Computers and Concrete, *Vol. 21, No. 5 (2018) 531-538*
DOI: https://doi.org/10.12989/cac.2018.21.5.531

Study on engineering properties of ready-mixed soil and slag

Tung-Tsan Chen[1], Chun-Ling Ho[2] and Her-Yung Wang[*3]

[1]*Departments of Civil Engineering and Engineering Management, National Quemoy University, 892, Taiwan, R.O.C.*
[2]*Department of Information Management, Kao Yuan University of Applied Sciences, 821, Taiwan, R.O.C*
[3]*Department of Civil Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, 807, Taiwan, R.O.C.*

(Received April 11, 2017, Revised January 2, 2018, Accepted January 25, 2018)

Abstract. The slag through sieve #4 replaced the natural fine aggregate in different proportions (0-50%) to make ready-mixed soil and slag (RMSAS). The fresh properties studied, and the concrete specimens were produced to test the hardened properties at different ages. Results showed that the workability of RMSAS decreases when the replacement increases. The unit weight increases with the replacement. The setting time extends when the replacement decreases and shortens when the replacement increases. The compressive strength, ultrasonic pulse velocity and hammer rebound value increase with the replacement. However, the high-replacement results decrease because of the expansion factor at late age. Resistivity is close and less than 20 kΩ-cm. 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.

Keywords: Ready-Mixed Soil and Slag (RMSAS); engineering properties; compressive strength; expansion; resistivity

1. Introduction

In the era of metals, the world demand for steel continuously grows. In 2014, the global crude steel output exceeded 1.6 billion tons. The Top Five steel exporters are Mainland china, Japan, the European-27, Korea and Ukraine. Taiwan ranked 9th with over 10 million tons of export volume (Chen 2014). In 2013, Taiwan's crude steel output was 22 million MT, which accounted for 1.39% of the global output; the domestic content ratio was 88.8%, which was mostly used in Taiwan. The output of steel slag is 10-15% of steel output. Therefore, Taiwan annually produces approximately 2.5 million tons of steel slag, but the utilization rate of these byproducts is lower than those of advanced countries and the concepts of environmental protection and recycling are slightly insufficient (Lo 2013).

Steel slag is a notably ideal secondary resource; it can be extensively used in building materials, cement and roads. If steel slag is recycled, it can result in huge social and economic benefits provide powerful support to the green development and circular economy of the steel industry. Therefore, the in-depth exploration of steel slag to change wastes into valuables helps the steel industry and the downstream building and building material industries solve the metal-waste, environmental-pollution and land occupation issues that result from steel slag discarding and implement a win-win of economic and social benefits (Li 2014).

Controlled low-strength material (CLSM) is a cementitious material. In general, the definition of the mix proportions of CLSM is based on empirical approaches (Alizadeh *et al*. 2014) CLSM support the use of recycled or reused components from diverse origin such as recycled fine aggregates (Etxebarria *et al*. 2013), waste materials, industrial by-products (Lee *et al*. 2013). Typically, a compressive strength of less than 8.3 MPa is needed; it is greater than 2.0 MPa (Alizadeh *et al*. 2014). The controlled-low strength material is defined as a self-compacting, cementitious material, currently known by names such as flow able fill, plastic soil-cement or slurry material (Zhang and Le 2013). Blanco *et al*. (2014) experimentally obtained the optimal CLSM mixture specifically for narrow trenches based on a deterministic procedure.

This procedure is not theoretically justified and implies an iterative testing process. In recent years, Controlled Low Strength Materials (CLSMs) have often been used in underground pipeline backfill engineering to apply engineering properties to backfill materials, and many industrial by-products or wastes can be used in the CLSM. Thus, the probability of backfilling surplus earth of construction is considered (Chen 2012, Liao 2013). Utilization of excavated soil in coal ash-based controlled low strength material (CLSM) (Kim 2016). Chang and Chen (2006) developed a ready-mixed soil material (RMSM) lying between CLSM and soil cement to combine the advantages of both materials but resolve their deficiencies. As a result, RMSM gained the adequate strength for its intended purpose but still allowed for future re-excavation. On-site surplus soil, which is generated from either pipe trench or deep-excavation projects has also been known to be an alternatively effective solution for producing CLSM, which is expected to apply to trench filling or backfilling constructions. CLSM prepared with soil is also called soil cement slurry or ready-mixed soil material (RMSM) (Finney *et al*. 2008, Wu and Lee 2011).

