EXPERIENCES FROM TESTS USING A INDUSTRIAL TEST-RIG FOR DRY GRANULATION OF BF-SLAG

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Content

- Introduction
- Setup of the test-rig
- Results and discussions
  - Summary of results including image analysis of high velocity film exposures
  - Properties of atomization product
- On-going work with image analysis and CFD
- Conclusions
- Questions?

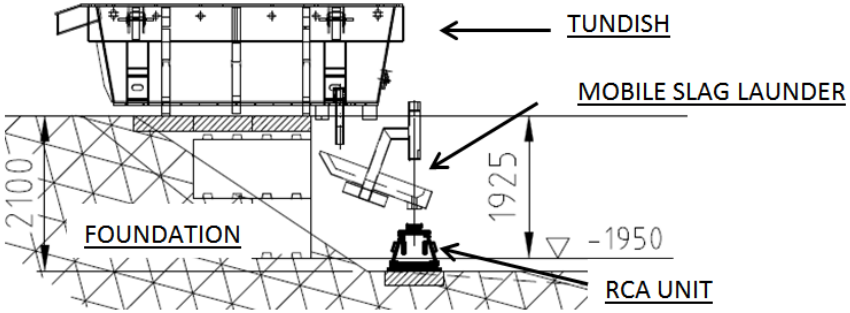
Introduction

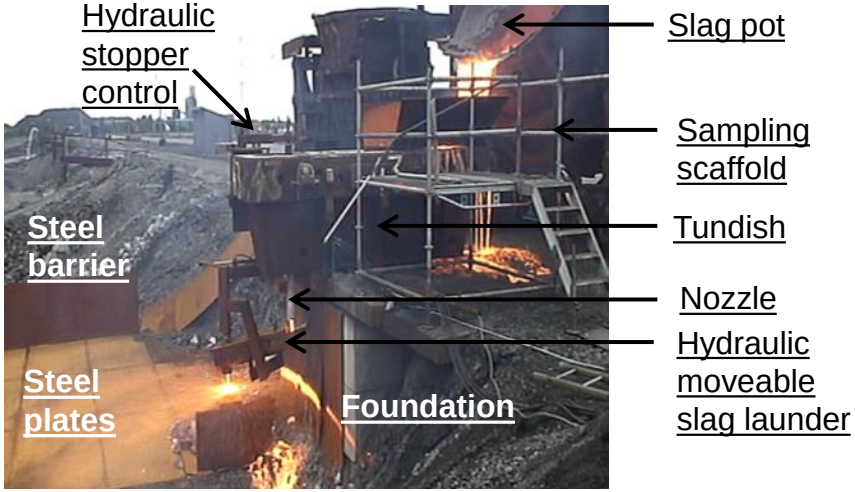
- A national project financed by the Swedish Energy Agency and the Swedish industry (2012-2014)
- The aim of the project was to examine different dry granulation techniques and apply them for BF-slag and Nordic conditions, mainly in terms of:
    - Properties of dry granulated slag
    - Potential use of the recovered heat

= > this presentation focus on the experiences from tests using a industrial test-rig and a rotary cup atomizer at SSAB.

Setup of the industrial test-rig at SSAB works

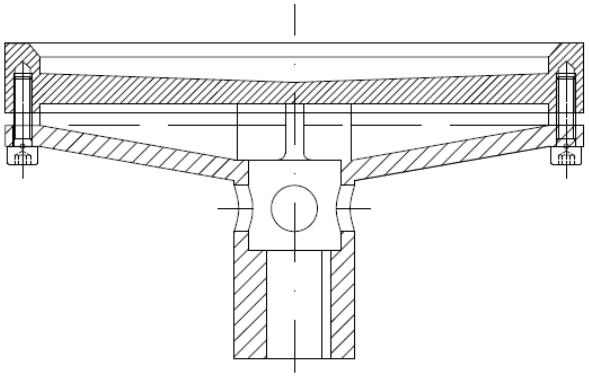
- Test-rig positioned close to the railway track in the slag yard at SSAB works in Luleå
- Slag feeding system includes a 3 m^3 tundish, hydraulic stopper and a hydraulic moveable slag launder
- Test procedure: pre-heating, pre-tilting of pot, pre-heating of nozzle with slag, flow control, launder moved into position for atomization, emptying of tundish to safety dich





