shown in Table 1 and Fig. 1.

Table 2 Mixing proportions of RMSM Unit: kg/m^3

N.O.	DSS (%)	Binding Materials	Fine Aggregate		Soil	Water	W/B
		Cement	DSS	Sand			
RMSM	0	100	0	992	673	340	3.4
	10		89.71	892.92			
	20		179.43	793.71			
	30		269.14	694.49			
	40		358.84	595.28			
	50		448.55	496.07			

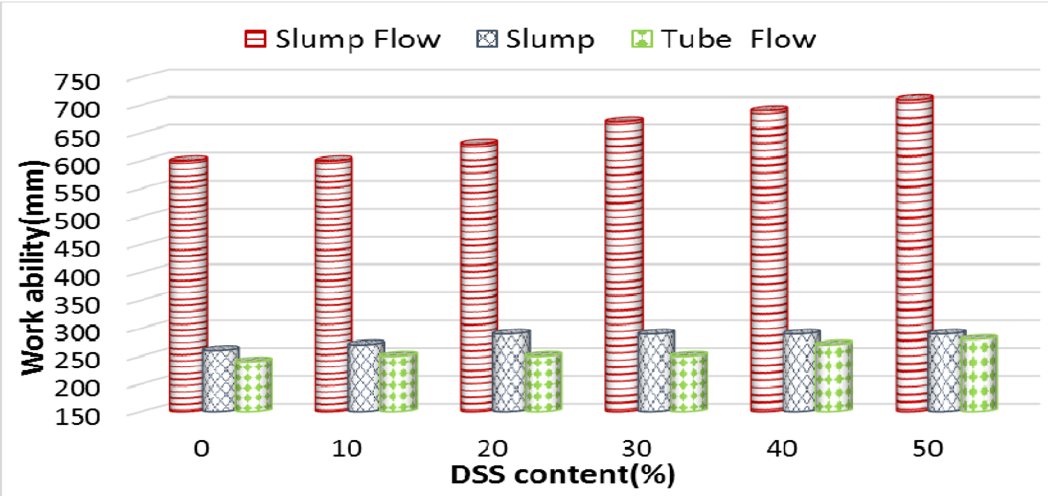

Fig. 2 Workability of RMSM with desulphurization slag replacement

2.2 Test mix proportions and variables

This study used the desulphurization slag derived from the integrated operation of steelmaking flow sheet, through #4 sieve-by-sieve analysis. The natural fine aggregate was replaced using the volumetric method (0%, 10%, 20%, 30%, 40%, and 50%) and made into ready-mixed soil materials (RMSM), after multiple trial mixes at different proportions. The W/B of the RMSM control group was 3.4, the sand-soil ratio was 6:4, and the cement content was fixed at 100 kg/m^3. The fresh properties (slump, slump flow, tube flow, initial setting time, and bleeding) were analyzed. The hardened properties (compressive strength, ultrasonic pulse velocity, and ball drop) were tested at ages of 1 day, 3 days, 28 days, 56 days and 91 days. The test mix proportions are shown in Table 2.

2.3 Test items and methods

Slump and slump flow were measured according to ASTM D6103 specifications. The tube flow was measured according to ASTM D6103-97 specifications. The initial setting time was measured according to ASTM C403 specifications. The bleeding was measured according to CNS

