ILASS–Europe 2022, 31th Conference on Liquid Atomization and Spray Systems, 6-8 September 2022, Virtual, Israel

Influence of Heated Gas on Atomization of Highly Viscous Melts

A. Weicht*[1], L. Achelis[2], M. Peters[1], V. Uhlenwinkel[1], U. Fritsching[1,2]
[1]Leibniz Institute for Materials Engineering - IWT, 28359 Bremen, Germany
[2]Particles and Process Engineering, Department of Production Engineering, University of Bremen, 28359 Bremen, Germany
*Corresponding author: a.weicht@iwt.uni-bremen.de

Abstract

Blast furnace slags are produced as a by-product of iron production. These slags typically are used in powder form in the building industry, e.g. in the production of concrete. Therefore, the liquid slags are wet granulated, dried and grinded, which is an energy, water and emission intensive process. To save natural resources, reduce the CO_2-emissions and enhance the flowability of the particles, the liquid state of the slag and its heat energy could be utilized by atomizing the melt directly at the blast furnace.

The high viscosity of slags complicates the atomization and reduces the time available for speroidization, which often leads to the formation of fiber material. To improve the generation of spherical particles, the use of hot gas in a new developed atomization plant is being investigated. Initial trials and first optimization measures in the plant and the process parameters show a stabilisation of the process and a reduction of the fiber content in the atomized product.

Keywords

Hot gas atomization, mineral melts, free-fall atomization, powder production

Introduction

In Germany, 8 Mio t of blast furnace slags are produced per year as a by-product of iron production in blast furnaces. In this, 90 % of the slag is granulated for producing cement additives, thus saving natural resources and emissions. In this way, 355 Mio t of natural stone has been saved from using granulated blast furnace slag instead of clinker in the production of cement in Germany within the last 70 years. [1]

The morphology of slag particles in the cement has an important influence on the processability and the quality and composition of a concrete. The conventional treatment process of the slag consists of granulation, drying and grinding and results in irregular shaped particles. However, powders consisting of spherical particles have a better flowability and therefore may reduce the amount of cement necessary in the production of the concrete.

Spherical slag particles may be produced by atomizing the liquid slag, which also may reduce the process steps and saves energy consumption and CO_2-emissions [2]. Due to the conventional wet granulation of the liquid slag, the high amount of heat energy of the melt, of about. 1.5 to 1.8 GJ per tonne [3, 4], is not utilized in the common processing route but may be used to atomize the slag directly at the blast furnace.

Since liquid slags differ considerably from molten metals in viscosity and density and also tend to form fibers during atomization, it is necessary to adopt the atomization process to the atomization of slags. As an example of slag properties, a decrease by 150°C at a temperature of 1700°C doubles the viscosity from 0.1 to 0.2 Pa*s (see figure 2).

The cooling of the slag during the disintegration of the melt with cold gas leads to a rapid increasing of the viscosity. Due to he high viscosity, the formation of drops may be uncompleted and fibers and elongated particles are formed. To enhance the spheroidization time, the cooling rate of the liquid has to be reduced. Therefore, the use of heated gas on the atomization of a blast furnace slag and its influence on the processed powder has to be investigated.

Different methods of the atomization of slags has been investigated so far. The atomization of slags with rotary cups and disks leads to particle sizes that are on average above 1 mm for cups [5, 6] and around 250 µm or higher for different kind of disks [7, 8, 9], which are too large for the use in concrete, where the requested particle size should be lower than 200 µm.

Close-coupled atomization (CCA) leads to very fine powder in metal atomization, but the risk of a solidification of melt on the nozzle in atomization of slags which leads to an abortion of the process is very high. Investigations of Lohner et al. (2005) [2] showed that free-fall atomizer (FFA) with hot gas could reach average particle sizes up to 200 µm and reduce the fiber content.in comparison to cold gas atomization of slags. However, the particles should be smaller than 200 µm for the use in concrete. So the FFA has to be optimize.