Setup of the industrial Test-rig at SSAB works - Disc design

- Rotary Cup Atomizer designed for maximum 200 kg/min
- 2kW electrical engine
- Steel sheet casing
- Cup holder connected to the engine shaft was cooled with pressurized air
- OD: 250 mm

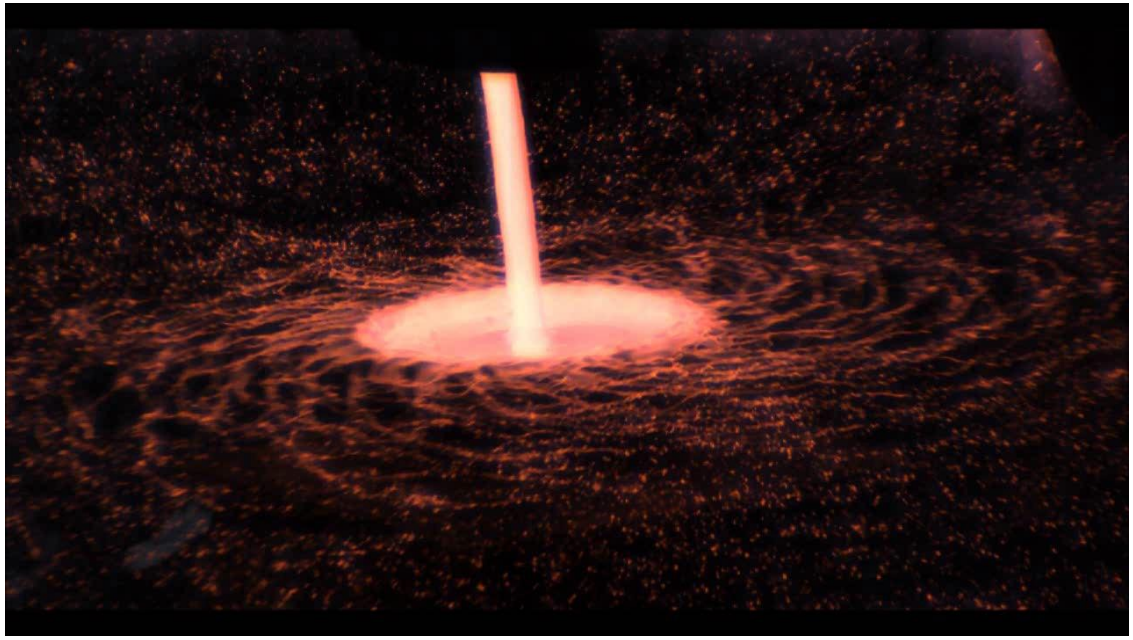


Summary of results - Overview

- Totally 5 tests were conducted
- Temperature in the tundish varied between 1330-1400°C
- BF slag flow was estimated by level measurements
- Most of the atomized slag were collected at a distance of 3-4m

Trial	Temp. (°C)	Casting nozzle (ID mm / mat.)	Flow control	Slag flow (kg/min)	Cup Material	Rotation (rpm)	Slag wool
1	1360	65 alumina-carbon	Not properly as the stopper position was moved	150	253MA	1000	Yes, in the end of the test
2	1400	65 alumina-carbon	No – stopper was broken during tundish filling	High flow	SSAB Toolox	1200	Yes, in the end of the test
3	1330	30 Graphite	Yes, stopper used for start and stop	Clogging occurred after some minutes	SSAB Toolox	1000 -> 600	Partly as the slag flow decreased, low temp.
4	1380	65 alumina-carbon	Yes	120	SSAB Toolox	1000 -> 1500	No
5	1350	65 alumina-carbon	Yes	100	SSAB Toolox	1500 -> 1800	No

Summary of results – Formation of granules studies with High-speed video, Good conditions (Test 5)