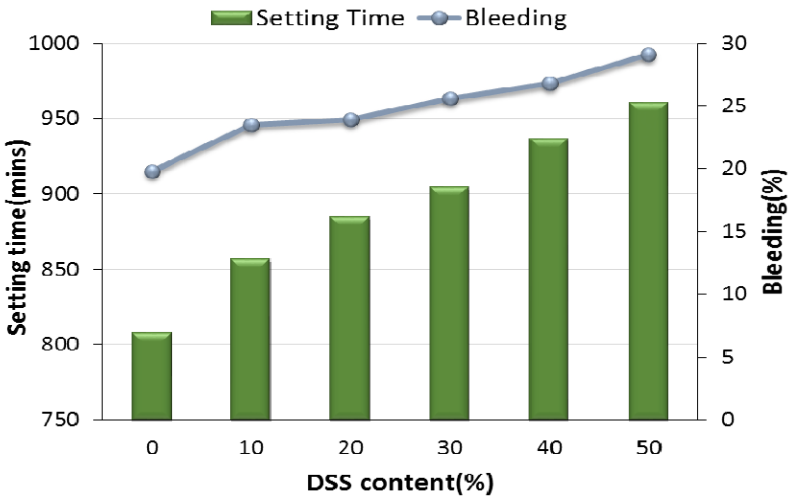

Fig. 1 Relationship between the RMSM setting time and bleeding

1235 specifications. The compressive strength was tested according to ASTM C39 specifications. The ball drop was measured according to ASTM D6024 specifications. The ultrasonic pulse velocity was measured according to ASTM C597 specifications.

3. Results and analysis

3.1 Slump

Fig. 2 shows that the slump of the RMSM control group replacing natural sand by desulphurization slag was 260 mm, that of the 10% replacement group was 270 mm, which was an increase of 3.8% compared with the control group. The slump of the replacement group above 20% was 290 mm. There was no apparent fluctuation in the slump, which increased by 11.5% compared with the slump of the control group. Because the soil and desulphurization slag aggregate had high water absorption, the slump of the RMSM increased under the effect of the desulphurization slag addition level. Therefore, the probability of aggregate segregation should be considered.

3.2 Slump flow

Fig. 2 shows that the slump flow of the control group was 600 mm. When the replacement was 10-50%, the slump flows were 600 mm, 630 mm, 670 mm, 690 mm and 710 mm, which represented increases of 5-18.3% compared with the control group. The slump flow of the replacement group was increased by 22 mm when the addition level was increased by 10%. When the desulphurization slag replacement reached 50%, the RMSM was 710 mm, which was an increase of 110 mm (18.3%) compared with the control group. This is because the particle size of the desulphurization slag aggregate and soil is small, contributing to the flowability of the aggregates; thus, the slump flow increases with desulphurization slag replacement.

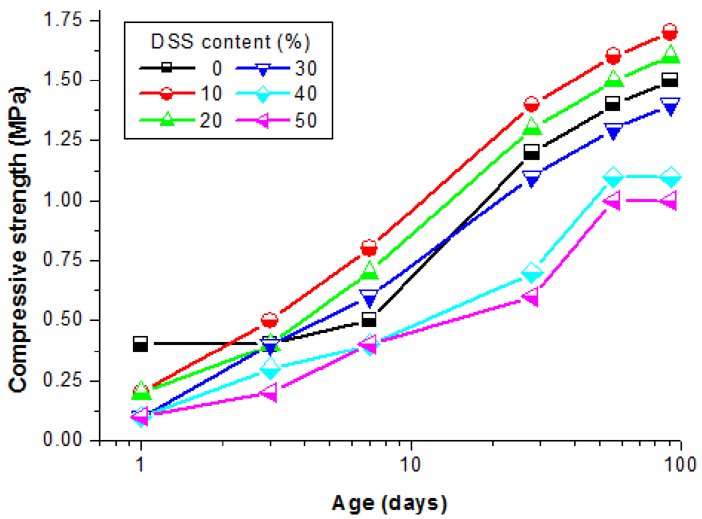

Fig. 2 Relationship between the age and compressive strength of RMSM

3.3 Tube flow

As shown in Fig. 2, the tube flow of RMSM in various mix proportions was 240 mm, 250 mm, 250 mm, 250 mm, 270 mm and 280 mm. When the replacement was 10-30%, the growth of tube flow was insignificant, and was increased by 10 mm (4.2%) compared with the control group. When the substitution value reached 50%, the tube flow was increased by 40 mm (16.7%). Thus, the tube flow increased gradually with the desulphurization slag replacement, showing good workability of RMSM.

