Experimental Study on Performance of Foamed Magnesium Slag Cement

Chen Guo^{1*}, Jianxun Ma¹, Yuheng Dai¹ and Rui Niu¹

¹School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an, Shanxi Province, 710049, China

Abstract. Magnesium slag is an industrial waste residue produced in magnesium smelting. Its chemical composition is similar to Portland cement and has potential activity. After the magnesium slag is foamed, it can be made into a new type of lightweight material, and its forming, mechanical and physical properties were closely related to dry material formula, water-cement ratio and foaming agent amount. In this paper, experiments were carried out to find the ingredients and processes suitable for the forming of foamed magnesium slag, making it have certain mechanical and physical properties at the same time.

1 Introduction

The chemical composition of magnesium slag is similar to that of Portland cement clinker and has potential activity. However, it has a low utilization rate. This paper combines the magnesium slag cement with foaming technology, and explores the factors affecting the performance of foamed magnesium slag cement through experiments, so that it tries to open up a new direction of magnesium slag utilization.

ash-slag ratio. The ash-slag ratios of the tests were set to 0.33, 0.4 and 0.6, meanwhile the water-cement ratios were set to 0.4 and 0.47. Owing to the air compression foaming technique used in this test, we employed the method of adding in a fixed volume of foam per kilogram of mixture. We used the autoclave curing method, of which the temperature is 185°C, the pressure is 1.2MPa and the duration is 6 hours.

2.1. Test results

The results of the forming test are shown in Table 1 below.

2 Forming test of foamed magnesium slag

Due to the low activity of magnesium slag, we mixed the magnesium slag with fly ash and adjusted the

Table 1. Results of forming test

No	Dry mix ratio			Water-cement ratio	Foam content / ml·kg ⁻¹	Density before curing / kg·m ⁻³	Curing result
	Ash-slag ratio	Slag	Ash				
1-1	0.33	75 %	25 %	0.47	1700	420	Not forming
1-2	0.33	75 %	25 %	0.40	325	1440	Not forming
1-3	0.33	75 %	25 %	0.40	1040	800	Not forming
1-4	0.33	75 %	25 %	0.40	1330	686	Not forming
1-5	0.4	71 %	29 %	0.40	1000	820	Not forming
1-6	0.6	63 %	37 %	0.40	1000	840	Not forming

* Corresponding author: 1639575414@qq.com

The test pieces could form and cement with certain strength with natural curing, but they turned into powder after being steamed in the autoclave.

2.2. Analysis and discussion of test results

Ash-slag ratio. We thought the reason why the pieces couldn't form was the low content of ash and that much of the slag was damped, while the difference under different curing conditions was due to high content of magnesium oxide which reacted relatively fast in the autoclave.

Hence we decided to raise the ash-slag ratio and add in some ordinary Portland cement and silica fume to get qualified test products.

Water-cement ratio. Through the observation in this test, we found that when the water-cement ratio was 0.40, the cement had a better workability and cooperation with foam.

Relationship between foam content and density. The density of the foamed cement mainly depends on the amount of foam. We tested the density of the pieces before autoclaving. Table 2 shows the density of the foamed cement under different foam contents.

Table 2. Density under different foam contents

Foam content/ ml·kg ⁻¹	Density before curing/ kg·m ⁻³
325	1440
1040	800
1330	686
1700	420

Scatter plot of foam content and density is plotted by the above table as Figure 1.

Figure 1. Scatter plot of foam content and density

As can be seen from the above figure, when the foam content increases, the density of the foamed cement decreases sharply.

