

# Preparation and Properties of a Composite Grinding Aid for Steel Slag and Granulated Blast Furnace Slag

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**Abstract.** This paper presented the design of a composite grinding aid for steel slag and granulated blast-furnace slag with glycerol distilled residue as main raw material. Several commonly used grinding aids were investigated and the optimal formulation of the composite grinding aid was obtained with the mass ratio of triethanolamine: glycerol: calcium lignosulfonate: glycerol distilled residue = 1:1:5:3. The suitable dosage was 0.03 % of the material to be ground. The steel slag and granulated blast-furnace slag powders ground with this composite grinding aid gave higher fineness and the cementing material produced exhibits higher mechanical strength at any age, indicating that there is a synergistic effect among the materials used.

## 1 Introduction

Cementing material is one of the most important building materials nowadays. However, the production of cement, especially in grinding step, consumes much electrical energy. Cement industry is a significant contributor to greenhouse gas emissions [1]. Various government has vigorously been promoting energy saving and low-carbon economy in recent years. Therefore, industrial waste residues have been widely used to produce cementing materials, which is helpful to the reduction of resource consumption, CO<sub>2</sub> emission and production cost [2-5].

Steel slag and blast-furnace slag, two major by-products or waste residues in steel plants, have potential hydration properties by grinding to a certain fineness [6]. Cementing materials of high replacement of clinker with steel slag and blast-furnace slag show better long-term strength and durability, while the strength development at the early age is slower than ordinary Portland cement because of the lower activity. In grinding process, many chemical additives called grinding aids were added, which can improve the early strength of cementing material by improving the fineness. Usually, some surfactants containing polar groups are used because they have better absorbability and dispersibility which are benefit to grinding process and thus increase the mechanical strength of cementing materials.

The common grinding aids include alcamines, alcohols, fatty acids and stearic acid. Phenol and phenol-derivates, acetates, organo silicones and molasses are also used as grinding aids. Currently, triethanolamine, was the most commonly used grinding aid in cement industry but with a high cost. Moreover, it seems not as effective as expected for some mineral admixture such as blast-furnace slag and steel slag which have higher hardness than clinker. Therefore, designing a cost effective grinding aids become an urgent need for cement manufacturers.

Glycerol distilled residue (GDR), which contains mixed glycerol of different degree of polymerization, is a side product in the production of glycerin. Because of complex compositions and difficult to purify, there is still

no method to use it effectively. The purpose of this work is to use GDR with other materials combinedly to produce a low cost and effective grinding aid for steel slag and blast-furnace slag. The performance of this grinding aid was tested by using in steel slag and blast-furnace slag based blend cement. Fineness and mechanical strength testing were used for evaluating the effect of GDR. FT-IR was used for characterization of the materials treated with this grinding aid.

## 2 Material and methods

### 2.1 Raw materials

The glycerol distilled residue used in this work contains glycerol 25%, diglycerine 45%, polyglycerols 22% and some salts. Blast-furnace slag and steel slag were provided by Beijing Steel Co. Ltd. Desulfurized gypsum was from Xibaipo Powder Plant. Portland cement used in this paper was supplied by the Orient Dingxin Cement Co. Ltd. The chemical compositions of some raw materials were listed in Table 1.

Table 1 Compositions of raw materials

Composition /Wt%	Blast-furnace slag	Steel slag	Desulfurized gypsum
CaO	41.37	31.37	41.24
SiO <sub>2</sub>	34.48	37.12	3.69
Al <sub>2</sub> O <sub>3</sub>	10.77	4.01	1.17
MgO	6.58	8.94	1.94
Fe <sub>2</sub> O <sub>3</sub>	5.75	13.22	0.33
SO <sub>3</sub>	—	—	43.85
f-CaO	—	1.44	—
SO <sub>2</sub>	—	—	—
Loss on ignition	-0.12	-0.85	6.39

## 2.2 Methods

Desulfurized gypsum was calcined at 800 °C for 1 hour before use. The grinding aids selected through initial experiments and brainstorming are A1 (triethanolamine), A2 (triisopropanolamine), B1 (glycol), B2(glycerol), C (ester), D (stearate), E (lignosulfonate), F (dodecylbenzene sulfonate) and G (GDR).

Each material was first ground to the desired fineness in a 5 kg laboratory-type ball mill. The cementing material was prepared with the mass proportioning of blast-furnace slag : steel slag : cement clinker : calcined gypsum = 37.5:37.5:15:10. Specimens of the cement paste with dimension of 40 mm×40 mm×160 mm were molded, which was de-molded after 24 hours, and then cured at 20°C ± 3°C and relative humidity of 90±5%. The mechanical strength values were measured at the age of 3 d and 28 d, respectively. The flexural strength was the average of every three tests, whereas the compressive strength value was the average of six tests.

For measurement of the fineness of blast-furnace slag powder and steel slag powder, 45µm sieve residue and Blaine values were used.

## 3 Results and discussion

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The grinding effects of several selected materials on the basis of the former work were studied. Table 2 listed the results of the 45 µm sieve residue and Blaine fineness for blast-furnace slag and steel slag powder with and without grinding aids. It was found that these grinding aids all increased the fineness to some extent. Among them, alcohol amines, alcohols and GDR exhibited better effects. The optimal additions of C, D, E, F and G were determined as 0.2%, 0.1 %, 0.1%, 0.1%, and 0.09 %, respectively.