3.4 Initial setting time

As shown in Fig. 3, the initial setting time of the RMSM control group was 808 min. The initial setting time was 857-961 min when the replacement was 10-50%, which was an increase of 1.1-1.2 times the control group. The initial setting time of the 10% desulphurization slag replacement group was 49 min longer than the group without replacement. When the replacement was 20-50%, the time was prolonged by only 25 min when the replacement was increased by 10%, which was shorter than the initial setting time of the 10% replacement and no replacement.

The initial setting time increased as the desulphurization slag replacement increased. Because the RMSM is a material with a high water-binder ratio, and the mixed aggregate reaches the saturated surface dry (SSD) state in advance, the water absorption of the desulphurization slag is 38%, which is higher than the fine aggregate (1.6%) by 23.8 times. Thus, the overall aggregate water content can be increased by increasing the desulphurization slag content, and the setting time is prolonged when the desulphurization slag replaces fine aggregate.

3.5 The bleeding

Fig. 3 shows that the measured bleeding of the RMSM control group was 19.8%, the bleeding

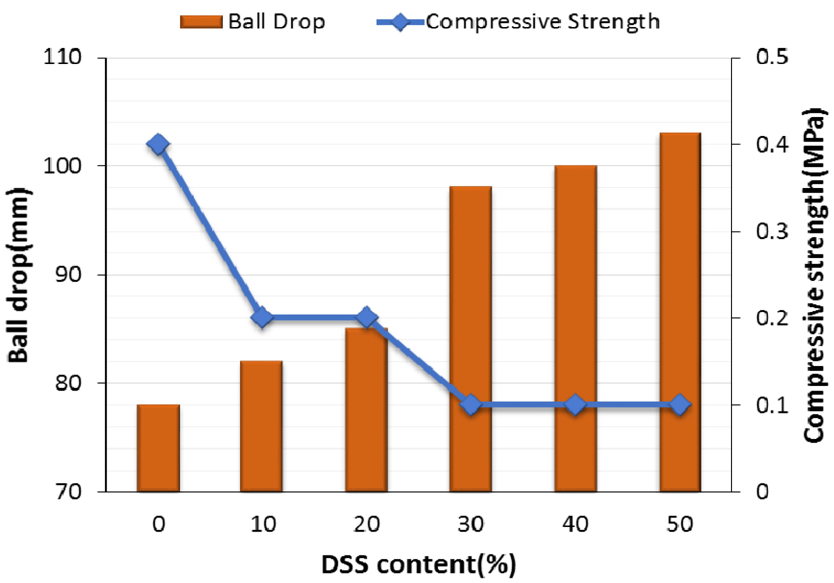

Fig. 3 Relationship between the ball drop and one-day compressive strength of various mixed proportion groups of RMSM

rate of 10- to 50% replacement groups was 23.5%, 23.9%, 25.6%, 26.8% and 29.1% respectively, which was an increase of 3.7-9.3% compared with the control group. The cumulative bleeding of 0% replacement was 96 ml; the range of the 10%~50% replacements was 114-141 ml, which was an increase of 18.8-46.9% compared with the control group. This suggests that the addition of desulphurization slag in the RMSM can increase the bleeding, responding to the result of the setting time. The bleeding of RMSM increases with the desulphurization slag replacement.

3.6 Compressive strength

Because the RMSM specimen is free of coarse aggregates, the compressive strength is lower than general concrete. Fig. 4 show that the 10% replacement had higher compressive strength than the control group. It was 0.2 MPa at one day, and then increased by 0.1-0.3 MPa. The highest compressive strength occurred at 7 days, which was an increase of 60% compared with the control group. The compressive strength of the 20% replacement was equivalent at 3 days, and which was higher than the control group by 0.1-0.2 MPa (6.7-40%) after 7 days. When the replacement was higher than 30%, the compressive strength decreased as the replacement of desulphurization slag increased.

The compressive strength increased with the age, and the compressive strength of the 10-50% replacements increased by 6-11 times. The low cement content limited the hydration; thus, the replacement a group was increased by only 1.2-1.7 times after 28 days.