The RMSM is a rising soil material mainly used for

∗Corresponding author, Professor
E-mail: wangho@nkust.edu.tw

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

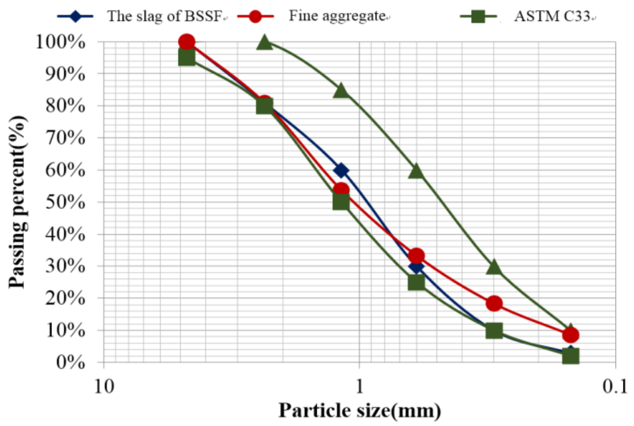

Fig. 1 Size distribution of fine aggregate and the slag

Table 1 Chemical composition of materials

Chemical content (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI	f-CaO
Cement	20.22	4.96	2.83	64.51	2.33	2.46	2.4	_
Slag	8.76	1.77	29.52	41.67	5.67	_	2.63	1.84

substructure backfill, where surplus earth replaces sand and gravel aggregate. Its properties are between those of CLSM and those of soil cement. RMSM has the advantages of these two materials and overcomes the poor excavation of CLSM and too low strength of soil cement, making it a new type of backfill material to solve the shortage of sandstone resources and surplus earth of construction in Taiwan (Chen 2010, Huang 2011). The RMSM can be considered a generalized CLSM; the major difference from CLSM is the use of aggregate. RMSM is free of coarse aggregate, it uses the surplus earth of construction or dredged sandstone from rivers as aggregate, which reduces construction waste and allows for reuse and environmental protection. RMSM has the advantages of CLSM, such as high flowability and being free from compaction, and its lower strength is more applicable to excavating backfill material than CLSM. However, there are no specific standards or specifications for RMSM, so the study on mix proportion and related tests will be performed according to general CLSM specifications (Lee 2010, Folliard *et al*. 2008, Wang and Chen 2010). Research shows that the use of incineration bottom ash in CLSM, reporting that in spite of some problems, such as bleeding and increased strength at later ages, the CLSM mixtures had setting times ranging from 3.7 to 8 h, fresh densities ranging from 1539 to 2100 kg/m^3, and compressive strengths ranging from 0.22 to 11.42 MPa (Razak *et al*. 2010, Naganathan *et al*. 2010, Naganathan *et al*. 2012). More recently, Lee *et al*. (2013) introduced the characteristics of alkali-activated, cement less, controlled low strength materials utilizing fly ash, slag, and bottom ash. Recycled ready-mixed soil materials (RRMSM) possess excellent follow ability (Huang *et al*. 2016). The other properties, applied to backfill engineering, can effectively save costs and are conducive to environmental protection (Huang *et al*. 2016, Hwang 2015, Sheen *et al*. 2015).

Table 2 Physical properties of materials

Material \ N.O.	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
Slag	3.22	2092	3.39	3.7

Table 3 Mixing proportions of RMSAS. Unit : kg/m^3

W/B	Substitution (%)	Binding Materials	Fine Aggregate		Soil	Water
		Cement	Slag	Sand		
3.4	0	100	0	1010	673	340
	10		123.5	909		
	20		247	808		
	30		370.51	707		
	40		494	606		
	50		617.51	505		

2. Experimental plan

2.1 Test materials

This study used Portland Type I cement, which was produced by a cement company of Taiwan (T'cement); the quality of the cement conforms to ASTM C150 specifications (ASTM C150 2005). Fig. 1 shows the size distribution of fine aggregate. The particle size distribution curve of natural sandstone after sieve analysis conformed to ASTM C33 specifications (ASTM C33 2013). The slag is provided by the supplier treated using a crusher, and screen mesh # 4 sieve. The soil was the surplus earth of the excavation of the Kaohsiung light rail project. The physical and chemical properties of the materials are shown in Table 1 and Table 2.

2.2 Test mix proportions and variables

The water-binder ratio is set to 3.4 in this study. The sandstone-soil ratio is 6:4. The slag is crushed and screen mesh # 4 sieve. The replacement for fine aggregate was 0%, 10%, 20%, 30%, 40% and 50%, and the volumetric method was used to make the RMSM. The mixture proportions are shown in Table 3 .

The RMSM mix design process is described as follows: Because RMSM is not required for strength, the binder is defined as 100 kg/m^3, and the water-binder ratio of RMSM is commonly higher than 3. A water-binder ratio of 3.4 was found to have the best workability after several trial mixes. However, in the case of a high water-binder ratio, if the sand-aggregate ratio is 5:5, the strength is too low. Therefore, the best sand-soil ratio is 6:4. Finally, the slag replaced 0%, 10%, 20%, 30%, 40% and 50% of the fine aggregate, and the volumetric method was used to make the RMSAS.