Material and Methods

The raw material used in the investigation for atomization is a common granulated blast furnace slag from the Holcim (Deutschland) GmbH. Three slags from different steel producers were analyzed with x-ray fluorescence spectroscopy (RFS) for its chemical components by the FEhS – Intitut für Baustoffforschung e.V. in Duisburg. They also calculated the slag viscosity according to the modified Urbain-Modell.

A free-fall atomizer as illustrated in figure 1 was developed for the disintegration of the slag with gas temperatures up to 850°C. In view of the first results of the experiments, a primary gas nozzle was implemented to the system to improve the process stability.

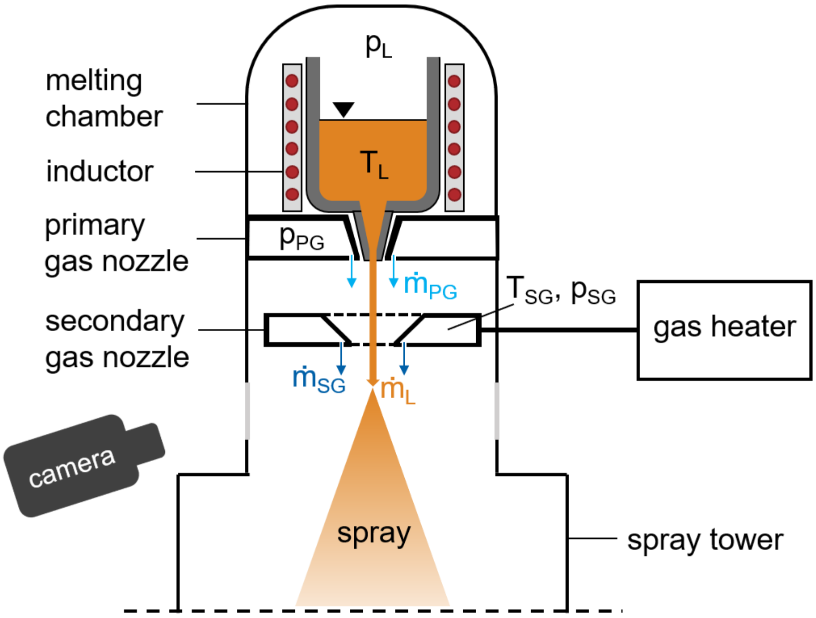


Figure 1: Schematic of the experimental setup for atomization of the melt.

The raw material in the melting crucible is heated to the temperature T_L, the chamber and the tower are flooded with argon or nitrogen as inert gas. T_L is the liquid temperature of 1720°C ± 20°C and p_L the pressure in the melting chamber at the atomization. The crucible orifice diameter is 2.5 mm. The primary gas (PG) with the gas mass flow $\dot{m}_{PG}$ and the pressure p_{PG} at room temperature and the preheated secondary gas (SG), with the gas mass flow $\dot{m}_{SG}$, the pressure p_{SG} and the temperature T_{SG} for the atomization is the same than the gas used for inertization of the plant. The area of the disintegration is recorded by a video camera and also by a high-speed camera at a frame rate of 16000 fps. The produced powder is collected in a container 5 m below the atomizer. The fine powder in the exhausted gas is filtered by a cyclone and collected in a container at its bottom. To extract the fibers from the particles, the powder is sieved by an air jet sieve (e200 LS, Hosokawa Alpine AG, Germany) and afterwards the particles are classified in different size fractions by a vibration sieving (Retsch Vibro, Retsch GmbH, Germany).

Results and Discussion

The main components of the three slags are shown in table 1. The atomized slag "Slag 1" is a common slag in the iron production with very similar components to the two other ones. Also the viscosity of Slag 1 and 2 is nearly the same (see figure 2). Slag 3 has a higher viscosity but especially in the interesting high temperature area above 1500°C, all three slags are very comparable.