We used the least squares method in mathematical statistics to carry out regression analysis on the data. The calculation process is as follows:

$$Y = a + bX \quad (1)$$

In which, X is foam content; Y is density before autoclaving.

$$r = \frac{\sum (X_i - \bar{X}) \times (Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \times \sum (Y_i - \bar{Y})^2}} \quad (2)$$

In which, r is correlation coefficient; $\bar{X}$ is average foam content; $\bar{Y}$ is average density before curing.

$$b = \frac{\sum (X_i - \bar{X}) \times (Y_i - \bar{Y})}{\sum (X_i - \bar{X})^2} \quad (3)$$

In which, b is the slope of the fitted line.

$$a = \bar{Y} - b\bar{X} \quad (4)$$

Bring the above four sets of data into the equation:

$$a = 1646.7; b = -0.7374; r = -0.992$$

Figure 2. Linear fit of foam content and density

The linear function is as follow:

$$Y = -0.7374X + 1646.7 \quad (5)$$

In which, X is foam content; Y is density.

3 Preparation test of foamed magnesium slag cement

Based on the forming test, the ash-slag ratio, the water-cement ratio and the dry mix ratio were further adjusted. And in this test, we used the autoclaved curing in the same condition. Finally, we carried out the dry density tests, the cubic-compressive-strength tests and the tests of the moisture content and the water absorption rate.

In addition, it was considered to increase the amount of Portland cement in the dry material. This could effectively improve the early strength of the cement and accelerate the initial setting time. On the other hand, relevant research indicated that Portland cement could improve the mechanical properties of magnesium slag-fly ash-cement system.

Besides, by comparing the content of magnesium slag with Portland cement, it is found that the content of silicon in magnesium slag is slightly insufficient, while the content of SiO₂ in silica powder is generally

up to 85%-98%. Hence, we tried to add a little silica powder in the products to improve performance.

Various parameters of the samples are shown in Table 3.

3.1. Test results

Table 3. Dry mix and water-cement ratio

No.	Dry mix					Water-cement ratio
	Ash-slag ratio	slag	ash	Portland cement	Silica powder	
2-1	0.8	55.6%	44.4%			0.30
2-2	0.8	55.6%	44.4%			0.33
2-3	0.8	55.6%	44.4%			0.36
2-4	0.8	41.7%	33.3%	20%	5%	0.35
2-5	0.8	41.7%	33.3%	20%	5%	0.37
2-6	0.8	41.7%	33.3%	20%	5%	0.39
2-7	0.8	30.6%	24.4%	40%	5%	0.37
2-8	0.8	19.4%	15.6%	60%	5%	0.37

The test records are shown in Table 4

Table 4. Preparation test record

No.	Foam content/ ml·kg ⁻¹	Foam density/ kg·m ⁻³	Situation note	Pre-curing density/kg·m ⁻³
2-1	700	47.6	Poor foaming effect	1235
2-2	700	8.3	Poor foaming effect	1675
2-3	700	50.3	Acceptable foaming effect	1215
2-4	700	18.0	Poor foaming effect	1420
2-5	700	92.0	Good foaming effect	925
2-6	700	55.5	Good foaming effect	915
2-7	700	86.0	Good foaming effect	906
2-8	700	60.0	Good foaming effect	1000

The tests results of the samples are shown in Table 5.

Table 5. Results of mechanical and physical properties tests

No.	Post-curing density/kg·m ⁻³	Dry density/ kg·m ⁻³	Moisture content	Water absorption	compressive strength/MPa	28d-natural-curing strength/MPa
2-1	1210	1095	10.5%	31.1%	13.73	1.41
2-2	1660	1510	9.9%	24.5%	24.50	2.10
2-3	1260	1135	11.0%	25.1%	14.43	1.92
2-4	1360	1230	10.6%	22.3%	16.97	9.25
2-5	870	745	16.7%	35.5%	4.50	1.00
2-6	880	760	15.7%	35.2%	4.23	0.90
2-7	973	796	22.3%	38.7%	Cracked	3.44
2-8	997	830	20.1%	38.5%	Cracked	5.82

3.2. Analysis and discussion of test results

After the ash slag ratio was increased to 0.8, all the test pieces formed and had certain mechanical strength after autoclaved curing. The reason was that fly ash could stimulate the activity of slag, which helped to increase the hydration reaction. Hence, we thought it would be suitable to set the ash-slag ratio to around 0.8.

