The 2017 World Congress on
Advances in Structural Engineering and Mechanics (ASEM17)
28 August - 1 September, 2017, Ilsan(Seoul), Korea

A study on the strength and expansion of composite cement mortar with BSSF slag

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ABSTRACT

This study uses Baosteel slag short flow (BSSF) through a No. 4 sieve to replace 0%, 25%, 50%, 75%, and 100% of a natural fine aggregate by the volumetric method, uses slag powder to replace 20% of the cement, and uses the three water-binder ratios of 0.45, 0.5, and 0.55 to make composite cement mortar, in order to implement a series of flows, setting times, compressive strengths, and expansion tests. Test results show that, when composite cement mortar is replaced by BSSF slag, the slump flow increases with the BSSF slag replacement and water-binder ratio values. When the water-binder ratio is 0.45, the flow of BSSF replacement for 0-50% of natural sand is 20.5-21.4cm, meeting the standard value of 20.5-21.5cm. When the BSSF replacement is 75% and 100%, respectively, the flow is 21.9cm and 22.3cm, respectively, which is slightly larger than the upper bound value of the standard. When the water-binder ratio is 0.50 and 0.55, respectively, the flow of mortar with BSSF is 21.6-23.4cm, exceeding the upper bound value of the standard. In addition, while the BSSF replacement has no significant impact on the initial setting time, the characteristic of the final setting time is slightly different. The compressive strength increases linearly with the BSSF replacement, and the linear increasing slope increases with the water-binder ratio. The overall average compressive strength increasing slope is about 10.84 MPa when the water-binder ratio is 0.45, about 12.73 MPa when the water-binder ratio is 0.50, and about 18.28 MPa when the water-binder ratio is 0.55. When the BSSF slag replacement is 50%, the average expansion is higher than that of the control group (BSSF slag replacement is 0%) by 1.5 times. When the BSSF slag replacement is more than 75%, the expansion potential rises sharply and tends to reach the rupture state. Finally, the expansion causes breakage when the BSSF slag replacement reaches 100%.

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1. INTRODUCTION

Steel slag is a by-product of steel production, and accounts for approximately 15% of mass steel output. Due to its high strength and durability, steel slag can be processed into high quality aggregates, which are comparable with those of natural aggregates. Steel slag has high bulk density, high strength, low abrasion and wear rates, and a rough texture, which qualify steel slag as a construction material. Xiang et al. (2016) investigated the application of cement-free steel slag cementitious material. Four kinds of steel slag, including hot-spray poured steel slag, hot-stuffing steel slag, Baosteel short-flow (BSSF) steel slag, and wind-quenched steel slag were used as fine aggregates to partially replace natural sand. In his work, the cementitious material had the characteristics of normal setting time, qualified boiling stability, high early strength, and excellent bending strength. Qasrawi, et al. (2009) found that the compressive strength of concrete using steel slag as a fine aggregate was 1.1 to 1.3 times that of common concrete. However, its volume instability is a very important and considerably unsafe factor for using steel slag as an aggregate in construction material (Chen 2013, Yi et al. 2012). Solving the volumetric expansion problem of steel slag is vital for slag recycling and reuse. Lee et al. (2014) conducted experiments and evaluation of 5 commercialized strategies for slag treatments to stabilize the volume of BOF slag. Their study showed that the hot stage slag modification technique was considered to be the most effective way to achieve volumetric stabilization of BOF slag; however, the processing equipment was far more expensive than others (Lee 2014).

Lee et al. (2014) indicated that the residual expansion ratio of BOF slag, with a particle size greater than 5mm after the roller process, is less than 50% of the original slag; however, this method is less effective than the hot stage slag modification technique, as the volume stability of BOF slag has been effectively enhanced. In addition, the BSSF particle size is relatively small and uniform, as 90% of the particles are less than 10 mm, while roller slag volume expansibility degrades greatly after stabilization, thus, this material is applicable to engineering applications, e.g. asphalt concrete pavement (Chen & Wei 2016, Huang et al. 2012, Xue et al. 2009), and can be used as appropriate earth material (Yildirim 2009).

