



# Value-added utilization of waste silica powder into high-quality chromite pellets preparation process

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## ABSTRACT

For improving the consolidation strength of chromite pellets with high Cr/Fe ratio of 2.55, industrial waste silica powder was innovatively applied as the additive to facilitate the pellet consolidation. Results showed that with the dosage of silica powder increasing, the drop number of green balls was enhanced obviously, while the compressive strength was increased initially and then dropped. Quality indexes of green balls were considerably improved with keeping the dosage of silica powder within 2–4%. When 4% silica powder was added, the compressive strength of both preheated and roasted pellets achieved an evident improvement from 231 N/P and 790 N/P to 431 N/P and 1298 N/P, respectively. The preheating and roasting temperatures decreased from 1100 °C and 1350 °C to 1075 °C and 1300 °C, respectively, which met the normal operation temperature range of grate-kiln process. The revealed mechanism of silica powder strengthening pellets consolidation consisted of three aspects: new minerals formed via solid phase reaction between silica powder and chromite facilitated the minerals crystallization; a small amount of liquid phase formed during roasting process facilitated the ion diffusion; the intertwined structure was formed between liquid phase and chromite particles. The research findings not only provide theoretical guidance to produce high quality chromite pellets for submerged arc furnace, but put industrial waste into value-added use, which exhibits great application prospect.

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## 1. Introduction

Chromium is an important metal characterized high melting point, good chemical activity and great resistance to erosion. It has been widely used in precision alloy, resistance alloy, and high temperature alloy smelting, and it is also the important raw materials for making stainless steel and high-speed steel [1,2]. Chromite resources are abundant throughout the world, which exceed 12 billion tons and are mainly distributed in South Africa, Zimbabwe, Kazakhstan, Turkey, etc. [3,4] 65% of chromite ores is used to produce stainless steel and various special alloy steels. Submerged arc furnace is the main equipment for ferrochromium smelting, with lump and fine (<8 mm) chrome iron ores used as the main raw materials. Taking the burden permeability into consideration, lump chromite ore is generally the more suitable raw material for smelting in submerged arc furnace [5]. However, the lump chromite ore only accounts for 20% of the annual total amount, and the rest are fine ores. Compared with the lump ores, the content of chrome in fine chromite ores is higher, which commonly characterizes higher Cr/Fe ratio, while the price is lower [6,7]. Therefore, the use of cheap fine chromite ore is an effective approach to reduce the production cost, and to

improve the market competitiveness of domestic ferrochromium plants.

It is necessary to agglomerate fine chromite ore for meeting the requirements of the size and performance for smelting. Currently, oxidized pellets preparation invented by Finland Outotec Company (OutocumPu method) and pellets pre-reduction technology using rotary kiln developed by Japan (SRC method) are widely-used preparation technologies due to their advantages of large output and stable product quality [8–12]. Compared with pre-reduction method, the oxidized pellet method has the advantages of better adaptability to different raw materials and uniform quality of the finished product. It is therefore more suitable for dealing with fine chromite ores and meeting the requirements of large-scale submerged arc furnace production. As for the chromite ores derived from different ore regions, the systematic research about the roasting process and operating parameters affecting the quality of chromite pellets showed that the consolidation strength of pellets would not achieve significant increase until enhancing the roasting temperature to 1300–1350 °C, especially for the pellets with higher Cr/Fe ratio [13–19]. However, high roasting temperature brings great difficulties to the grate-kiln production process, and it is not conducive to saving energy. Currently, there is no effective measure found to solve the problem. For satisfying the requirements of slag behavior during chromite smelting process, silica was simultaneously added into submerged arc furnace together with chromite pellets. According

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**Table 1**  
Chemical compositions and loss on ignition (LOI) of raw materials.

Raw materials	Chemical compositions/%							LOI/%	Cr/Fe
	TFe <sup>a</sup>	FeO	Cr <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	MgO	Al <sub>2</sub> O <sub>3</sub>	CaO		
Chromite-A	20.55	19.75	40.60	4.96	11.13	14.70	0.39	0.87	1.35
Chromite-B	19.03	18.38	42.11	5.07	11.98	13.46	0.39	1.31	1.51
Chromite-C	17.51	17.01	43.62	5.19	12.83	12.22	0.40	1.75	1.70
Chromite-D	12.94	12.90	48.15	5.53	15.37	8.49	0.41	3.08	2.55
Silica powder	1.16	ND <sup>b</sup>	ND	91.70	0.87	0.87	1.01	ND	ND
Bentonite	2.24	ND	ND	60.95	2.15	13.75	2.25	13.44	ND

<sup>a</sup> TFe: Total iron content.

<sup>b</sup> ND: No data.

to this property, if adding silica into chromite pellets during preparation process can improve pellets strength, it will be a desirable approach to prepare high-quality chromite pellets with high Cr/Fe ratio. For realizing successful addition of silica into pellets preparation process, most of the particles should be kept at the size range <0.074 mm through grinding. In accordance with our investigation, silica powder can be collected from the flue gas generated during ferrosilicon smelting process, which can be used as the silicon-bearing additive [20,21]. The annual output of silica powder reaches 1.5 million tons, while its utilization rate is quite low [22]. The SiO<sub>2</sub> existed in silica powder is amorphous form, which characterizes high activity and fine particle size.