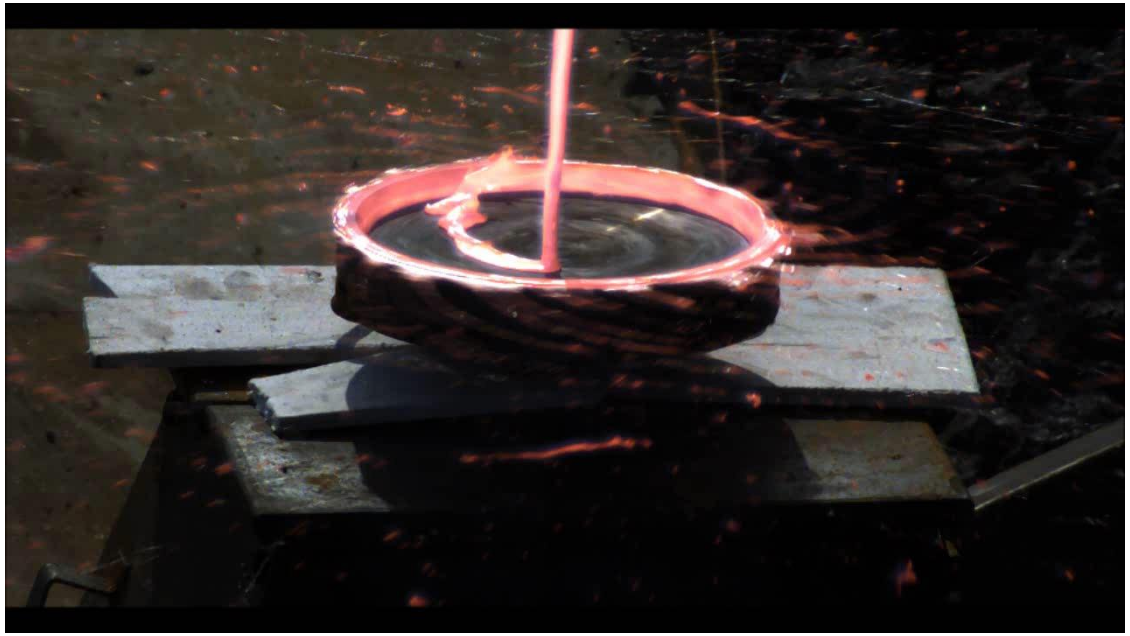
Video information:

- Recording speed: 3000 fps
- Resolution: 960x496
- Playback speed: 15 fps

Formation of the granules can be summarized into two stages:

1. Radial stringers, also known as ligaments, are formed at the cup edge and curves back due to the velocity decrease as they move out from the edge.
2. Slag stringers are disintegrated into slag granules.

Summary of results – Formation of granules studies with High-speed video, Poor conditions (Test 3)