With sustainable development and reusing waste materials as a starting point, applications involving the addition of BSSF steel slag and furnace slag powder to replace some of the raw materials in concrete or cement mortar constitute a research topic worthy of study. In this study, a series of slump flows, setting times, compressive strengths, and expansion tests are conducted on composite cement mortars with three types of water-binder ratios containing BSSF steel slag (where the replacement rates of BSSF steel slag for fine aggregate are 0%, 25%, 50%, 75%, and 100%) and furnace slag powder (the cement is replaced by 20% furnace slag powder), in order to discuss the workability, setting time, compressive strength, and expanding properties of composite cement mortars with BSSF.

2. EXPERIMENTAL PLAN

2.1 Test materials

This study used Type I Portland cement produced by the Taiwan Cement Corporation, with quality conforming to the Type I Portland cement specified in ASTM C150. The natural sand was originated from the Ligang District and tested by sieve analysis, the particle size distribution curve conforms to ASTM C33. The Baosteel slag short flow (BSSF slag) was provided by the manufacturer. It was treated by a crusher, screened through a No. 4 sieve, and the fineness approaches the natural aggregate size. The slag powder was ground granulated blast furnace slag produced by the China Steel Corporation of Taiwan, pulverized by CHC, with properties conforming to ASTM 989. The mixing water conforms to ASTM C94. The basic physical and chemical properties of the materials are shown in Tables 1 and 2. The particle size distribution curves of the fine aggregate and BSSF steel slag are shown in Figure 1.

Table 1. The physical properties of materials.

Items	Specific gravity	Water absorption (%)	F.M	Fineness (cm^2/g)
Fine Aggregate	2.63	2.65	2.9	-
Baosteel slag short flow	3.22	2.94	3.02	-
Cement	3.15	-	-	3500
Slag Powder	2.8	-	-	4500

Table 2. The chemical properties of the materials. Unit:%

Properties	Cement	Slag Powder	Baosteel Slag
SiO_2	20.22	33.46	8.76
Al_2O_3	4.96	13.7	1.77
Fe_2O_3	2.83	0.42	29.52
CaO	64.51	42.69	41.67
MgO	2.33	6.21	5.67
SO_3	2.46	1.48	-
LOI	2.4	0.27	2.63
f-CaO	-	-	1.84

2.2 Test variables and method

This study uses the standard mix design for cement mortar according to ASTM C109, meaning a fixed binder-fine aggregate ratio of 1:2.75. The volumetric method is used for the design. Three values of W/B (0.45, 0.5, 0.55) are used. Different proportions (0, 25, 50, 75 and 100%) of sand are replaced by the BSSF slag, and 20% of the cement is replaced by furnace slag powder for the production of composite cement mortar. A 5 cm * 5 cm * 5 cm cement mortar specimen is constructed and solidified. The flow and setting time are tested in accordance with ASTM C230 and ASTM C403, respectively. The compressive strength is tested at the ages of 3, 7, 28, 56, and 91 days according to ASTM C109. The swelling capacity test followed ASTM C151, and an autoclave is used for the autoclave expansion test.

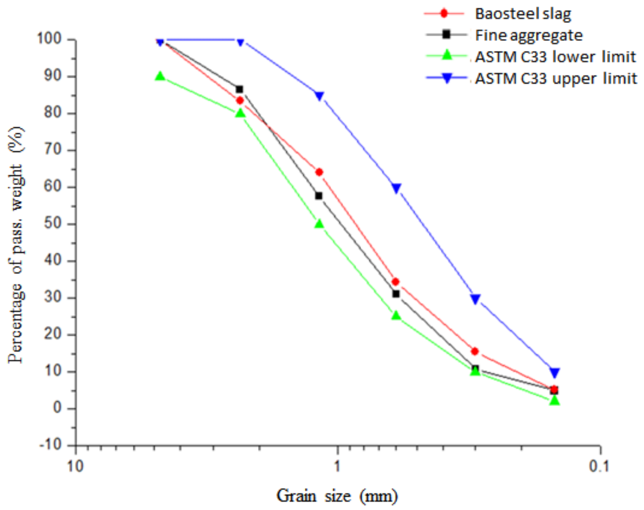


Fig 1 Cumulative particles distribution of fine aggregate and Baosteel slag

3. EXPERIMENTAL RESULTS

3.1 Slump flow

Figure 2 shows the slump flow test results of slag powder mortar with BSSF. It is observed that the flow value increases with the replacement of natural sand by BSSF and the water-binder ratio. When the water-binder ratio is 0.45 and BSSF replaces 0%~50% of the natural sand, the flows are 20.5, 20.9, and 21.4cm, respectively, which is within the standard value of 20.5~21.5cm. When the BSSF replacement is 75% and 100%, the flows are 21.9 and 22.3cm, respectively, which slightly exceeds the upper bound value of the standard. When the water-binder ratio is 0.5 and 0.55, respectively, the mortar flow increases with the water consumption, and the flow of the composite cement mortar with BSSF is 21.6-23.4cm, which exceeds the upper bound value of 21.5cm.