Table 2 Fineness of blast-furnace slag and steel slag

No	Dosage Wt%	Blast-furnace slag		Steel slag	
		45µm sieve residue Wt%	Blaine fineness m <sup>2</sup> /kg	45µm sieve residue Wt%	Blaine fineness m <sup>2</sup> /kg
X*	0	8.6	342.1	20.9	376.7
A1	0.027	5.3	426.1	10.5	499.6
A2	0.090	5.9	396.8	12.7	465.7
B1	0.024	6.2	405.4	14.2	438.5
B2	0.022	5.1	411.9	13.5	451.2
C	0.05	7.0	367.3	17.5	396.4
	0.10	7.3	377.2	18.9	387.6
	0.15	6.6	358.1	18.7	390.2
	0.20	6.9	378.4	17.6	400.2
D	0.05	7.8	365.8	19.1	379.4
	0.10	7.5	374.6	15.9	398.8
	0.15	8.2	382.3	16.6	391.3
	0.2	7.7	379.1	17.0	382.7
E	0.05	7.6	348.6	17.6	387.5
	0.10	7.1	386.5	15.3	412.8
	0.15	7.9	362.4	15.8	396.1
	0.20	7.6	365.3	16.1	405.6
F	0.05	7.3	367.3	17.4	398.4
	0.10	6.9	386.1	16.9	402.1
	0.15	6.5	401.6	17.1	387.2
	0.20	7.2	396.8	18.6	391.0
G	0.025	5.6	402.6	17.23	498.8
	0.05	5.1	455.2	12.63	513.2
	0.075	6.0	457.0	11.64	506.3
	0.09	5.5	462.8	13.69	496.5

X\*:Blank

Table 3 presented the physical and mechanical properties of the cementing materials produced from blast-furnace slag and steel slag with and without grinding aids. It was clear that an increase in Blaine fineness of blast-furnace slag and steel slag powder facilitated the strength increase of cementing material. Alcohol amines contained both hydroxyl and amino groups, the former possesses good grinding effect, and the latter endowed it with excellent dispersibility through electrostatic repulsion. The early strength development of cementing material with A2 was higher than that with A1. The reason may be that adsorption of A2 was easier and more stable for its planar structure. However, cementing material with the A1 showed higher strength value at later age owing to the stronger dispersibility brought by its three-dimensional molecular structure. Alcohols with hydroxyl group also have good adsorption capacity and dispersibility. E has poorer grinding effect than alcohol amines and alcohols. G contains glycerol and polyglycerols, which contribute the excellent effect for grinding.

Table 3 Physical and mechanical properties

No	Initial settig /min	Final setting min	Flexural strength		Compressive strength	
			3d MPa	28d MPa	3d MPa	28d MPa
X*	116	222	3.4	6.1	13.3	35.0
A1	112	212	4.5	6.9	21.2	39.9
A2	121	216	4.2	7.2	17.2	41.7
B1	117	214	3.9	6.6	18.9	38.9
B2	112	208	4.5	6.9	19.3	44.7
C	126	219	3.6	5.9	14.3	35.7
D	129	228	3.7	6.2	16.4	37.7
E	125	211	4.1	7.0	16.8	39.1
F	119	233	3.5	6.4	13.9	36.8
G	130	229	3.9	6.3	15.7	37.2

Considering the grinding effect and cost of various grinding aid combinedly, A2 (for early strength), B2 (for later strength), E (for later strength, low cost) and G (low cost, for finer grinding) were selected to prepared the composite grinding aid and the optimized proportion was obtained: A2 : B2 : E : G=1:1:5:3 ( mass ratio). Consider the grinding effect and cost, the optimized addition of the composite grinding aids was determined as 0.03 % of the material to be ground, see Table 4.

Table 4 Evaluation of the composite grinding aids

Sample	Dosage /Wt%	Steel slag	
		Blaine fineness m <sup>2</sup> /kg	Blaine fineness m <sup>2</sup> /kg
Blank	0	342.1	376.7
Triethanolamine	0.027	426.1	499.6
Composite grinding aids	0.01	411.5	478.5
Composite grinding aids	0.03	445.5	515.2
Composite grinding aids	0.05	452.7	518.6
Composite grinding aids	0.07	458.2	522.8

The grinding effect of composite grinding aid was also evaluated by the mechanical properties of the cementing materials from steel slag and blast-furnace slag. Compared with the blank, the addition of composite grinding aid significantly improved mechanical strength

of cementing materials at both early and later ages compared with triethanolamine. The initial and final setting times were slightly decreased, which can be attributed to the higher fineness and larger hydration rate of the powders. The excellent grinding effect was also attributed to the synergistic effect of different materials. The prepared cementing material with composite grinding aids conformed to Grade 42.5 of GB175-2007 (Ordinary Portland Cement, China national standard).

## 4 Conclusions

A composite grinding aid for steel slag and blast furnace slag was prepared with the mass proportion of alcohol triethanolamine: glycerol: calcium lignosulfonate: GDR = 1:1:5:3 ( in mass ratio) and the suitable dosage was determined as 0.03% of ground materials. This provided an effective approach to utilize GDR, a side product or solid waste difficult to dispose. The grinding effect of this composite grinding aid can be well explained using FT-IR and SEM. Compared to the commonly used grinding aids, the composite grinding aid had a better grinding effect resulted from the synergistic effect of functional groups as hydroxy and amine groups. The steel slag and blast furnace slag based cementing material containing 0.03% composite grinding aids has higher flexural strength and compressive strength at the age of 3 d and 28 d, and possesses higher consistency, and conforms to Grade 42.5 of GB175-2007 (Ordinary Portland Cement, China national standard). In all, the application of the composite grinding aid makes it easier to utilize industrial waste residues, such as steel slag, in construction and building materials, thus reducing the environment pollution, energy consumption and production cost.

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