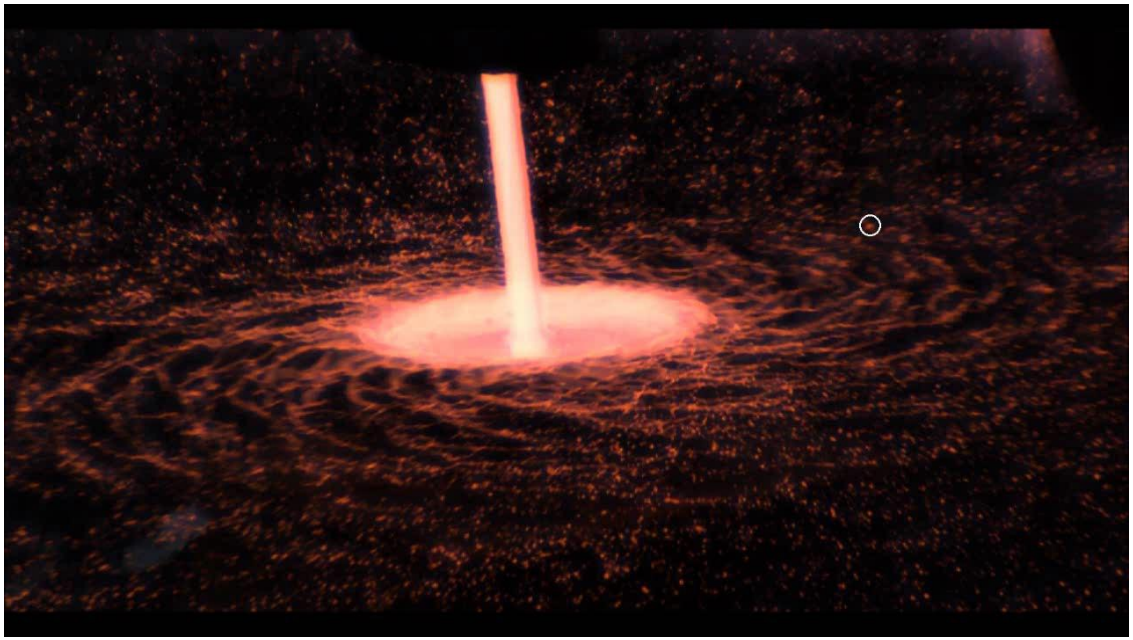


Video information:

- Recording speed: 1000 fps
- Resolution: 960x496
- Playback speed: 15 fps

In this case there are some major visual differences; the cup is not covered by slag and the process creates both fine slag granules, large slag chunks and slag wool. This is probably due to low slag temperature and low slag flow.

Summary of results - Image analysis of high-speed video from DSG-trial



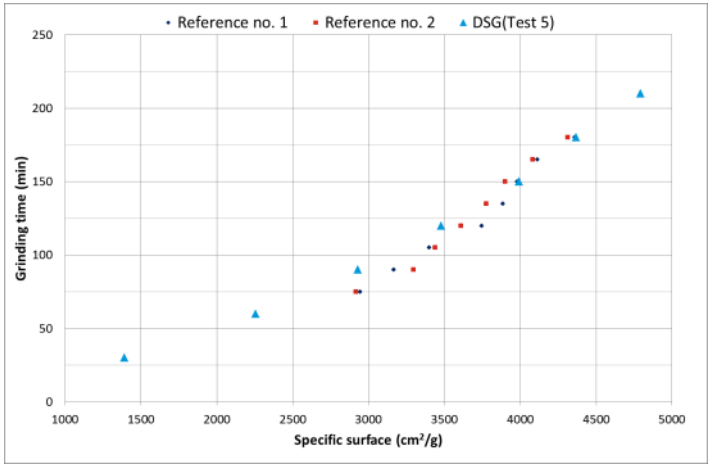
Particle Tracking Velocimetry, PTV:
By knowing the parameters of the experimental setup (e.g. the cup diameter) and the recording properties of the high-speed video particle velocity can be calculated.

The mean particle velocity for a single granule at a distance of 0.2 m from the edge of the cup was calculated by manually analyze a sequence of five images. The analyzed particle moves mainly in the horizontal direction, i.e. the travelled distance in the image and in reality can be directly correlated.

For this particular case the mean velocity of the particle was calculated to 15.5 m/s. This can be compared to the cup speed at the edge, 19.6 m/s.

Summary of results - Properties of granules

- Morphology, <3mm, some are partly connected by a thin string
- Glass content (polarization microscopy) was in general 98%
- Leaching results similar / improved to air-cooled BF-slag (Ca, SO4)
- Grindability comparable with water granulated BF-slag



Binding time (EN196-3), min	50/50 dry/Norcem	50/50 wet/Norcem	100% Norcem
	220	180	135
Compressive Strength (EN196-1)			
7/28/91d, MPa	30.5/56.3/68.4	25.5/50.8/65.1	41.8/50.5/56.9