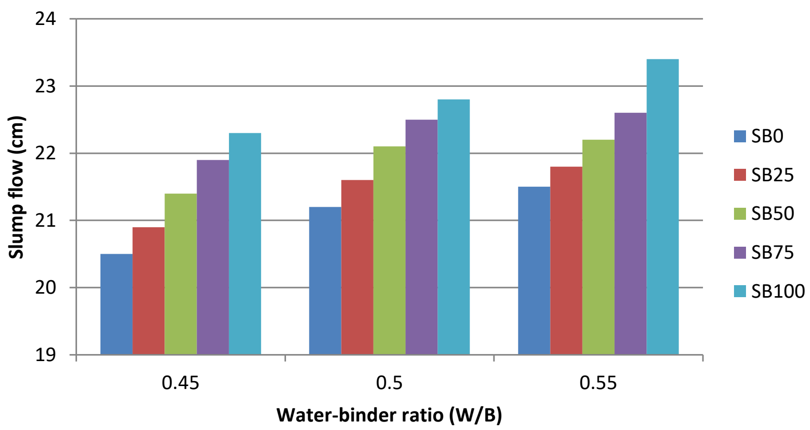
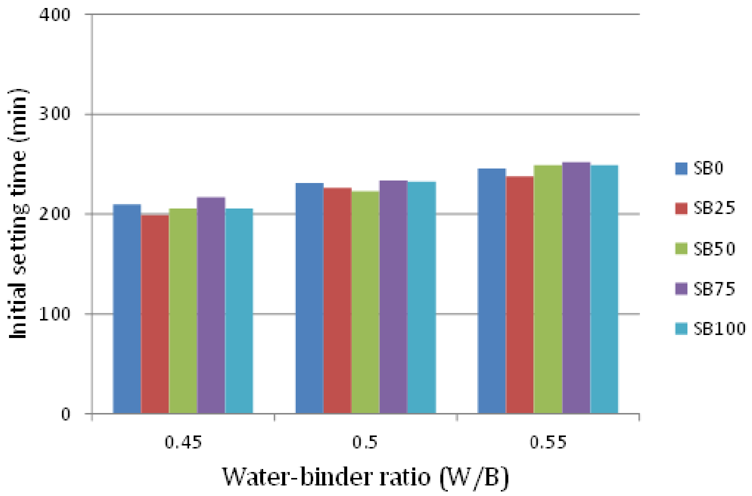


Fig 2 Relationship of slump flow and Baosteel slag content

3.2 Setting time

Figure 3 shows the setting time test results of slag powder mortar with BSSF. It is observed that, at the same water-binder ratio, the effect of BSSF replacement on the initial setting time is not obvious; however, the final setting time is extended as the BSSF replacement is increased, and the setting time is increased with the water-binder ratio. When the water-binder ratio is 0.45, the average initial setting time and final setting time are 208 min and 281 min, respectively. When the water-binder ratio is 0.50, the average initial setting time and final setting time are about 110% and 113% of the 0.45 water-binder ratio, respectively. When the water-binder ratio is 0.55, the average initial setting time and final setting time are about 119% and 122% of the 0.45 water-binder ratio, respectively.



