



Melting behaviour of raw materials and recycled stone wool waste

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ABSTRACT

Stone wool is a widely used material for building insulation, to provide thermal comfort along with fire stability and acoustic comfort for all types of buildings. Stone wool waste generated either during production or during renovation or demolition of buildings can be recycled back into the stone wool melt production. This study investigates and compares the thermal response and melting behaviour of a conventional stone wool charge and stone wool waste. The study combines differential scanning calorimetry (DSC), hot stage microscopy (HSM) and X-ray diffraction (XRD). DSC reveals that the conventional charge and stone wool waste have fundamentally different thermal responses, where the charge experiences gas release, phase transition and melting of the individual raw materials. The stone wool waste experiences glass transition, crystallization and finally melting. Both DSC and HSM measurements indicate that the wool waste initiates melting at a lower temperature than the conventional charge. Also DSC measurements show that the wool waste requires less energy for heating and melting than the conventional charge, making stone wool waste recycling desirable both for environmental and for process purposes.

1. Introduction

Stone wool is a widely used material for building insulation, to provide thermal comfort along with fire stability and acoustic comfort for all types of buildings. As the focus on environmentally friendly buildings has increased over the past decades, so has the production of stone wool. There will be an estimated amount of 2,450,000 tons of mineral wool, i.e. stone wool, glass wool and slag wool, produced in Europe in 2017 [1]. Recycling of stone wool back into the stone wool production process has thus become increasingly relevant. Ideally, the recycling should account for both stone wool waste generated during production and external stone wool waste i.e. waste resulting from demolition and renovation of buildings. The external stone wool waste is subject to a manual sorting on the building site and again at the factory before being re-introduced into the production process. The sorting ensures that no other types of waste are present. Both the internal and external stone wool waste contain organic binder. This binder along with any other organic wastes that might be present in the external stone wool waste will burn off once reintroduced into the furnace.

Stone wool is produced by spinning stone wool melt into fibers. The stone wool melt is traditionally produced on a cupola furnace in which blocks of coke and stone are combusted and melted, respectively.

Recycling of stone wool waste in the cupola is done by casting the waste into briquettes using cement [2]. For the cupola, the individual raw materials and wool waste melts in large blocks.

This study focuses on raw materials used in a new cyclone based melting process. For this melting process pulverized raw materials are used, and therefore mixing of the materials during melting is important.

The introduction of stone wool waste into the cupola furnace is suggested to lower the coke consumption [3]. In the glass industry it is known that re-melting of recycled glass i.e. glass cullets, requires less energy than melting virgin raw materials [4].

The stone wool recipe is constructed according to the required chemical composition of the stone wool fibers that is optimized to ensure that the fibers are biosoluble [5,6]. The stone wool melt investigated in this study comprises five raw materials; four virgin stone materials: anorthosite, dolomite, diabase and olivine sand, and a secondary raw material: Linz-Donawitz (LD) slag; a waste product from steel production [7]. The chemical composition of the individual raw materials, the mixed charge and the wool waste is shown in Table 1 as determined by X-ray fluorescence (XRF).

Diabase is chosen as a raw material based on its overall chemistry that corresponds well with the final fiber chemistry; anorthosite is chosen because of its high aluminum content; dolomite for its high calcium and magnesium content; olivine sand for magnesium and iron;

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Table 1

Chemical composition of the investigated raw materials, charge and wool waste as determined by XRF given in wt%. An.: Anorthosite, Do.: Dolomite, Di.: Diabase, Ol.: Olivine sand, LD: LD slag, Ch.: charge, Wo.: stone wool waste.

	An.	Do.	Di.	Ol.	LD	Ch.	Wo.
SiO ₂	47.6	0.4	52.1	41.5	10.6	42.8	42.6
Al ₂ O ₃	28.6	0.0	14.0	0.1	0.5	18.4	18.1
TiO ₂	0.2	0.0	1.7	0.0	1.3	0.7	0.8
Fe ₂ O ₃	1.4	0.1	11.7	7.2	23.3	7.5	7.1
CaO	13.6	29.8	8.9	0.2	40.1	18.1	18.3
MgO	0.9	21.9	4.8	49.9	10.5	9.2	8.4
Na ₂ O	2.6	0.0	2.5	0.0	0.0	2.0	2.1
K ₂ O	1.0	0.3	1.1	0.4	0.6	1.0	0.6
P ₂ O ₅	0.0	0.0	0.2	0.0	0.4	0.3	0.4
MnO	0.0	0.0	0.2	0.1	3.0	0.2	0.3
LOI	2.3	46.4	1.2	0.4	1.4	–	2.1
Sum	98.1	98.9	98.3	99.8	91.6	100.2	100.8

and finally LD slag for its calcium and iron content.

The crystalline content of some of the stone raw materials can be found in literature. Anorthosite is known to consist of plagioclase ((NaAlSi₃O₈)-(CaAl₂Si₂O₈)) [8], dolomite is a known mineral phase (CaMg(CO₃)₂) [9] as is olivine ((Mg,Fe)₂SiO₄) [10].

The chemical composition of diabase is entered into a mineral norm calculator [12] known as a CIPW [11] mineral norm calculator used in geology to predict mineral phases based on chemical composition. The identified phases are as follows: plagioclase ((NaAlSi₃O₈)-(CaAl₂Si₂O₈)), hypersthene ((Mg,Fe)SiO₃) and diopside (MgCaSi₂O₆) as the most likely major crystalline phases.