2.3 Test items

1. Workability: the slump, slump flow and tube flow of

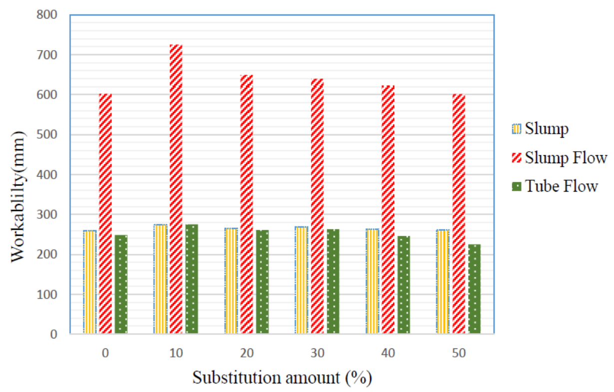

Fig. 2 Workability of RMSAS

Table 4 Fresh properties of RMSAS

Substitution (%)	Slump mm	Slump Flow mm	Tube Flow mm	Unit Weight kg/m^3	Setting Time mins
0	260	600	240	2005	808
10	270	720	270	2043	873
20	260	650	260	2057	812
30	260	635	260	2069	800
40	250	620	230	2113	786
50	240	600	210	2195	762

the prepared specimen are tested according to ASTM C143 specifications (ASTM C143 2015) and ASTM D6103-97 specifications (ASTM D6103-97 2004).

2. Unit weight: the unit weight of the fresh specimen is tested according to ASTM D6023 specifications (ASTM D6023 1996).

3. Setting time: conforming to ASTM C403 specifications (ASTM C403 2008), the time consumption is measured for the fresh specimen with penetration strength of 400 psi.

4. Ball drop: the bearing capacity of RMSM is tested according to ASTM D6024 specifications (ASTM D6024 2015).

5. Compressive strength: the compressive strength is tested according to ASTM C39 specifications (ASTM C39 2015).

6. Ultrasonic pulse velocity: the ultrasonic pulse velocity is tested according to ASTM C597 specifications (ASTM C597 2009); the fundamental purpose is to measure the compactness inside the specimen without destruction. The ultrasonic pulse velocity in the concrete is calculated according to the transmission path length, and the internal condition of concrete is known according to the ultrasonic transmission speed in different materials.

7. Test of hammer rebound**:** a 20 cm×20 cm×15 cm specimen is made according to ASTM C805 specifications (ASTM C805 2013); the variance in hammer rebound value is tested at different ages to estimate the compressive strength.

8. Resistivity: the resistivity is tested according to ASTM C876 specifications (ASTM C876 2009).

9. Sulfate attack**:** The sulfate attack test followed ASTM C1012 specifications (ASTM C1012 2015), drying and soaking sulfate at 7 for 5 cycles to observe the weight loss and appearance.

3. Results analysis

3.1 Workability

RMSM has a high water-binder ratio, and the soil particles are fine. Therefore, RMSM can reduce the overall particle size of the material, and the flow ability significantly increases. The high flow ability provides the material with self-compacting and exemption from compaction and the narrow trench backfill is easier.

Table 4 and Fig. 2 show that the replacement of the slag in the RMSAS can enhance workability. However, the workability declines when the replacement increases. The slump value of the control group is 260 mm; the slump value (270 mm) for the 10% replacement of the slag is increased by 10 mm. The slump is reduced by 10~30 mm when the replacement increases by 20~50% (260~240 mm). The slump value is identical with that of the control group when the replacement is 20% and 30%.

The slump flow is 720 mm when the replacement of the slag is 10%, which is approximately 20% higher than that of the control group (600 mm). The slump flow value is 635 mm when the replacement is 30%, which is approximately 12% lower than that of the 10% replacement group. The slump flow is identical to that of the control group when the replacement is 50%; on average, the slump flow value is reduced by 4% when the replacement is increased by 10%.

The tube flow is higher than that of the control group (240 mm) by 30~20 mm when the replacement is less than 30%. When the replacement is 40% or 50%, the tube flow is 230 mm or 210 mm, respectively, which is lower than the value of the control group. Therefore, the tube flow is closest to that of the control group when the replacement is 30~40%.

Because the material is free of coarse aggregate and contains the surplus earth of field excavation, the paste has properties similar to those of cement mortar. Because the particle size of the slag is large, the pores in the paste are enlarged after the fine aggregate is replaced, but the pores can be filled with soil when the replacement is low. Therefore, the workability is enhanced when the replacement is low. There are more large particles of the slag when the replacement increases, which affects the flow of the paste. Therefore, the workability degrades when the replacement is high.