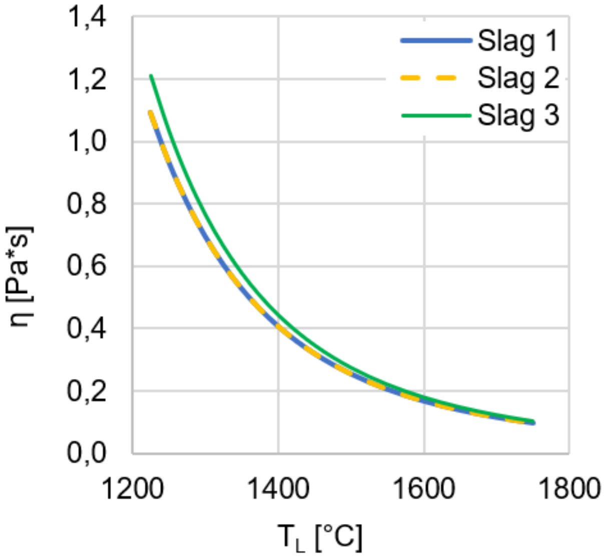


Figure 3: Temperature dependency of the viscosity of three common blast furnace slags from different iron producers in Germany, calculatet by FEhS – Intitut für Baustoffforschung e.V.

Table 1: Main ingredients of the three common blast furnace slags, analysed with RFS by FEhS – Intitut für Baustoffforschung e.V..

	Slag 1	Slag 3	Slag 2
CaO	39,5	40,6	42,4
SiO2	35,2	37,0	34,7
Al_2O_3	12,3	11,0	11,0
MnO	8,1	7,8	6,8

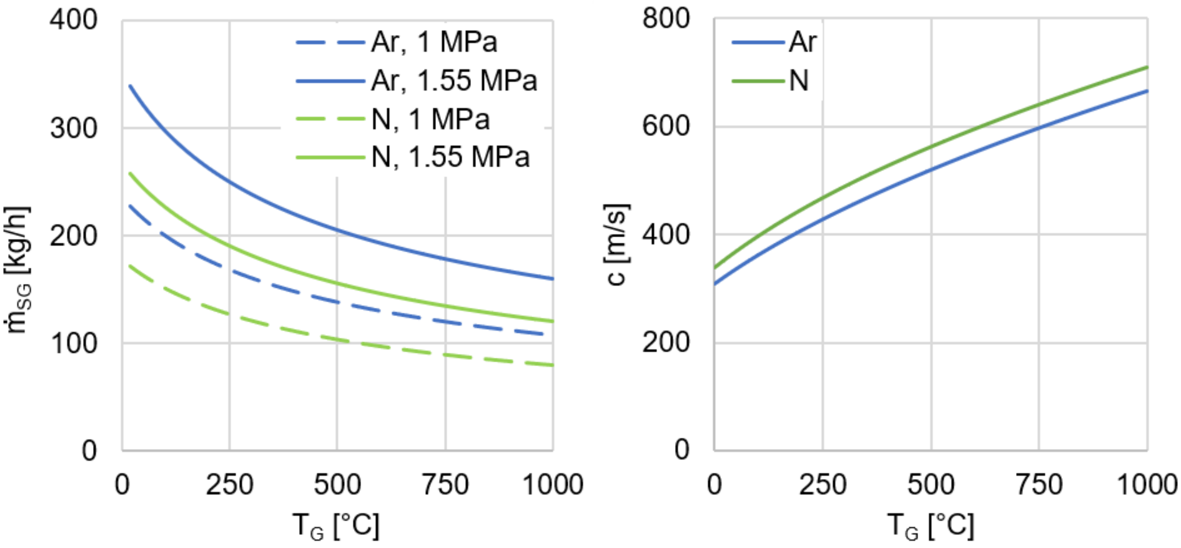


Figure 4: Temperature dependent secondary gas mass flow calculated according to Bohl and Elmendorf [10] for the used nozzle (left) and sound speed (right) for argon and nitrogen.

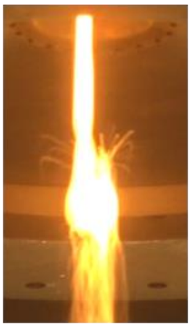
paremeters	**snapshot of the atomization**		
	start	**middle**	**end**
T_{SG} = 300°C p_{SG} = 1 MPa No primary gas			
T_{SG} = 300°C p_{SG} = 1.55 MPa No primary gas			
T_{SG} = 750°C p_{SG} = 1.55 MPa No primary gas			
T_{SG} = 750°C p_{SG} = 1.55 MPa with primary gas			

Figure 5: Images taken from the videos of different experiments after beginning, in the middle and before the end of the atomization. You see the region of atomization with the secondary gas nozzles at the top of the pictures.