LD slag is known to contain multiple crystalline phases: portlandite (Ca(OH)₂), srebrodolskite (Ca₂Fe₂O₅), merwinite (Ca₃Mg(SiO₄)₂), larnite/belite (Ca₂SiO₄), calcite ((Ca,Mn)CO₃), lime (CaCO₃), dolomite (CaMg(CO₃)₂) and FeO.

A previous study aimed to model the melting behaviour and melting energy requirement of individual mineral materials used for stone wool production. However, the predictive capability of the model turned out to be limited [13].

Stone wool comprises amorphous glassy fibers, shots and glass fragments formed during the cascade spinning process. A scanning electron microscopy (SEM) analysis shows stone wool fibers to have a mean arithmetic diameter of 4.0 μm with a standard deviation of 2.4 μm and various lengths in the range of five to several hundred micrometers [14]. Another study shows that sieving allows fibers to pass through a 63 μm sieve [18], indicating that it is in fact the diameter of the fibers that influences the particle size distribution presented on

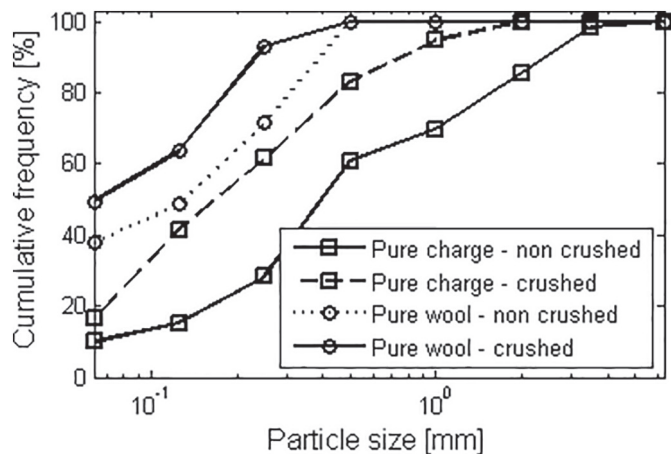


Fig. 1. The particle sizes of the pure wool waste, pure charge, crushed wool waste and crushed charge measured in a sieve column with sieve dimensions of 0.063 mm, 0.125 mm, 0.25 mm, 0.5 mm, 1 mm, 2 mm, 3.5 mm and 6.3 mm.

Fig. 1.

The glass transition temperature and crystallization onset of stone wool depend on the specific chemical composition of the wool [15], this is therefore also expected to be the case for the melting temperature of the formed crystal phases, however data obtained on stone wool of slightly different chemistries will still provide useful knowledge of the expected melting temperatures.

Stone wool fibers are studied thoroughly with the focus on uncovering the mechanisms behind the high temperature stability of the fibers [15–19]. These investigations show the stone wool fibers crystallize when heated above 1120 K, explaining why stone wool products keep their shape when exposed to high temperatures up until melting initiates at 1375–1425 K [16,17]. The crystallization is driven by an oxidation of Fe²⁺ to Fe³⁺ that subsequently drives the migration of cations from the bulk to the surface [16]. The formed crystals are identified in multiple studies to be augite [15,17], diopside [18,19], nepheline [15] and grossular [15].

Another study [20] shows that samples comprising 50% stone wool waste and varied amounts of clay, dolomite and cement dust have liquidus temperatures in the region 1500–1510 K and crystallization of the stone wool fibers taking place in the range 1100–1125 K.

The objective of this study is to obtain an understanding of the difference in melting behaviour of a conventional stone wool charge and stone wool waste in order to understand and optimize the melt production process. The effect of adding wool waste to the conventional charge is investigated in terms of melting temperature and energy consumption.

2. Experimental

2.1. Samples

Samples were prepared of each of the five raw materials of the stone wool charge: anorthosite, dolomite, diabase, olivine sand and LD slag for simultaneous thermal analysis (STA) and XRD investigations. For both investigations the raw materials were crushed using a Herzog HSM 100 pulverizing mill. The original grain sizes along with those of the crushed materials are seen on Fig. 1.

For STA and HSM investigations five samples were prepared comprising 100%, 75%, 50%, 25% and 0% charge and 0%, 25%, 50%, 75%, 100% wool waste, respectively. The samples were mixed of material of original grain sizes as seen on Fig. 1. The grain sizes were obtained by sieving. In order to facilitate the sieving of the fibers the organic binder in the wool waste was burned off by heating the wool waste to 863 K for 20 min prior to sieving. A rubber stamp was used to guide the fibrous material through the sieve.

For the STA measurements and selected HSM experiments the mixed samples were crushed to the sizes seen on Fig. 1.

For the XRD measurements samples of pure charge and pure stone wool waste were exposed to heat treatment. 50 g of the material, either pure charge or pure wool waste of the original grain sizes, were placed in platinum crucibles in a hot oven at either 1473 K or 1623 K for 30 min. The samples were then immediately quenched in water, dried and subsequently crushed. The crushed samples were then investigated by XRD.

2.2. STA

A NETSCH STA 449 F1 Jupiter simultaneous thermal analyzer was used to conduct simultaneous Differential Scanning Calorimetry (DSC) and Thermogravimetric (TG) measurements.

The individual raw materials analyzed by STA were investigated using Pt crucibles and a two-step measurement: a baseline measurement on the empty Pt crucible and a sample measurement of approximately 30 mg of sample material. The heating rate was 20 K/min and the maximum temperature was 1748 K. A thin sapphire disk was placed

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