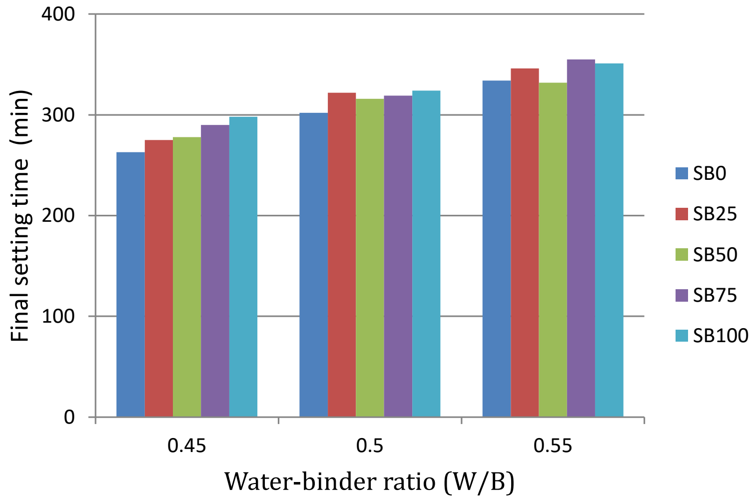


Fig 3 Relationship of setting time and Baosteel slag content

3.3 Compressive strength

Figure 4 shows the compressive strength test results of composite cement mortar with water-binder ratio W/B=0.45 and various BSSF replacements. The test results show that compressive strength increases with BSSF replacement, and increases with age. The relationship between compressive strength and BSSF replacement has the same tendency for others water-binder ratio, but the compressive strength decreases as the water-binder ratio increases. The compressive strength of various BSSF replacements is 15.9-30.8 MPa at the age of 3 days; 24.1-36.6 MPa at the age of 7 days; 31.6-53.1 MPa at the age of 28 days; 34.1-59.4 MPa at the age of 56 days; and 36.8-64 MPa at the age of 91 days. When the water-binder ratio W/B is 0.45, if the compressive strength at the age of 28 days is taken as the standard ($f'_{c,28}$), the compressive strength on Day 3 ($f'_{c,3}$) is 49-61% of the strength on Day 28, the compressive strength on Day 7 ($f'_{c,7}$) is 60-72% of the strength on Day 28, the compressive strength on Day 56 ($f'_{c,56}$) is 112-128% of the strength on Day 28, and the compressive strength on Day 91 ($f'_{c,91}$) is 129-142% of the strength on Day 28. When the water-binder ratio W/B is 0.50, the compressive strength ratios $f'_{C,3} / f'_{C,28}$, $f'_{C,7} / f'_{C,28}$, $f'_{C,56} / f'_{C,28}$, and $f'_{C,91} / f'_{C,28}$ are 53-64%, 69-78%, 103-130%, and 113-138%, respectively. When the water-binder ratio W/B is 0.55, the compressive strength ratios $f'_{C,3} / f'_{C,28}$, $f'_{C,7} / f'_{C,28}$, $f'_{C,56} / f'_{C,28}$, and $f'_{C,91} / f'_{C,28}$ are 50-58%, 69-81%, 106-123%, and 112-128%, respectively. Figure 5 shows the relationship between compressive strength and BSSF replacement under water-binder ratio W/B=0.45. It is observed that compressive strength increases linearly with the BSSF replacement. It has also the same tendency for others water-binder ratio, and the linear increasing slope increases with the water-binder ratio. The overall average compressive strength increasing slope is about 10.84 MPa when the water-binder ratio is 0.45, about 12.73 MPa when the water-binder ratio is 0.50, and about 18.28 MPa when the water-binder ratio is 0.55.