3.2 Setting time

As shown in Table 4 and Fig. 3 because of the low binder and high water-binder ratio of RMSSM, the setting time is longer than that of normal concrete. The setting time of various replacement groups is 873~762 min; compared to the control group, the setting time is extended by 8% because of slight bleeding when the replacement is 10%. However, when the replacement increases to 50%, the pores resulting from the slag increase the water absorption of the

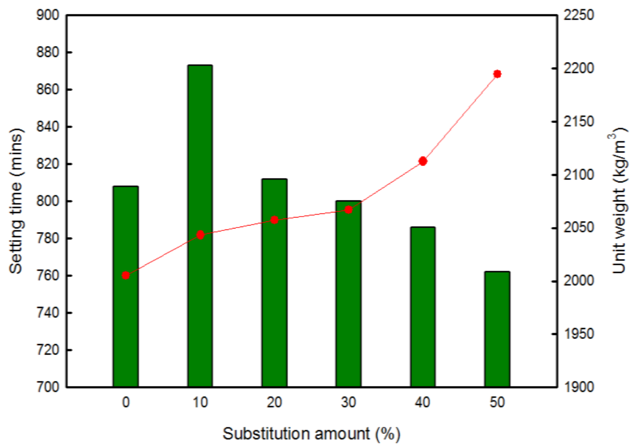

Fig. 3 Relationship between the Setting time and Unit weight of various mixed proportion groups of RMSAS

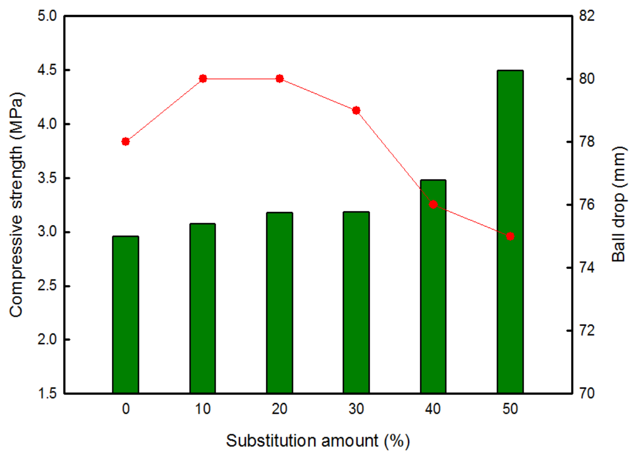

Fig. 4 Relationship between the ball drop and one-day compressive strength of various mixed proportion groups of RMSAS

paste and the setting time is reduced by 5.7%. The setting time is identical to that of the control group when the replacement is 30~40%.

The material hardening time can be shortened by increasing the cement content or agent; however, increasing the cement content may mismatch the concept of low strength, and the addition of agent is uneconomic. Therefore, the use of RMSAS can be enhanced by effectively controlling the water consumption.

3.3 Unit weight

The slag is a higher specific gravity than fine aggregate by 22%.

Table 4 and Fig. 3 shows that when the fine aggregate is replaced, the unit weight of RMSAS increases with the replacement of the slag. Table 4 shows that the unit weight of various replacements is 2004~2195 kg/m^3; the unit weight of various replacement groups is higher than that of the control group by 38-190 kg/m^3. The unit weight of a specimen increases by approximately 1.8% when the replacement is increased by 10% on average.

Increased replacement of the slag corresponds to a smaller ball drop value of RMSAS and better road bearing capacity. The ball drop value of the control group and various replacements is 75~80 mm. Because the high water-binder ratio results in an unstable early hardening effect, the control group has a slightly smaller ball drop value than the 10~30% replacement group, but the difference is only 2 mm.

Fig. 4 shows the relation between the balls drops value of various replacements of RMSAS and the one-day compressive strength. The compressive strength of various replacements at the age of 1 day is 0.225~0.353MPa. The ball drop value is inversely proportional to the compressive strength. A larger ball drop value corresponds to a lower compressive strength at the age of 1 day and worse road bearing capacity.

3.4 Compressive strength

The water-binder ratio of RMSM is as high as 3.4, so

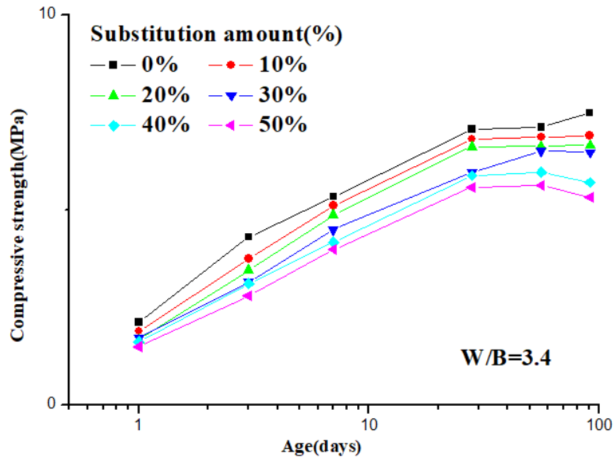

Fig. 5 Compressive strength of RMSAS

the specimens have lower compressive strength than normal concrete. Because the RMSAS was mixed with the low-strength excavation surplus earth without coarse aggregate, the compressive strength development of the specimens is limited. The compressive strength is analyzed as follows.

As shown in Fig. 5, because the particle size of the slag is large, the pores in the paste increase with the replacement in the specimen, and the overall water absorption of paste increases so that the water-binder ratio is reduced and the compressive strength is enhanced. However, the strength difference among various replacements is small; the compressive strength of various replacements at the age of 28 days is higher than that of the control group by 0.065~0.453 MPa. The compressive strength increases by 9.2% when the replacement is increased by 10% on average.

