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De-agglomeration rate of silicate bonded sand cores during core removal

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ABSTRACT

The here presented criterion describes the disintegration kinetics of cast in sand cores, which is influenced by transient thermal and mechanical casting process loads.

A semi-permanent mould setup allowing for various thermal exposure intensities was developed and used with wedge shaped, hot hardened silicate bonded sand cores. During defined mechanical agitation of such produced castings the minimum core removal mass rate was identified and combined with the de-agglomeration degree of the collected core sand. The de-agglomeration degree was evaluated from particle size analysis with specifically adapted sieving parameters and a modelling approach for the size distribution. The retained mass on the top mesh constituted the lump mass.

Cast-in cores generally exhibited higher de-agglomeration rates compared to non-cast-in reference cores, which confirmed a deteriorating influence of a casting process on the sand core. Increased de-agglomeration rates and more disintegrated core lumps were observed for the samples with longer thermal exposure. Avoiding ambient humidity resulted in a significantly increased de-agglomeration rate compared to openly stored samples.

1. Introduction

Sand cores are used in numerous metal casting technologies to shape complex internal contours and undercut sections. After the solidification and cooling of a casting, a sand core removal process is required to obtain a sand-free casting. Czerwinski et al. (2015) recently reviewed the state of the art in sand core technology. Over the past century, demands by the automotive casting industry for higher productivity and complex cores have led to the replacement of inorganic binders with organic binders. Due to of more restrictive health and safety guidelines and emissions regulations, inorganic core production technologies are once again being implemented, because these technologies are odourless and nearly emission free. According to Izdebska-Szanda et al. (2012) thermal degradation during casting affects core removal less in inorganic bonded cores than in organic binder systems. Therefore, applying inorganic core binder systems requires special attention to core removal properties.

Gamisch (2002) reviewed existing industrial solutions for core removal. Mechanical core removal processes usually consist of hammering and shaking steps. Fig. 1 shows a typical setup applied for an aluminium cylinder head with inorganically bonded sand cores.

Quantitative evaluation methods for core removal properties are rarely available. Henry (Ashland) et al. (1999) studied the shake-out behaviour of wedge shaped Coldbox test cores cast in aluminium. Using a pressure-controlled pneumatic hammer, they documented the shaken-out sand mass at specific times and the required shake-out time for complete sand core removal. According to them, binder properties influenced core removal more than casting process variations. To transfer their method to foundry applications, they recommended customising a trial setup for given process conditions. Fennell and Crandell (2008) used a similar setup with an in-line scale for sand collection, and evaluated the average shake-out mass rates of different inorganically and organically bonded sand core types. Inorganically bonded samples had a higher shake-out mass rate than organically bonded cores.

At the Polish Foundry Institute, several investigations have been performed using knock-out testing, according to standard (PN-85/H-11005, 1985). In such tests, strokes with a defined energy are placed directly onto a cast-in test core. Izdebska-Szanda et al. (2012) presented the residual strengths of different binders after thermal exposure and using parallel knock out tests. Different organically and inorganically bonded samples were cast in copper and aluminium. The knock-out work remained similar, in contrast with the different retained strength levels after pre-conditioning to equivalent temperature exposures. Subsequent investigations by Major-Gabryś et al. (2014) demonstrated that retained strength measurements could not be used as the criterion for the knock-out properties of silicate bonded cores, once a secondary

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Fig. 1. Cylinder head with inorganic test cores during (a) hammering process and (b) shaking process (Nemak, 2005).

hardening maximum above 600 °C was attained. The authors postulated a high degree of mechanical interaction by casting contraction counteracting the expansion of the cast-in core. They proposed high temperature thermal expansion as a more significant criterion for predicting knock-out properties.