The increased temperatures of the atomization gas should reduce the amount of fibres due to the lower cooling at the disintegration. Further the preheating of the gas can reduce the amount of gas necessary for the atomization due to the lower gas density, which leads to lower gas mass flowrates with increasing temperature (see figure 3, left). The use of nitrogen instead of argon reduces the gas consumption also. Since the gas nozzles have a cylindrical shape, the maximum gas velocity is limited to the speed of sound, which also increases with increasing gas temperature (see figure 3, right). This could lead to a higher impact between atomization gas and melt in the atomization region and should improve the disintegration of the melt.

The influence of the secondary gas pressure and temperature on the behaviour of the slag in the region of atomization is shown in figure 4. A higher gas pressure leads to a more pronounced recirculation of the gas flow back to the nozzle instead of downwards into the spray tower (see figure 4, row 2). This improves the amount of melt, which is transported upwards to the nozzle by the recirculating gas. The melt comes into contact with the nozzle and possibly adheres there. At higher gas pressures, more fibers are produced but the amount of the smallest particle fractions also increases with increasing pressure (see figure 5, left). By increasing both, the gas pressure and the gas temperature, the gas recirculation gets stronger and the contact of melt and nozzle becomes even more critical, since the temperature of the nozzle is also higher and the formation of melt adhesions are heavy (see figure 4, row 3). By further development of the melt solidifications at the nozzle, the abortion of the process becomes more probable due to the blockage of the outlet. Furthermore, the melt adhesions improve the formation of fibers (see figure 5, right). The higher gas temperatures increase the particle fraction smaller than 90 µm as well.

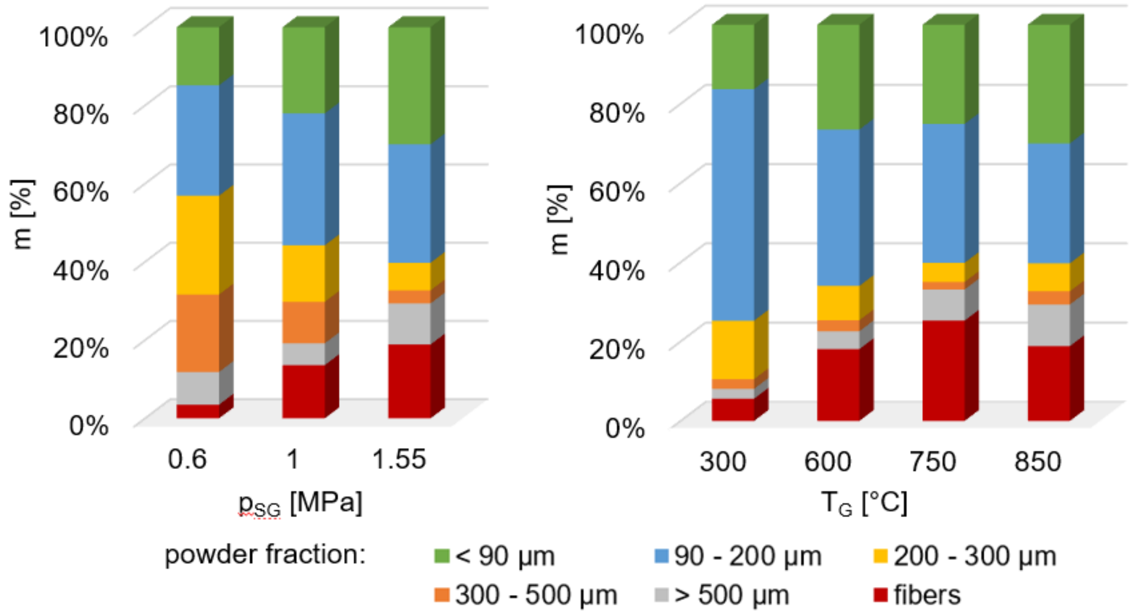


Figure 7: Particle and fiber mass fraction of the atomized slag with nitrogen in dependence of the secondary gas pressure at a gas temperature of 850 °C (left) and secondary gas temperature at a gas pressure of 1.55 MPa.

