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Recycling options for steel working slag and upcycling perspectives

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Abstract

The steel working industry is energy intensive. Even a byproduct like molten slag has a high specific energy (1.5°GJ/t). Most of this energy is still dissipated during cooling-down the slag despite a lot of processes for heat recovery that have been developed. Also there are some concepts to use slag more effective by material recovery. Here we suggest an upcycling process to produce foamed slag. This approach combines energy and material recovery by using minerals containing carbonates or hydroxides as foaming agent. As foamed glassy materials capture the market for construction they might pave the way towards an economically attractive upcycling of steelwork slag.

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Keywords: foam slag; blast furnace slag, upcycling, energy recovery; material recovery

1. Revue of energy and material recovery technologies

In 2014 the German steel industry produced about 42,9 million tons of crude steel and thus more than 13 million tons of slag [1]. Producing Steel is very energy intensive. Nowadays the blast-furnace slag is typically granulated with water and used in the cement industry while the converter slag is mostly cooled down in slag pits and used as building material for road construction and hydraulic engineering or as fertilizers [1,2,3]. The energy in molten slag, in Germany alone 19.5 million GJ/a, is the most meaningful untapped potential. To reuse this high heat potential at a level of 1450 °C – 1650 °C a lot of ideas for heat recovering were published, and only a few publications see the molten slag as a raw material for processing new materials (chapter 2.2). This paper will introduce some recovering procedures and give a short look at the perspective concerning new materials.

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Nomenclature

Al_2O_3	Aluminium oxide
$Al_2Si_2O_5(OH)_4$	Kaolinite
b	Basicity
BSSF	Beosteel Slag Short Flow
$CaCO_3$	Calcite
CaF_2	Calcium fluoride
$CaMg(CO_3)_2$	Dolomite
CaO	Calcium oxide
CO	Carbon monoxide
CO_2	Carbon dioxide
d	particle diameter
Fe_2O_3	Iron(III) oxide
H_2O	Water
$Mg_3(OH)_2Si_4O_{10}$	Talc
$MgCO_3$	Magnesite
MgO	Magnesium oxide
$MgSiO_3$	Bridgmanite
$Na_2B_4O_7 \cdot 5H_2O$	Tincalconite
$Na_3PO_4 \cdot 12H_2$	Trisodium phosphate
SiO_2	Silicon dioxide
SO_2	Sulfur dioxide
TiO_2	Titanium dioxide
ZrO_2	Zirconium dioxided

1.1. Heat recovery

The challenge for an efficient heat transfer is the low thermal conductivity of slag. The highest value of 2 W/mK is located at a temperature of about 1200 °C. With falling temperature the thermal conductivity decreases, and in molten state the thermal conductivity is even ten times lower (0.2 W/mK). This is why a high ratio of surface to volume is necessary for heat transfer. [4]

In the 80's the so called Merotec process was used by Svenskt Stål AB in Oxelösund. This process granulates blast-furnace and converter slag using a fluid bed. At a temperature of 1300 °C the slag flows out of a ladle into a granulation chute. The slag in this chute is shot, crushed and cooled down by accelerated small slag particles (d < 3 mm). The crushed slag arrives in the multilevel fluid bed with a temperature of 600 – 700 °C. The heat transfers into the air of the fluid bed and into the water cooled pipes. Theoretically the efficiency of this process is about 65 %. Preceding the Merotec process the main complications are wears on the shot blasting equipment and in the fluid beds, as well as disruption caused by big slag chunks. [4,5,6]

Two other granulation processes were invented by Nippon-Kokan in 1981. One of it was an air-atomizing process. Converter slag at a temperature of 1500 – 1600 °C is flushed by 100 m³ air per ton of slag. With a velocity of 100 m/s the air crushes the slag into pallets with a diameter of 0.5 – 3 mm. In a downstream heat recovery vessel the slag cooled down by radiation, convection and conduction. The theoretical efficiency is given by 40 - 45 %.

The other by Nippon-Kokan invented process is cooling drum process for blast-furnace and converter slag. The molten slag flows between two drums rotating in opposite directions. At the surface of the cooling drums the slag solidifies into a thin slag film which is stripped of by special wipers. The efficiency amounts 60 %. [4,5,6]

The Kawasaki Steel Company presents a granulation method with a stirrer tank, a downstream cooling shaft and a waste heat boiler. Molten slag is mixed in the stirrer tank while water in the lid evaporates. With a temperature of 1100 or 1000 °C the still molten slag flows into the cooling shaft. There it is broken down with roll crushers. The