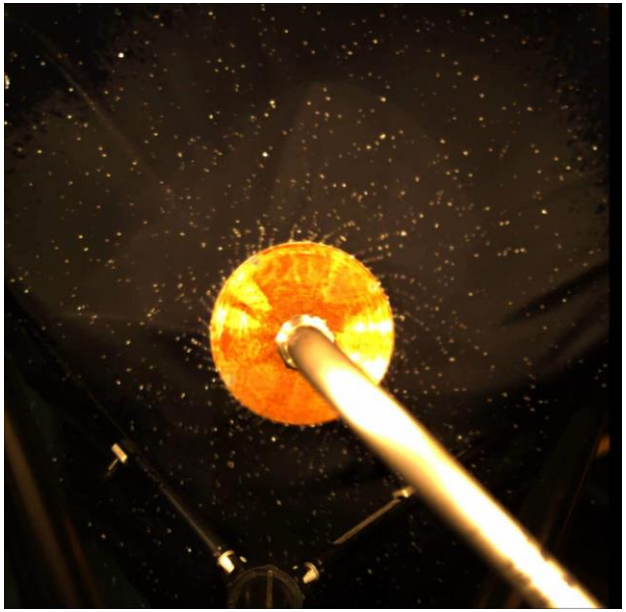
Development of an image analysis method for atomization processes, PTV and particle size analysis

The CCD-camera has large potential for analyzing atomization processes; both by increasing the understanding about the acting physics in the flow (e.g. ligament and granule formation) but also by getting knowledge about the particle velocities and particle sizes.

Therefore, more sophisticated image analyze methods have been developed at Swerea MEFOS recently. Those methods have been developed by conducting **water experiments** at lab scale with RCA.

The experiments were carried out by Swerea MEFOS (same RCA that was used in the pilot trials but with a disc diameter of 150 mm). The experiments were manufactured to favor image analysis (straight disc, CCD-camera placed directly above the process etc.).

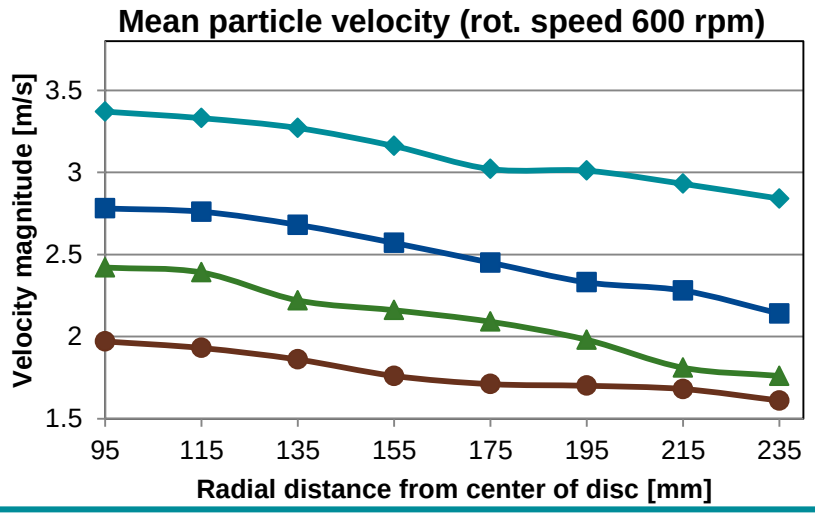
High-speed video
400 rpm, 2 liters/minute



Development of an image analysis method for atomization processes – PTV and particle size analysis

Particle tracking velocimetry, PTV

- PTV-module for MATLAB used for particle tracking
- 200 images analyzed per experiment
- Resulting mean particle velocities for a rotational speed of 600 rpm:



Particle size analysis

- The software ImageJ used for particle size analysis
- 200 images analyzed per experiment, standard deviation calculated from three additional sequences á 50 images
- Resulting mean particle diameters:

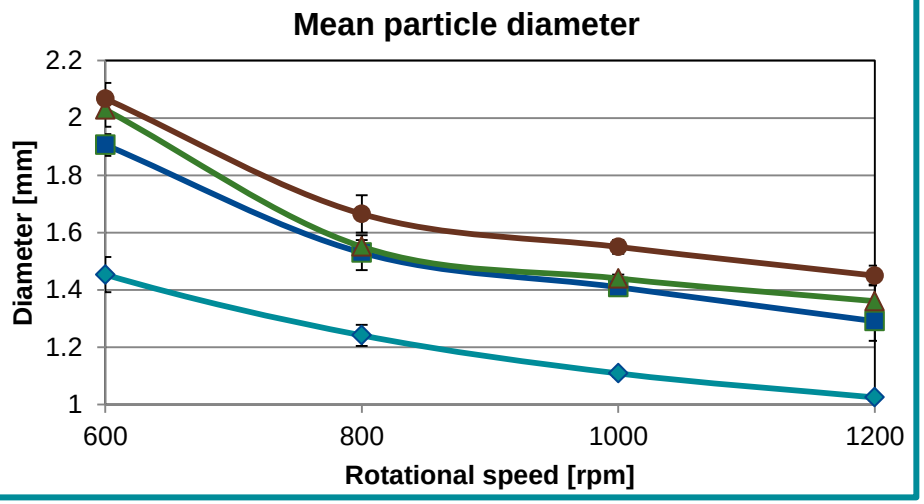


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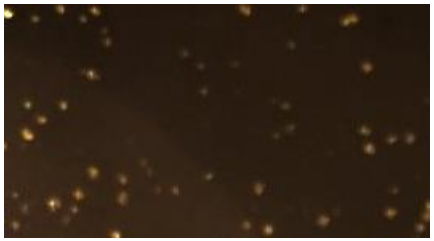
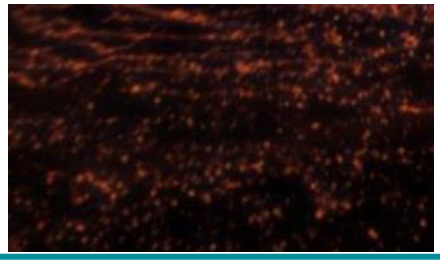
Image analysis methods for DG processes

- Plans to apply the developed methods on pilot atomization trials. Use experience gathered from water experiments (e.g. camera positioning, software experience) to favor image analyze. Advantages by analyzing DSG compared to water atomization is that the **slag particle edges are more distinct compared to the edges of the water droplets**. Also, the particle diameter can be measured after the experiment for the DSG-process, which makes it possible to validate the analysis method.

Water droplets

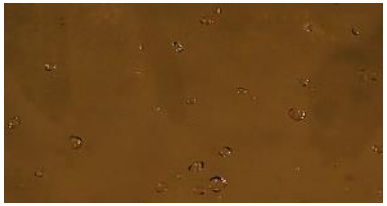


Slag granules

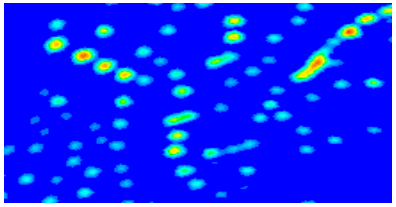


- **A CFD model is currently under development where the result from the image analysis is working as validation data***. The CFD model can further be developed to describe the DSG-process including heat transfer, chemical reactions and solidification of the slag granules. Parametrical studies on the CFD model can thereafter work as indicators for industrial scale trials, which can be economically advantageous.

Image from high speed video



Contour plot from CFD-model of volume fraction of water



***** The image from the CCD-camera and the contour plot from the CFD-model gives comparable information about the particle size.

Conclusions

- The test-rig is well suited for granulation of BF-slag and a controllable slag flow to the centre of the cup could be achieved
- The RCA seems to be a robust process capable of handling large variations in slag flows
- The temperature drop of the slag compared to the BF-runner is at least 100°C, which affects the process
- Flow control using the stopper was preferred, for a large scale plant flow control using a nozzle/stone should be considered
- Pressurized air was sufficient for cooling, no wear of the cup made by SSAB Toolox was observed after the tests
- Slag wool was clearly visualized in tests with both low slag flow and low temperature
- Properties of the atomized product is equal / improved compared to water granulated slag
- CCD-camera has large potential for analyzing atomization processes


Questions?
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