The results showed that the compressive strength of RMSM decreased as the desulphurization slag replacement increased. When the replacement was 10% and 20%, the compressive strength was higher than that of the control group because the particle size of desulphurization slag is larger than soil, providing the material with higher strength, but when the replacement reaches a certain level, the value is the same as the control group.

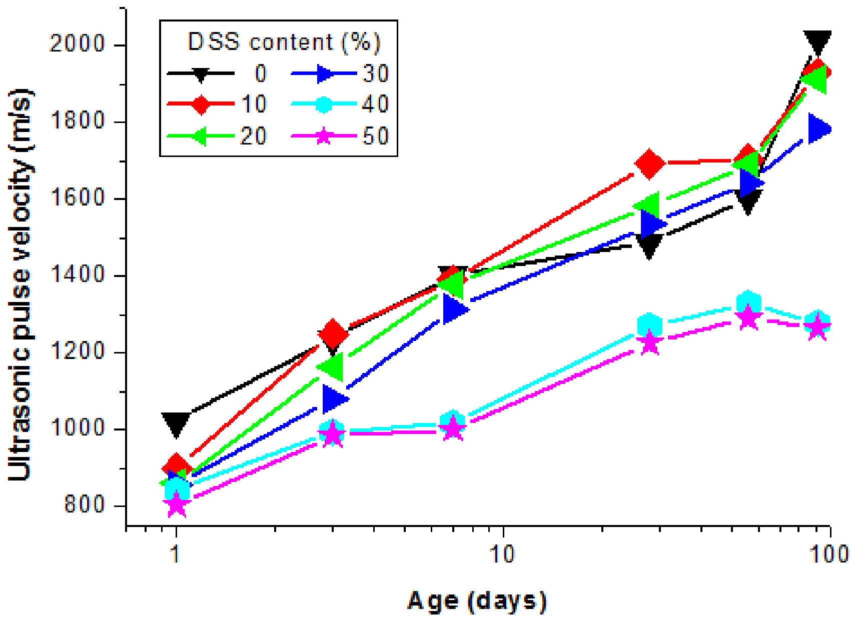

Fig. 6 Relationship between the age and ultrasonic pulse velocity of RMSM

3.7 Ball drop

As shown in Fig. 5, the value of the ball drop of the RMSM control group was 78 mm. This value was 82-103 mm when the replacement was 10-50%, which was an increase of 5.1-32.1% compared with the control group. The ball drop of the RMSM control group increased by 9% (7 mm) when the desulphurization slag replacement was 20%; and increased by 25.6% (20 mm) when the replacement was 30%, which was an increase of 16.6% (13 mm) as compared with the 20% replacement group. When the replacement was higher than 40%, the value of the ball drop increased by 28.2-32.1% (22-25 mm), indicating that the increased amplitude of the value of the ball drop between 20% and 30% is larger than the other replacements. The ball drop is correlated with compressive strength. The value of the ball drop of RMSM was inversely proportional to the one-day compressive strength. The compressive strength decreased as the replacement increased, and the bearing capacity decreased, thus the ball drop diameter increased.

3.8 Ultrasonic pulse velocity

Because the RMSM differs from general concrete material, its strength is lower due to the lack of coarse aggregate, and the wave velocity is lower. As shown in Fig. 6, the ultrasonic pulse velocity of the control group at various ages was 1023 m/s, 1237 m/s, 1403 m/s, 1488 m/s, 1601 m/s and 2018 m/s. At various ages, the ultrasonic pulse velocity of the 10-50% replacements was lower than the control group; but at 28 days, the velocity of the 10-30% replacements was increased by 3.1-13.8% compared with the control group. The velocity was reduced by 14.6-17.6% when the replacement was 40-50%.