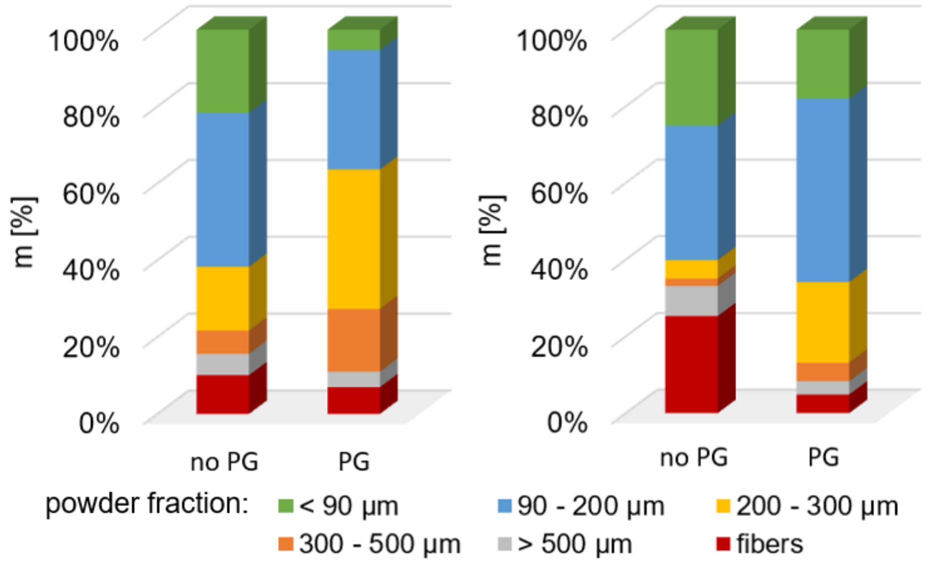


Figure 8: Particle and fiber mass fraction of the atomized slag with argon in dependence of the use of primary gas (PG) with a secondary gas temperature of 750°C and a secondary gas pressure of 1 MPa (left) and 1.55 MPa (right).

To stabilize the atomization at high pressure and temperature of the secondary gas, a primary gas nozzle has been implemented in the system at the melt outlet between the melting chamber and the secondary gas nozzle. A parameter study was done to find the proper mass flow ratio of primary gas, secondary gas and melt. As is seen in figure 4, row ,4 the atomization process become stable due to the primary gas utilization at a ratio of $\dot{m}_{PG}$ / $\dot{m}_{SG}$ = 0.15 and $\dot{m}_{PG}$ / $\dot{m}_{L}$ = 0.11. In addition, a stabilized atomization reduces the fiber content especially for the higher atomization gas pressure (see figure 6). Unfortunately, it decreases the fraction of finest particles, but lesser for the higher pressure. At the gas pressure of 1.55 MPa an increase of the particles smaller than 200 µm is achieved, which increases the fraction of powder that could be used for the production of concrete.

The reproducibility of the atomization process has been investigated at four atomizations with the same parameters which leads to good match (see figure 7).

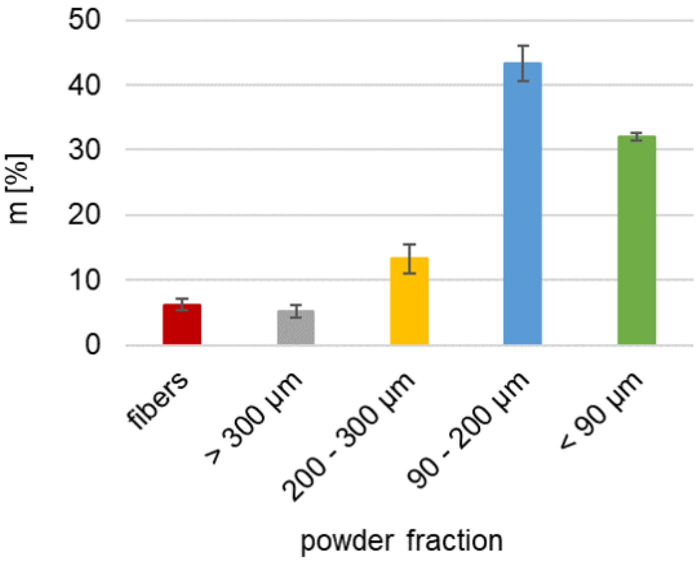


Figure 9: Reproducibility of the atomizations. Powder mass fractions and standard deviation for four experiments with the same parameters.