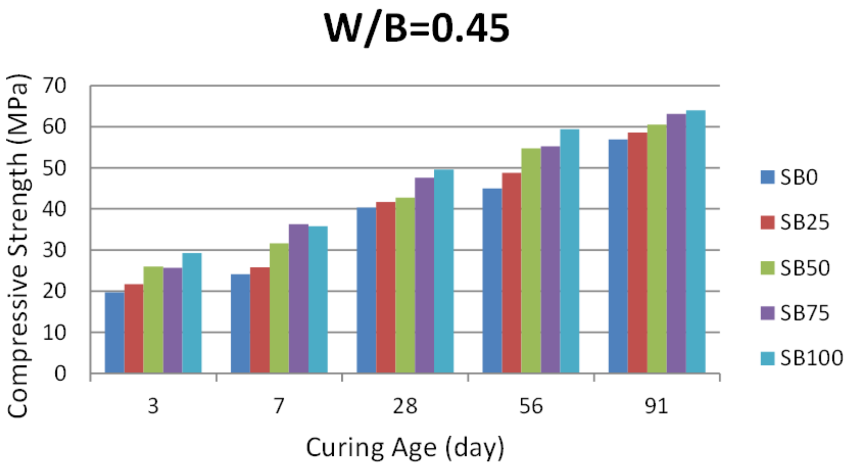


Fig 4 Compressive strength of Baosteel slag cement mortar

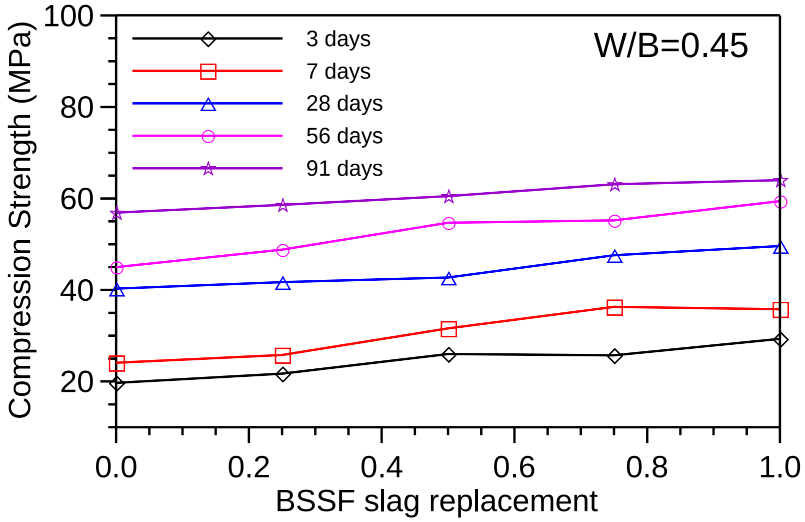


Fig 5 Relationship between compressive strength and BSSF slag replacement.

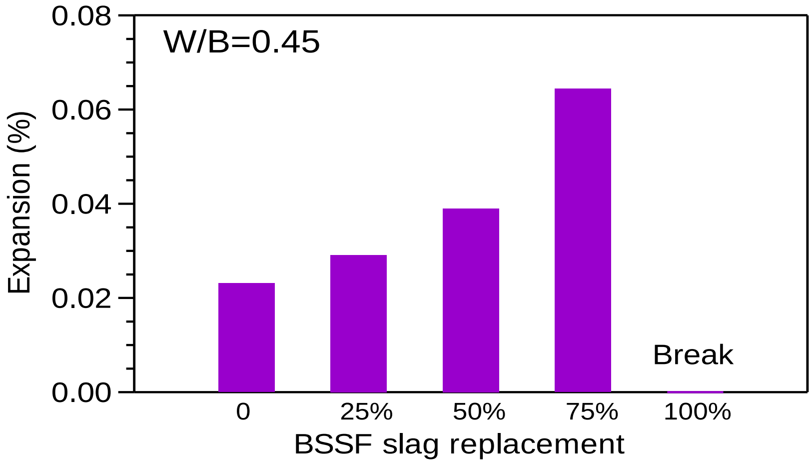


Fig 6 Relationship between expansion and BSSF slag replacement.

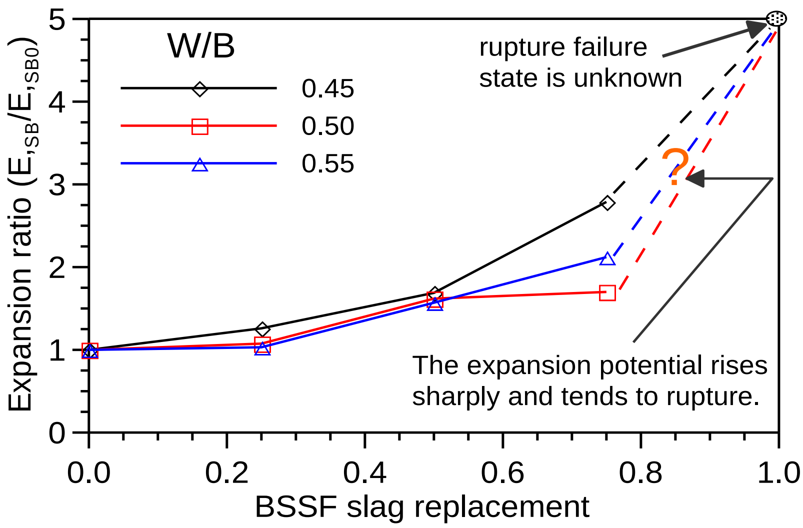


Fig 7 Relationship between expansion ratio and BSSF slag replacement.