3.5 Ultrasonic pulse velocity

Fig. 6 shows that the ultrasonic pulse velocity of RMSAS at the age of 28 days increases with the replacement of the slag. The velocity is lower than that of the control group by 59~205 m/s when the replacement is 10-50%, which indicates that various replacements of

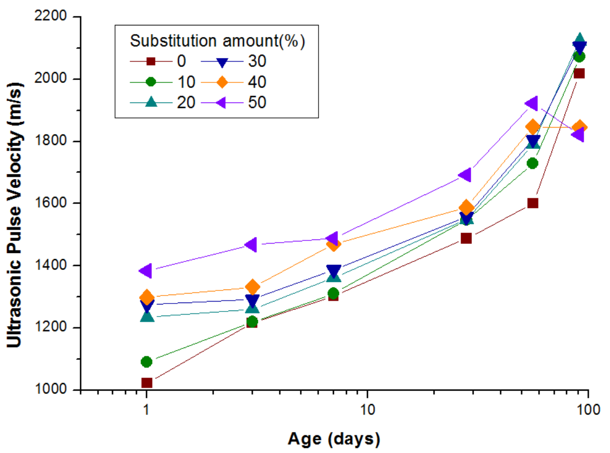

Fig. 6 Ultrasonic pulse velocity of RMSAS

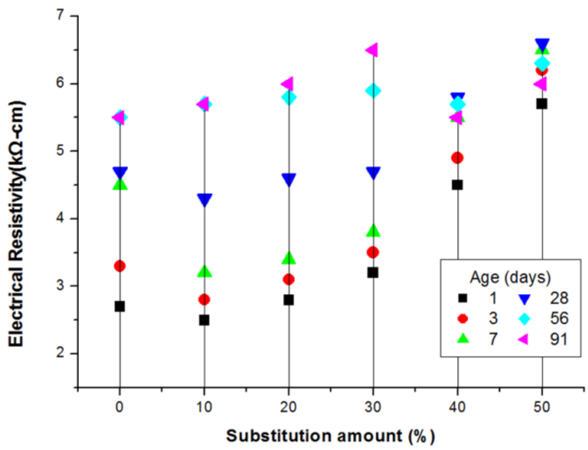

Fig. 8 Relationship between substitution amount and resistivity of RMSAS

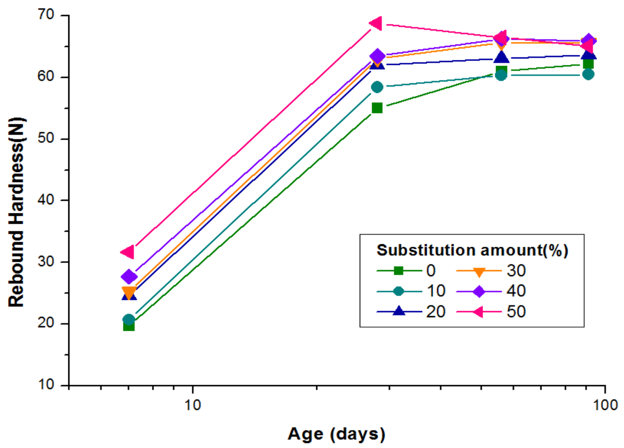

Fig. 7 Rebound hammers value of RMSAS

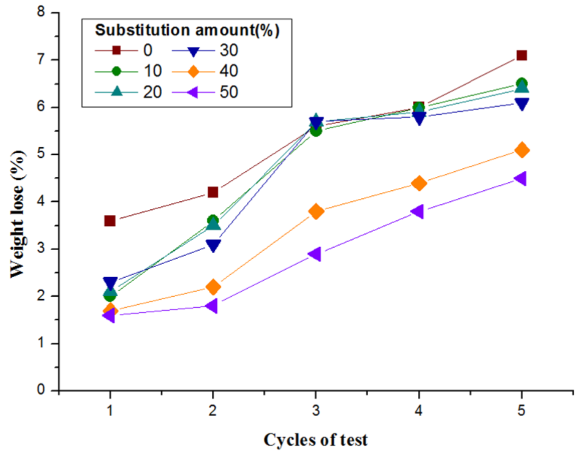

Fig. 9 Sulfate attacks of RMSAS

RMSAS have slight differences in ultrasonic pulse velocity. The ultrasonic pulse velocity of various replacement groups at the age of 28 days is 1488~1693 m/s, the pulse velocity increases by 41 m/s when the replacement is increased by 10% on average. The number of pores in the specimen gradually increases because of the large particle size of the slag, but these pores are effectively filled with the excavation surplus earth in fine particle size, the specimen compactness is improved, and the pulse velocity increases accordingly.

3.6 Low-strength hammer rebound test

The hammer rebound values of various replacement groups are shown in Table 8. The hammer rebound value of RMSAS gradually increases with the replacement. The hammer rebound value of various replacement groups at the age of 28 days is larger than that of the control group by 6.4~25.1%.