The growth of control group was 31.2% from day 1 to day 28, and the growth of various

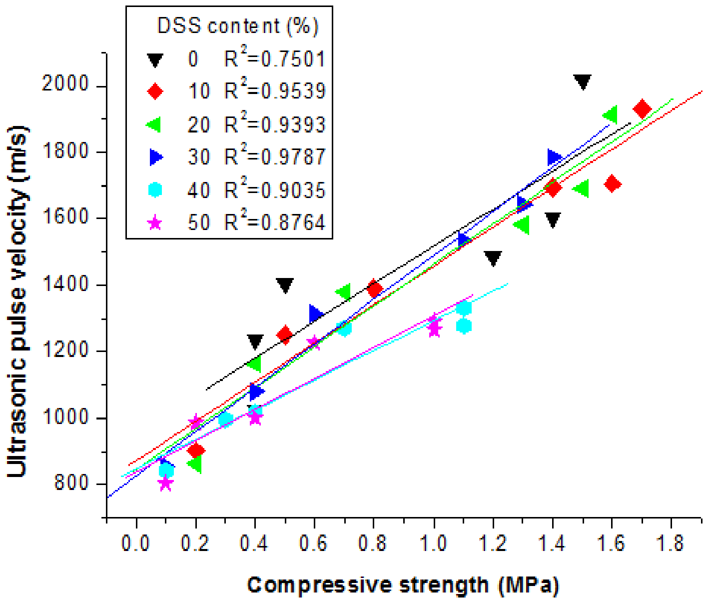

Fig. 7 Linear regression relationships between the compressive strength and ultrasonic pulse velocity of RMSM

replacement groups was 34.4-46.8%. From day 28 to day 91, the growth of the control group was 35.6%, and the growth of the 10-50% replacements was 0.6-20.9%.

The results showed that the growth of various replacement groups at early age was higher than at late age because when the desulphurization slag replaces fine aggregates in the RMSM, hydration is accelerated; thus, the specimen compactness and wave velocity increased. The growth was smooth at the late age, and the wave velocity decreased as the replacement increased.

Fig. 7 shows the linear regression of the compressive strength and ultrasonic pulse velocity. The regression line shortened gradually as the replacement increased, indicating that the compressive strength and ultrasonic pulse velocity were reduced. The R2 coefficient was higher than 0.7, indicating that the compressive strength is related to the ultrasonic pulse velocity.

4. Conclusions

• When desulphurization slag replaced 20% of fine aggregate, there was no apparent change in the slump. It was increased by 11.5% compared with the control group. The slump of RMSM was increased, but the probability of aggregate segregation should be considered.

• The slump flow was increased by 5-18.3% when the replacement was 10-50% and was increased by 110 mm when the replacement reached its maximum. The slump flow of various replacement groups was increased by 20-40 mm when the replacement was increased by 10%.

• The tube flow of the desulphurization slag replacements of 10-50% was increased by 4.2-16.7% compared with the control group, indicating that the workability of RMSM is good.

• When the replacement of desulphurization slag was 20-50%, the time was prolonged by only 20-32 min when the replacement was increased by 10%. The initial setting time was shorter than the 10% replacement group and the control group.

• The bleeding rate of the 10-50% replacements was increased by 3.7-9.3% compared with the control group, responding to the result of the setting time. The bleeding of RMSM increased with the replacement of desulphurization slag.

• The compressive strength of RMSM10 and RMSM20 was higher than the control group that of RMSM10 was increased by 0.1-0.3MPa after 3days, and that of RMSM 20 was increased by 0.1-0.2 MPa after 7 days.

• The compressive strength had the same trend, and the value of the ball drop was inversely proportional to the one-day compressive strength. The compressive strength decreased as the replacement increased, and the bearing capacity decreased accordingly; thus, the ball drop diameter increased.

• The ultrasonic pulse velocity of various replacement groups was increased by 34.4-46.8% before 28 days. The growth of various replacement groups was 0.6-20.9% at 28-91days. The growth of various replacement groups at an early age was larger than that at the late age because the replacement of fine aggregate with desulphurization slag in RMSM can accelerate hydration.

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