3.4 Expansion

As shown in Figure 6, the expansion capacity of composite cement mortar increases with the BSSF slag replacement, which is because the BSSF slag contains f-CaO, which may expand after reacting with water. When the replacement is 50%, the average expansion is higher than that of the control group (BSSF slag replacement is 0%) by 1.5 times. When the slag of BSSF replacement more than 75%, the expansion potential rises sharply and tends to the rupture state. Finally, expansion causes breakage when the BSSF slag replacement reaches 100%, failing the measurement. In addition, the expansion ratio $E_{,SB}$ /$E_{,SB0}$ (ratio of expansion capacity with BSSF $E_{,SB}$ to expansion capacity without BSSF $E_{,SB0}$) increases nonlinearly with the BSSF replacement, where the larger the BSSF replacement, the larger the expansion ratio increasing slope. When the replacement exceeds 75%, the expansion capacity increases sharply, and the mortar bar breaks, as shown in Figure 7.

4. CONCLUSIONS

1. When composite cement mortar is replaced by BSSF slag, the slump flow increases with the BSSF slag replacement and water-binder ratio values. When the water-binder ratio is 0.45, and the replacement of natural sand with BSSF is less than 50%, the flow is 20.5-21.4 cm, which meets the standard of 20.5-21.5 cm. However, when BSSF replacements are 75% and 100%, respectively, the flows are 21.9 cm and 22.3 cm, respectively, which slightly exceed the upper bound value of the standard. When the water-binder ratios are 0.50 and 0.55, respectively, the flow of mortar with BSSF is 21.6-23.4 cm, which exceeds the upper bound value of the standard.
2. BSSF replacement has slight effect on initial setting time, and influences the final setting time. When the water-binder ratio is 0.45, the final setting time increasing amplitude with the BSSF replacement is larger than that where the water-binder ratio is 0.50 and 0.55, respectively. In addition, the initial setting time and final setting time increase with the water-binder ratio.
3. The test results show that compressive strength increases linearly with the BSSF replacement, and the linear increasing slope increases with the water-binder ratio. The overall average compressive strength increasing slope is about 10.84 MPa when the water-binder ratio is 0.45, about 12.73 MPa when the water-binder ratio is 0.50, and about 18.28 MPa when the water-binder ratio is 0.55. Therefore, the higher the water-binder ratio, the more significant the contribution of BSSF replacement to compressive strength.
4. When the BSSF slag replacement is 50%, the average expansion is higher than that of the control group (BSSF slag replacement is 0%) by 1.5 times. When the slag of BSSF replacement more than 75%, the expansion potential rises sharply and tends to the rupture state. Finally, expansion causes breakage when the BSSF slag replacement reaches 100%.

REFERENCES

Chen J.S. and Wei S.H. (2016), “Engineering properties and performance of asphalt mixtures incorporating steel slag”, *Constr. Build. Mater*. 128, 148–153.

Chen L.A. (2013), “Investigating the swelling behavior and the mitigation methods of highway subgrade with basic oxygen furnace slag”, Master Dissertation, National Cheng Kung University, Tainan.

Huang L.S., Lin D.F., Luo H.L. and Lin P.C. (2012), “Effect of field compaction mode on asphalt mixture concrete with basic oxygen furnace slag”, *Constr. Build. Mater*. 34, 16–27.

Lee Y.C., Yang C.C., Tsai L.W. and Yue M.T. (2014), The application and breakthrough of BOF slag modification technique in CSC”, *Mining & Metallurgy*, 58(4), 23-32.

Qasrawi H, Shalabi F and Asi I. (2009), “Use of low CaO unprocessed steel slag in concrete as fine aggregate”, *Constr. Build. Mater*. 23, 1118-1125.

Xiang X.D, Xi J.C., Li C.H. and Jiang X.W. (2016), “Preparation and application of the cement-free steel slag cementitious material”, *Constr. Build. Mater*. 114, 874–879.

Xiao Y.L., Li Y.Q. and Liu Y. (2009), “Research and applications of Baosteel’s BSSF process for molten steelmaking slag treatment”, *Baosteel Technology*, 90-94.

Xue Y.J., Hou H.B., Zhu S.J. and Zha J. (2009), “Utilization of municipal solid waste incineration ash in stone mastic asphalt mixture pavement performance and environmental impact”, *Constr. Build. Mater*. 23, 989–996.

Yi H., Xu G., Cheng H., Wang J., Wan Y. and Chen H. (2012), “An overview of utilization of steel slag”, Procedia Environmental Sciences 16, 791 – 801

Yildirim I.Z. (2009), “Experimental study of the use of steel slag as a geotechnical material”, Degree of Doctor of Philosophy, Purdue university graduate school.