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Bakker, Maarten

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Feasibility of surface sampling in automated inspection of concrete aggregates during bulk transport on a conveyor

M.C.M. Bakker

Resources and Recycling group, Delft University of Technology, Stevinweg1, 2628CN, The Netherlands

Abstract

Automated optic inspection of concrete aggregates for pollutants (e.g. wood, plastics, gypsum and brick) is required to establish the suitability for reuse in new concrete products. Inspection is more efficient when directly sampling the materials on the conveyor belt instead of feeding them in a sampled stream to the sensor system. However, this does not reveal the true volume contents if the concrete and pollutants have segregated. Moreover, even if the concrete was homogenous, the relation between the number of visible pollutants and those in the volume varies depending on the size of the pollutants relative to the size of the concrete. A few fundamental issues must be investigated and technically resolved before this improved way of automated inspection becomes possible. First we investigated if it is possible to feed concrete at a high rate in a homogenous volume to a conveyor belt using batches of several tonnes. Second we investigated the surface-volume numbers for specified pollutants. Progress in the first part was a promising method of feeding that appears to produce not a true homogenous volume, but at least a volume with a mild and most of all reproducible degree of segregation for the different pollutants. This suggests the segregation could be corrected for in the data using a model. As a follow-up, a theory was developed that predicted accurately how thin plastic flakes of different sizes correlate with the number of visible flakes on the surface of a granular matrix. This theory is now extended and tested successfully in the laboratory using batches of 2-8 mm dry and moist river gravel with added 1% plastic flakes.

Keywords: concrete aggregates; segregation; quality inspection; sampling; solid binary mixtures.

Introduction

Surface scanning sensor techniques such as visual cameras, NIR and HSI [Bonifazi, 2015] are in growing demand in the recycling industry due to their excellent performance to price ratio. But also an emerging stand-off laser technique such as LIBS [Xia, 2014] is finding its way to an industry that is hungry for quantitative information and more efficient ways of obtaining it. A common method to employ these techniques for quality inspection is to sample the waste stream, or divert a small sample stream, and present the sample in a monolayer to the sensor. The sensor data are accumulated to build reliable statistics, resulting in an average per sampled unit of volume or mass. Point is that all such special measures intervene with the primary recycling process and increase the costs of inspection. It would be far preferable if the optic sensor could be positioned directly above an existing conveyor belt which transports the material in bulk as part of the primary process. Unfortunately, this is as yet not an option because there is no theory to predict the relation between sensor readings and the material contents in the granular bulk, even if the concrete and pollutants would be homogenously mixed. Since homogeneity was never an issue in concrete waste recycling practice, an investigation was warranted if it possible to feed at the same high mass rate but without segregating the pollutants and concrete to allow for automated inspection. Assuming the homogeneity can be established or the inhomogeneity can at least be predicted, the next challenge is how to relate the observable pollutant numbers to the true number in the volume. This work proposes some advancement on the latter challenge.

Materials and Method

Table 2 and Figure 1 show the composition and properties of the materials 2-8 mm in the 30kg batch. Six tests were performed with three dry batches and three moist batches.

Table 2. Composition of the 2-8 mm gravel batch.

	particles		**batch**		
	mass	density	Nr particles	mass	bulk density
Gravel 2-4 mm	0,0403 g	2685	383586	15.459 kg	1586 (□= 0.591)
Gravel 4-8 mm	0.368 g		39100	14.401 kg	
Plastics 2-4 mm	0.00706 g	910	2294	16.2 g	
Plastics 4-8 mm	0.0290 g		1468	42.6 g	

Figure 1. Material batch of natural 2-8 mm river gravel and shredded polypropylene flakes.

Figure 2 shows the setup for feeding the granular batch to a conveyor belt. The pre-mixed material is poured into a 200 mm diameter funnel, which is internally covered by a plastic mesh to reduce surface contact. Gravity leads the material onto a shortened shaker, which serves only to increase the material volume flowing from the funnel. The material then flows with minimal disturbance onto the moving belt (0.35 m/s). The feeding is tuned so that the initial material bed height on the belt is on average 14-15 mm and has a width of at least 45 mm for moist material or 75 mm for dry material. A belt-synchronized counter-rotating roller slightly compresses the top of the material to create a flat bed of 14 mm high and at least 35 mm wide. It is noted the roller should not crush the material since that would disturb the homogeneity of the material bed. Behind the roller a laser triangulation sensor measured accurately the average height of the bed, which proved to be 13 mm as the material also slightly sags with the belt. Directly behind the laser is a video camera that recorded the top surface in real-time. The video is then analysed for the time that the belt feeding is stationary to count the number of red flakes appearing within the 35 mm wide strip of the material bed.

Figure 2. Conveyor setup for testing the gravel batches.

Results and Discussion

The average gravel grain was close to an ellipsoid with normalized elliptical axes 0.7:1.0:1.41 (2-4 mm) and 0.64:1.0:1.51 (4-8 mm), where the middle size is the sieve size. The river gravel could therefore be approximated in the model by a sphere with diameter 3.29 mm. The plastic flakes were approximated by the average square flake 3.90x3.90x1 mm. These and other material–specific parameters such as bulk density and packing behaviour were fed into the theoretical model. The theory could then be compared to the experimentally observed number of flakes on the gravel surface. The results are shown in Tab. 1.

Table 1. Comparison of detected flakes in a 100 s video and theoretical prediction.

<table>
<tr><th>Batch</th><th>Nr flakes</th><th>theory</th><th>deviation %</th><th>mean / STD^S</th></tr>
<tr><td>Dry</td><td>860</td><td rowspan="6">mean = 947
STD^B = 31
(3.3%)</td><td>-9.2</td><td rowspan="3">-4.3%
/ 5.6%</td></tr>
<tr><td>Dry</td><td>964</td><td>1.8</td></tr>
<tr><td>Dry</td><td>895</td><td>-5.4</td></tr>
<tr><td>Moist</td><td>869</td><td>-8.2</td><td rowspan="3">2.1%
/ 9.4%</td></tr>
<tr><td>Moist</td><td>1046</td><td>10.4</td></tr>
<tr><td>Moist</td><td>986</td><td>4.1</td></tr>
</table>

The moisture had a clear influence on the results. The results are quite satisfactory as the average deviation from the theory is only 4.3% lower for the dry materials and 2.1% higher for the moist ones. Percolation (small flakes sliding downwards into the volume) is the obvious segregation mechanism that caused the lower count for the dry materials. The moisture clearly eliminated percolation effects, but instead introduced its own specific segregation effects. The main mechanism was that small flakes stuck to the plastic funnel surface and accumulated there to some degree, resulting in the slightly higher surface flake count in Table 1. These effects could be well reproduced in additional tests.

Conclusions

This work applied an extended earlier theory from same author to predict the relation between the number of surface pollutants and the volume contents in a size-range mixture of granules and thin flakes. It is put to the test in the laboratory using a 30 kg batch of 2-8 mm river gravel that was ‘polluted’ with 1% of shredded plastic flakes in the same size range. The tests showed that the theory offers a reliable prediction and, moreover, a simple way to test the number of pollutants in the homogenous volume by first counting the visible ones on the surface. This result is a step towards efficient camera-based quality inspection of granular waste streams. A next step is to develop the theory towards higher complexity pollutants such as encountered in true recycle concrete aggregates [Tam, 2009].

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