As shown in Fig. 7, the hammer rebound value of various replacement groups during the age of 7~28 days increases by 2.1~2.8 times. The hammer rebound value during the age of 28~56 days' increases by only 4-10% because the hydration is stopped. When the replacement is 50%, the hammer rebound value at the age of 56 days decreases because the internal structure is destroyed. At the age of 91 days, the 30% and 40% replacement groups have identical results.

3.7 Resistance

Because of the high water-binder ratio of RMSAS, the internal structure of the specimen is loose, so it has a lower resistivity than normal concrete. Fig. 8 shows that the resistivity of RMSAS increases with age. The resistivity of 0~30% replacements increases by 103~114% over the age of 1~91 days. The micro cracks caused by expansion also affect the resistivity development. Therefore, the resistivity of 40% and 50% replacements decreases at the age of 56 days. The resistivity of 40% and 50% replacements during 1-28 days increases by 22.2% and 14.0%, respectively, and decreases by 0.3 and 0.6 kΩ-cm, respectively, during 28~91 days.

3.8 Sulfate attack

Fig. 9 shows that the weight loss rate of RMSAS after 5 cycles is the weight loss rate of various replacement groups after 5 cycles of sulfate attack. A larger replacement of the slag corresponds to a lower weight loss rate and better sulfate resistance. The weight loss rate of the control group

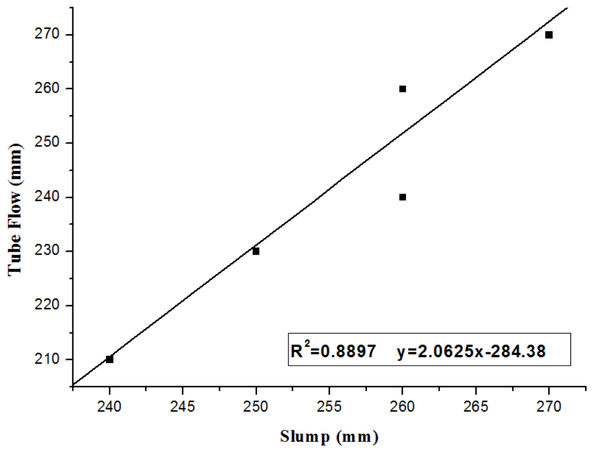

Fig. 10 Linear regression relationships between the slump and tube flow of RMSAS

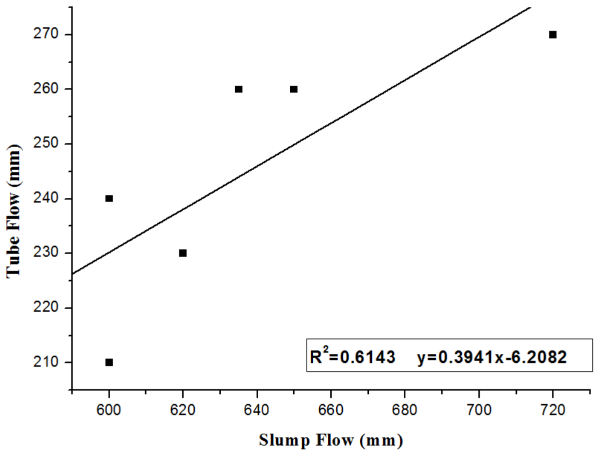

Fig. 11 Linear regression relationships between the slump flow and tube flow of RMSAS

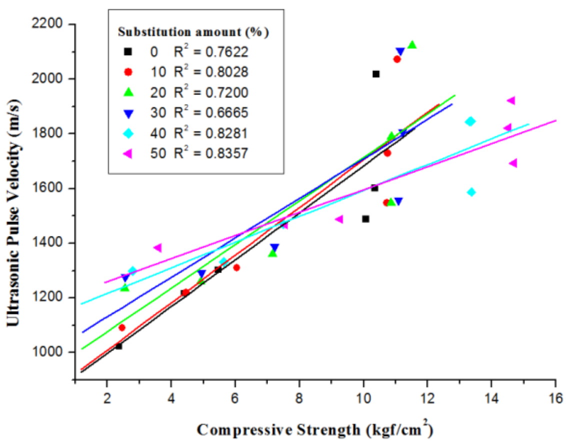

Fig. 12 Linear regression relationships between the compressive strength and ultrasonic pulse velocity of RMSAS

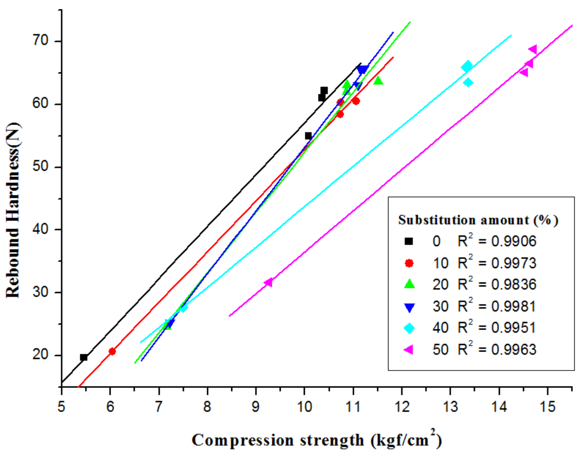

Fig. 13 Linear regression relationships between the compressive strength and Rebound hardness of RMSAS

after the 5th cycle is 7.1%, the weight loss rate of various replacement groups of the slag is 6.5~4.5%, which is lower than that of the control group by 0.6-2.6%. On average, the weight loss rate is reduced by 0.52% when the replacement is increased by 10%.