Meanwhile, it was found that when 20% Portland cement was added to the dry material, the initial setting time of the test pieces was obviously improved. It took only 2 to 3 days to get the samples demolded. And it was also good for foaming equality and producing efficiency

And after the addition of 5% silicon powder, the viscosity of the slurry and foaming effect were improved. Therefore, incorporation of silicon powder

was beneficial to the performance of foamed magnesium slag cement.

During the test, we found that lower water-cement ratio made the slurry hard to mix with foam, and the foam would finally end up in rupture, while if the ratio was too high, the slurry would be so close to fluid, that the initial setting time is too long with bad foaming effect. Therefore, through the test, we thought the suitable water-cement ratio should be in the range from 0.37 to 0.40.

3.3. Dry density and cube compressive strength

The dry density and cubic compressive strength of the test pieces are shown in Table 6.

Table 6. Dry density and compressive strength

No.	Dry density/ kg·m ⁻³	Dry level	Post-curing compressive strength/ MPa	Reference range in specification
2-1	1095	A12	13.73	4.5~6.0
2-2	1510	/	24.50	/
2-3	1135	A12	14.43	4.5~6.0
2-4	1230	A14	16.97	5.5~10.0
2-5	745	A08	4.50	1.8~3.0

It can be seen from the above table that the mechanical strength of the test pieces, dry density over A08, can meet the requirements of the recommended values in the specification.

The least square method is used to analyze the data of the strength and dry density of samples after steaming. The function image after regression fitting is shown in Figure 3.

The fitted function with dry density as the independent variable and cube compressive strength as the dependent variable is:

$$Y = 0.0261X - 14.98 \quad (6)$$

In which, X is dry density of foamed cement; Y is cube compressive strength.

Figure 3. Linear fit of strength and dry density after curing

4 Conclusion

In terms of dry mixture, we recommend the ratio of 0.8, in which the slurry could form and at the same time, magnesium slag could be consumed at most. Adding in silica powder could shorten the initial setting time and improve the slurry viscosity to protect the foam. In terms of water-cement ratio, proper value should range from 0.37 to 0.4.

The density and strength of the magnesium slag cement would decrease as the amount of foam incorporation increases.

Through the comprehensive performance comparison, the preferred formula is 0.8 ash-slag ratio, 0.39 water-cement ratio, 39.4% slag, 31.6% ash, 20% Portland cement and 9% silica powder, and the foam content is determined by the product density.

Acknowledgments

Thank my mentor, Professor Ma. Without his tireless guidance, selfless revision and helpful improvement of my thesis, there will be no possibility for this thesis to finish. I would like to express my thanks to the teachers who have guided and helped me. What I need to thank most is my family. Thank them for supporting me all the time. It is because of their

support that I can complete my studies and put my heart into scientific research.

Reference

1. Xiao Lg, Wang Sy, Luo F. Research and Prospect Analysis of Application Status of Industrial Waste Residues Such as Magnesium Slag [J]. Journal of Jilin Jianzhu University, 2008, 25(1): 1-7.
2. Jones MR, Carthy M. Utilising Unprocessed Low-lime Coal Fly Ash in Foamed Concrete [J]. Fuel, 2005 (84)1398-1409.
3. Tikalsky PJ, Pospisil J, Donald WM. A Method for Assessment of the Freeze-thaw Resistance of Preformed Foam Cellular Concrete [J]. Cement and Concrete Research, 2004, (34): 889-893.
4. Xu W, Liu Xy, Zhu Qh. Experimental Study on Chemical Foamed Concrete Slab for External Thermal Insulation [J]. Concrete, 2012(3): 131-134.
5. China Academy of Building Research, etc. Foam Concrete: JG/T 266-2011[S]. 2011.