In the present study, the kinetics of sand core de-agglomeration are investigated; no contributions to such research could be found in the available literature. Therefore, the field of mineral processing has been evaluated in greater depth, as the fragmentation properties (e.g. of ores or rocks) are central to this field. Rosin and Rammler (1933) developed a basis for investigating coal dust particle size distributions. Based on their work, the Rosin-Rammler-Sperling-Bennet (RRSB) approach was used to describe the particle sizes of dusts, soils, and crushed materials. Note that the RRSB approach represents a specific case of the later-established, widely known Weibull probability distribution (Weibull, 1951). This was applied by Paluszny et al. (2016) to describe the particle size distributions of crushed rocks. Bayat et al. (2015) reviewed the fitting accuracy of several particle size distributions. The physical evidence of various functional approaches for describing particle size distributions was demonstrated by Brown and Wohletz (1995).

In summary, the RRSB approach is widely accepted, and is generally documented in mineral processing handbooks (Fuerstenau and Han, 2003; Zogg, 1993). It is a convenient and approved approach for describing de-agglomeration process results. In this study, this approach will be applied for the first time to a foundry application, to model the achieved particle size distributions of raw sand and removed core sand.

2. Material and methods

Sample production for core removal trials are presented. These include the different applied cooling conditions, the core removal setup, and the particle size evaluation method.

2.1. Test casting production

Silica sand H32 (Quarzwerke, 2009) bonded with 2,5% mass of sodium silicate binder with a molar SiO_2:Na_2O ratio of 325 was used. The sand cores were produced using an electrically heated core box on a Roeper H1 core blowing machine. The cores were hardened in the core box at 160 °C for 2 min, followed by drying in a 120 °C chamber furnace for 5 min. After cooling, the sand cores were sealed in foil to avoid air exchange and intensive humidity condensation during storage.

For casting the test core was placed in a steel mould and liquid Al (alloy AlSi7Cu0,5Mg) at a temperature of 745 ± 10 °C was poured in. Fig. 2 illustrates (a) the schematic mould setup, (b) the test core dimensions, and (c) the core.

The steel mould was operated based on the mould side wall temperature T_M according to Fig. 2a. The mould temperature at the start of pouring was 400 °C. After T_M exceeded its maximum, the casting was gently demoulded at 450 °C. Overall, a cycle time of approximately 7 min was obtained.

Four different thermal exposure scenarios were defined. The following colour coding applies throughout the text and figures:

Hardened reference: non cast-in cores, realised by re-filling the empty cavities of test castings with virgin core sand mixture hardened therein (yellow).

a. Water cooling: realised by setting the casting with the feeder 40 mm deep into a water bath of 60 − 70 °C (blue).
b. Air cooling: cooling the cast samples at non-agitated air ambience (green).
c. Insulation: completely embedding the cast part between 30 mm thick ceramic fibre mats (red).

Table 1 summarises the evaluated thermal exposure time for the casting and cast-in cores, and the time and value of the achieved sand core peak temperatures after the start of pouring. It is not applicable for the hardened reference sample.

Times of thermal exposure of the sand cores are significantly different with the different cooling types. Because the sand cores have low thermal conductivity, they show long heating delays relative to the short pouring time of < 10 s. For the water-cooled case, the sand cores reach their peak temperature even after the casting has been cooled by water quenching. For air and insulation cooled cases, the cooling of the cores is fully linked to that of the castings.

2.2. Core removal trials

A vibration unit equipped with two electrical imbalance drives rotating at 50 Hz has been used for the shake-out trials. The shaken-out sand was directly funnelled onto a balance, and the removed sand mass was recorded with 1 Hz resolution. The test castings were clamped into a vertically guided sample holder, which is shown in Fig. 3.

On top of the sample, a knocking mass has been placed. Both the sample and mass are freely movable in the vertical direction. The maximum vertical acceleration of the vibration unit was measured as 6 *g*. On the sample, a maximum vertical acceleration was measured as 40 *g* for 99 % of the values, with peaks of up to 100 g.

2.3. Particle size analyses

A Retsch AS200 digit sieve machine with meshes of 0 (tray), 63, 90, 125, 180, 250, 355, 500, 710, 1000 and 1400 µm width was used for the particle size analysis, according to the standard sieving procedure (ISO, 2016).

The removed core sand from castings also contains larger agglomerates and core lumps. To avoid their excessive breakdown during sieve analysis, the sieving amplitude was reduced from 1,5 to 0,2 mm, and