3.9 Workability correlation

As shown in Fig. 10 and Fig. 11, the linear regression equation of the slump and tube flow of RMSSM is y=2.0625x-284.38, the equation of relation between slump flow and tube flow is y=0.3941x-6.2082, the correlation coefficient R^2 of the slump and tube flow is 0.8897, and the R^2 of slump flow and tube flow is 0.6143, which indicates that there is a certain correlation among the slump, slump flow and tube flow. Therefore, the workability can be preliminarily determined from the tube flow.

3.10 Compressive strength correlation

The ultrasonic pulse velocity is a nondestructive testing method, which is extensively used at present to evaluate the compressive strength and test the internal porosity. Fig. 12 shows the linear regression relation between the ultrasonic pulse velocity and compressive strength of various replacements of RMSAS. The correlation coefficient R^2 of the control group and most replacement groups is above 0.7, which indicates that the pulse velocity is highly correlated with the compressive strength.

The hammer rebound test is the easiest and most straightforward method to evaluate the compressive strength, but it is likely affected by environmental factors or specimen condition. Therefore, the hammer rebound test has poor precision. Fig. 13 shows that the growth in strength is directly reflected in the hammer rebound value. Therefore, the linear regression correlation coefficient R^2 of the hammer rebound value and compressive strength is higher than 0.98, which indicates that their correlation is notably high.

3.11 Cost benefit estimation

The unit price of the slag is NT$ 0.15/kg, which is approximately 72% lower than the NT$ 0.53/kg of natural fine aggregate. Therefore, the cost of RMSAS is reduced by 17.8% with the increase in replacement of the slag for natural fine aggregate. The cost is reduced by 3.56% when the replacement is increased by 10% on average.

The soil in this study is the waste surplus earth from construction, so the cost is lower than that of general RMSSM. The unit price of soil is NT$0.03/kg. The cost is reduced by 4.33~21.65% with the increase in replacement of the slag for natural fine aggregate. The cost is reduced by approximately 20% when the replacement is 50%.

The carbon footprint of natural sandstone is 7.24 $kgCO_2$/ton, and the CO_2 emission of the basic-oxygen-furnace slag aggregate is approximately 2.85 kg/ton (Hwang 2015), which implies that the basic-oxygen-furnace slag has notably slight environmental impact compared with natural sand. Therefore, the effective replacement of natural sandstone by the slag significantly contributes to environmental protection.

4. Conclusions

1. When the replacement increases in RMSAS, the increasing particles of the slag affect the flow of the paste. Therefore, the workability degrades when the replacement is high.
2. The slag has a higher specific gravity than fine aggregate by 22%, so the unit weight increases with the replacement of the slag.
3. In comparison to that of the control group, the setting time of RMSAS is extended by 8% due to slight bleeding when the replacement is low. However, when the replacement increases to 50%, the pores in the slag increase the water absorption of the paste and the setting time decreases by 5.7%.
4. Because the particle size of the slag is large, the number of pores in the paste increases with the replacement in the specimen and the overall water absorption of the paste increases. Thus, the water-binder ratio decreases, and the compressive strength increases; however, the strength differences among various replacements are small.
5. The ultrasonic pulse velocity of RMSAS increases with the replacement of the slag. The internal porosity gradually increases because of the large particle size of the slag. However, the excavation surplus earth with fine particle size can effectively fill these pores, the specimen compactness is improved, and the pulse velocity accordingly increases.
6. The workability correlation and correlation of hardened properties of RMSAS are mostly higher than 0.6, but the ultrasonic pulse velocity and resistivity are reduced under the direct effect of cracks from the expansion. Therefore, the R^2 values of the two tests are affected.

References

Alizadeh, V., Helwany, S., Ghorbanpoor, A. and Sobolev, K. (2014), “Design and application of controlled low strength materials as a structural fill”, *Constr. Build. Mater*., **53**, 425-431.

ASTM C1012 (2015), Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution, ASTM International, USA.

ASTM C143 (2015), Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, USA.

ASTM C150 (2005), Standard Specification for Portland cement, ASTM International, USA.

ASTM C33 (2013), Standard Specification for Concrete Aggregates, ASTM International, USA.

ASTM C39 (2015), Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International, USA.

ASTM C403 (2008), Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance.

ASTM C597 (2009), Standard Test Method for Pulse Velocity through Concrete, ASTM International, USA.

ASTM C805 (2013), Standard Test Method for Rebound Number of Hardened Concrete, ASTM International, USA.