Therefore, for realizing the comprehensive utilization of waste silica powder and producing high-quality chromite pellets for submerge arc furnace production, adding silica powder into chromite pellets to facilitate consolidation was firstly proposed. In this investigation, for addressing the problem encountered during the preparation process of high-quality chromite pellets with high Cr/Fe, the influence of adding silica powder into chromite pellets on the pelletizing and consolidation characteristics of pellets was studied, and the mechanism of silica powder strengthening consolidation of chromite pellets were revealed as well.

## 2. Materials and methods

### 2.1. Properties of raw materials

Raw materials used in this investigation included four kinds of fine chrome iron ores, bentonite and silica powder, of which chemical

compositions are shown in Table 1. It can be seen that chromite-A characterized a lower Cr/Fe ratio of 1.35, while chromite-D characterized a higher Cr/Fe ratio of 2.55. The main mineral in chromite was spinel of (Fe, Mg)(Cr, Fe, Al)<sub>2</sub>O<sub>4</sub>. Since crystal lattices replacement occurred between Mg/Al and Fe/Cr, the chromite with low contents of Fe and Cr characterized higher contents of MgO and Al<sub>2</sub>O<sub>3</sub>. The content of SiO<sub>2</sub> in the silica powder was 91.07%, while the contents of MgO and Al<sub>2</sub>O<sub>3</sub> were 2.90% and 0.87%, respectively.

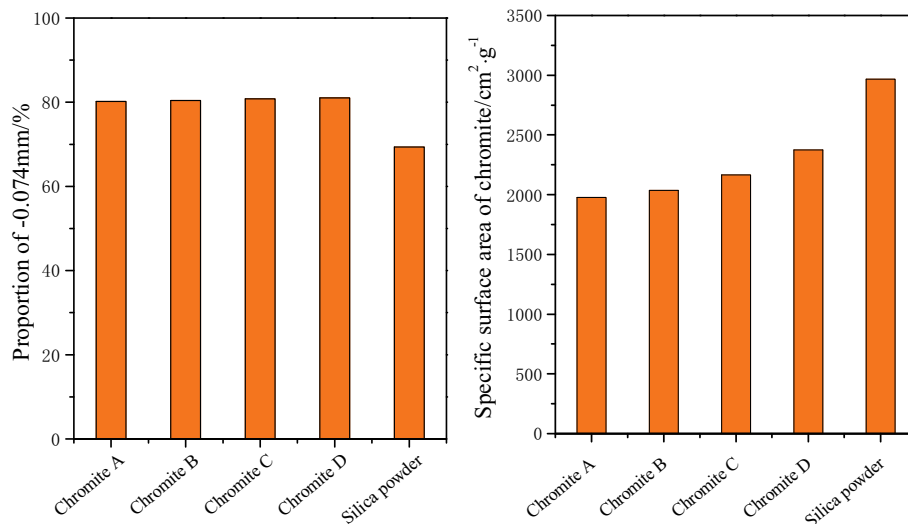
The bentonite was used as a binder during chromite pellets preparation process, and its physical properties included colloid index of 98 ml·(15 g)<sup>-1</sup>, swelling capacity of 16.25 ml·g<sup>-1</sup>, water absorption rate (2 h) of 367% and the montmorillonite content of 60.52%.

The size distribution and specific surface area of chromite ores and silica powder were given in Fig. 1. It can be found that the proportion of particles <0.074 mm in chrome iron ores all reached around 80%, and it accounted for 69.35% in silica powder, which was close to the required proportion of 80%. Moreover, the specific surface area of silica powder was considerably bigger than that of chromite ores, which indicated that more fine-grained particles contained in silica powder.

### 2.2. Experimental methods

The whole preparation process of chromite pellets consisted of ore proportioning, mixing, pelletizing, drying, preheating, roasting and pellet quality testing. The pelletizing test was carried out in a laboratory-scale disk granulator, and raw materials provided consisted of 4 kg of chromite concentrate (dry base), and bentonite at a fixed mass proportion of 1.25% for each individual case. Moreover, silica powder was added when doing the tests strengthening the consolidation of chromite pellets. After ore proportioning, raw materials were fully mixed, and then underwent the pelletizing process in a disc of 1000 mm in diameter, 25 r/min in speed, and 47° in dip angle. After pelletizing, green balls of 12–14 mm in diameter were selected and dried under 105 °C in a drying oven.

A two-stage horizontal tube furnace was used to simulate the practical grate-kiln production process, which consisted of one preheating stage and the other roasting stage. A corundum porcelain boat was used to carry dried pellets, and then moved it into the furnace. As the furnace was open-type, it could ensure that the whole preheating and roasting process proceeded in air atmosphere. According to the pre-set heating rate, heating time, and cooling rate, pellets in the furnace experienced preheating, roasting and cooling process in sequence (Fig. 2).



**Fig. 1.** Size distribution and specific surface area of chromite and silica powder.

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