The used inert gas has changed between the two series of tests with and without primary gas, so the next step is to investigate the influence of the type of gas on the process stability.

Conclusions

In respect to the lower density and higher viscosity of slags compared to molten metals, a specific free-fall atomizer concept is developed which is able to operate at gas temperatures up to 800 °C. The impact of the gas temperature and the atomization gas pressure on the atomization quality and the product properties is investigated. Increased gas pressures may reduce the mean or average particle diameter, but also result in a higher content of fibers in the product. The atomization process at higher gas pressures and temperatures result in an increased recirculation movement of the gas in a region above the atomization area. This recirculation may cause melt splashing back towards the atomizer where slag elements adhere and solidify at the gas nozzle, leading to an increasing melt build-up in the course of atomization and potentially termination of the process. The recirculation of slag melt may be avoided by optimizing the geometry of the atomizer and the process conditions. Due to the improved process stability the amount of fibers in the slag atomization process is reduced.

Acknowledgments

The financial support of this project AUF0014 by the BAB Bremer Aufbau-Bank GmbH through the EFRE-Program (Europäischer Fonds für Regionale Entwicklung) is gratefully acknowledged.

Nomenclature

m	mass fraction [%]
$\dot{m}_L$	melt mass flow [kg/h]
$\dot{m}_{PG}$	gas mass flow of the primary gas nozzle (primary gas) [kg/h]
$\dot{m}_{SG}$	gas mass flow of the secondary gas nozzle (atomization gas) [kg/h]
p_L	pressure within the melting chamber [MPa]
p_{PG}	gas pressure within the primary gas nozzle [MPa]
p_{SG}	gas pressure within the secondary gas nozzle [MPa]
T_L	temperature of the liquid [°C]
T_{SG}	gas temperature within the secondary gas nozzle [°C]

References

[1] FEhS – Institut für Baustoff-Forschung e. V, https://www.fehs.de.

[2] Lohner, H., Czisch, C., Schreckenberg, P., Fritsching, U., & Bauckhage, K. (2005). Atomization of viscous melts. Atomization and Sprays, 15(2).

[3] Zhang, H., Wang, H., Zhu, X., Qiu, Y. J., Li, K., Chen, R., & Liao, Q. (2013). A review of waste heat recovery technologies towards molten slag in steel industry. Applied energy, 112, 956-966.

[4] Doschek, K. (2013). Energetische Betrachtung einer Versuchsanlage zur trockenen Granulation von Hochofenschlacke (Master's Thesis, University of Leoben).

[5] Mizuochi, T., Akiyama, T., Shimada, T., Kasai, E., & Yagi, J. I. (2001). Feasibility of rotary cup atomizer for slag granulation. Isij International, 41(12), 1423-1428.

[6] Kashiwaya, Y., In-Nami, Y., & Akiyama, T. (2010). Development of a rotary cylinder atomizing method of slag for the production of amorphous slag particles. ISIJ international, 50(9), 1245-1251.

[7] Mizuochi, T., & Akiyama, T. (2003). Cold experiments of rotary vaned-disks and wheels for slag atomization. ISIJ international, 43(9), 1469-1471.

[8] Czisch, C., & Fritsching, U. (2008). Atomizer design for viscous-melt atomization. Materials Science and Engineering: A, 477(1-2), 21-25.

[9] Wang, D., Peng, H., & Ling, X. (2014). Ligament mode disintegration of liquid film at the rotary disk rim in waste heat recovery process of molten slag. Energy Procedia, 61, 1824-1829.

[10] Bohl, W. and Elmendorf, W. (2014). Technische Strömungslehre. Vogel Buchverlag, Würzburg.