ASTM C876 (2009), Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete, ASTM International, USA.

ASTM D6023 (1996) Standard Test Method for Density (Unit Weight), Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low-Strength Material (CLSM).

ASTM D6024 (2015), Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to Determine Suitability for Load Application.

ASTM D6103-97 (2004), Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM).

Blanco, A., Pujadas, P., Cavalaro, S.H.P. and Aguado, A. (2014), “Methodology for the design of controlled low-strength materials. Application to the backfill of narrow trenches”, *Constr. Build. Mater*., **72**, 23-30.

Chang, C.F. and Chen, J.W. (2006), “Development and production of ready-mixed soil material”, *J. Mater. Civil Eng*., **18**(6), 792-799.

Chen, J.H. (2012), “Study on engineering properties of Ready-Mixed Soil Material with applied of recycled materials”, Master Thesis, National Kaohsiung University of Applied Sciences.

Chen, J.R. (2014), *Steel Yearbook 2014*, Global Steel Articles, Metal Industries Research and Development Centre.

Chen, Y.R. (2010), “Quality inspection for ready-mixed soil materials by non-destructive testing”, Master Thesis, National Kaohsiung University of Applied Sciences.

Etxebarria, M., Ainchil, J., Pérez, M.E. and González, A. (2013), “Use of recycled fine aggregates for Control Low Strength Materials (CLSMs) production”, *Constr. Build. Mater*., **44**, 142-148.

Finney, A.J., Shorey, E.F. and Anderson, J. (2008), “Use of native soil in place of aggregate in controlled low strength material (CLSM)”, *International Pipelines Conference*, Atlanta, Georgia.

Folliard, K.J., Du, L., Trejo, D., Halmen, C., Sabol, S. and Leshchinsky, D. (2008), “Development of a recommended practice for use of controlled low-strength material in highway construction”, NCHRP Report 597, TRB, Washington D.C..

Huang, W.L., Wang, H.Y. and Chen J.H. (2016), “A study of the fresh properties of Recycled ready-mixed soil materials (RRMSM)”, *Comput. Concrete*, **17**(6), 787-799.

Huang, Y.F. (2011), “The effect of slag on the engineering properties of ready-mixed soil material”, Master Thesis, National Kaohsiung University of Applied Sciences.

Hwang, C.L. (2015), *High Performance Concrete Theory and Practice*, Taipei, Chans.

Kim, Y.S., Do, T.M., Kim, H.K. and Kang, G. (2016), “Utilization of excavated soil in coal ash-based controlled low strength material (CLSM)”, *Constr. Build. Mater*., **124**, 598-605.

Lee, C.H. (2010), “Properties of ready-mixed soil materials made of residual soil”, Master Thesis, National Kaohsiung University of Applied Sciences.

Lee, N.K., Kim, H.K., Park, I.S. and Lee, H.K. (2013), “Alkali-activated, cement less, controlled low-strength materials (CLSM) utilizing industrial by-products”, *Constr. Build. Mater*., **49**, 738-746.

Li, J. (2014), “Accumulated slag dumps across the country, nearly one billion tons comprehensive utilization rate is only 10%”, www.ce.cn.

Liao, Y.J. (2013), “Engineering properties of ready-mixed soil materials using stainless steel reducing slag”, Master Thesis, National Kaohsiung University of Applied Sciences.

Lo, C.Y. (2013), “Over-capacity in China iron and steel industry: estimation and its impact”, Master Thesis, National Sun Yat-sen University.

Naganathan, S., Razak, H.A. and Hamid, S.N.A. (2010), “Effect of kaolin addition on the performance of controlled low-strength material using industrial waste incineration bottom ash”, *Waste Manage. Res*., **28**(9), 848-860.

Naganathan, S., Razak, H.A. and Hamid, S.N.A. (2012), “Properties of controlled low-strength material made using industrial waste incineration bottom ash and quarry”, *Dust. Mater. Des*., **33**, 56-63.

Razak, H.A., Naganathan, S. and Hamid, S.N.A. (2010), “Controlled low-strength material using industrial waste incineration bottom ash and refined kaolin”, *Arab. J. Sci. Eng.*, **35**(2B), 53-67.

Sheen, Y.N., Wang, H.Y., Lin, R.Y. and Kuo, W.T. (2015), *Technology of Concrete*, Chuan Hwa Book CO. LTD, Taipei.

Wang, H.Y. and Chen, J.S. (2010), “Mix proportions and properties of CLSC made from thin film transition liquid crystal display optical waste glass”, *J. Environ. Manage.*, **91**(3), 638-645.

Wu, J.Y. and Lee, M.Z. (2011), “Beneficial reuse of construction surplus clay in CLSM”, *Int. J. Pavement Res. Technol*., **4**(5), 293-300.

Zhang, L.H. and Le, D.H. (2013), “Engineering properties of soil-based controlled low-strength materials as slag partially substitutes to Portland cement”, *Constr. Build. Mater*., **48**, 822-829.

CC