Expert Systems With Applications 000 (2015) 1–16

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Statistical monitoring for continual quality control of railway ballast

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ARTICLE INFO

Keywords:
Quality management
Quality inspection
Statistical process control
Life-cycle cost
Attrition
Drift detection
Novelty detection

ABSTRACT

Existing quality control methods for railway ballast are arduous and expensive since they are based on manual material inspections. Thus, test intervals are typically fairly wide. As a consequence, short-term and mid-term fluctuations of ballast quality may not be detected. This results in increased costs for maintenance work such as tamping. To make test intervals shorter and even allow for continual quality control, a new statistical monitoring system for railway ballast is proposed. It combines traditional test methods with an innovative measurement device, the Petroscope® 4D. This device measures the geometrical parameters directly in a manner superior to that of traditional tests. The mechanical properties are statistically estimated based on geometric and spectrographic features. This procedure is called virtual testing since automatic measurements and statistical prediction replace manual measurements and manual tests. To guarantee a high prediction performance, the proposed statistical monitoring of samples from daily production involves novelty detection. It also allows for surveying drift of geometric and spectroscopic distributions and the dynamics of the mechanical properties. The proposed statistical monitoring system is expected to yield a better ballast quality and reduce ballast life-cycle costs.

1. Introduction

1.1. Technical and economic background

Railway ballast is a mass product. To build 1 km of railway line some 7000 tonnes of ballast are required (ÖBB (Austrian Railways) – Infrastructure Department, 2002). Austrian Railways alone have an annual demand of some 1 million tonnes p.a. (Kuttelwascher, 2011).

The life cycle costs of railway ballast are governed by the cost of maintenance work such as tamping and ballast cleaning. These operations are necessary due to the fact that railway ballast is subject to attrition, caused by the large forces acting within the ballast layer (see Fig. 2).

Tamping becomes necessary whenever track position and stability reaches a critical value. The main cause of track settlement is rearrangement of the ballast particles within the ballast layer (i.e. rotation and displacement, see also Fig. 1 first row). Settlement remains small as long as the angular ballast particles prevent substantial realignment between neighbouring particles. However, as soon as edges and corners break off ("chipping", see Fig. 1 second row) and particle angularity decreases (i.e. particles become more rounded), particle readjustments become easier (see Fig. 2(a)). Thus, stability of the particle edges is a quality criterion for railway ballast.

Ballast cleaning is carried out when the percentage of fines reaches a critical value. The fine particles fill the voids inbetween the larger particles and thus increase ballast bed stiffness. This in turn leads to larger wear of other track components such as sleepers and rails. Furthermore, fines decrease permeability of the ballast bed and thus impedes rainwater drainage.

Fines result from particle fragmentation, chipping and abrasion (polishing). Thus, resistance to wear (abrasion) and fragmentation also constitute quality criteria for railway ballast.

Both tamping and ballast cleaning operations entail temporary track closure and incur downtime costs (establishment of bus replacement services, train diversions, and delays etc.). Such downtime costs usually exceed track construction costs by far. For example, closure and downtime equivalent to a loss of track operating life of one year, generate costs of about € 6.42 per km and year, and a loss equivalent to 2 years results in costs of € 15.53 per km and year. Given that the Austrian railway network has a length of about 5500 km, the detection of material of minor quality yields savings of € 35,000 to € 80,000 per year. Similarly, for the Union Pacific Railroad (USA) with a railway network of about 81,500 km in length, expected savings are in the region of € 523,000 to € 1,265,000 per year.

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http://dx.doi.org/10.1016/j.eswa.2015.07.011

Please cite this article as: V. Hofer, H. Bach, Statistical monitoring for continual quality control of railway ballast, Expert Systems With Applications (2015), http://dx.doi.org/10.1016/j.eswa.2015.07.011

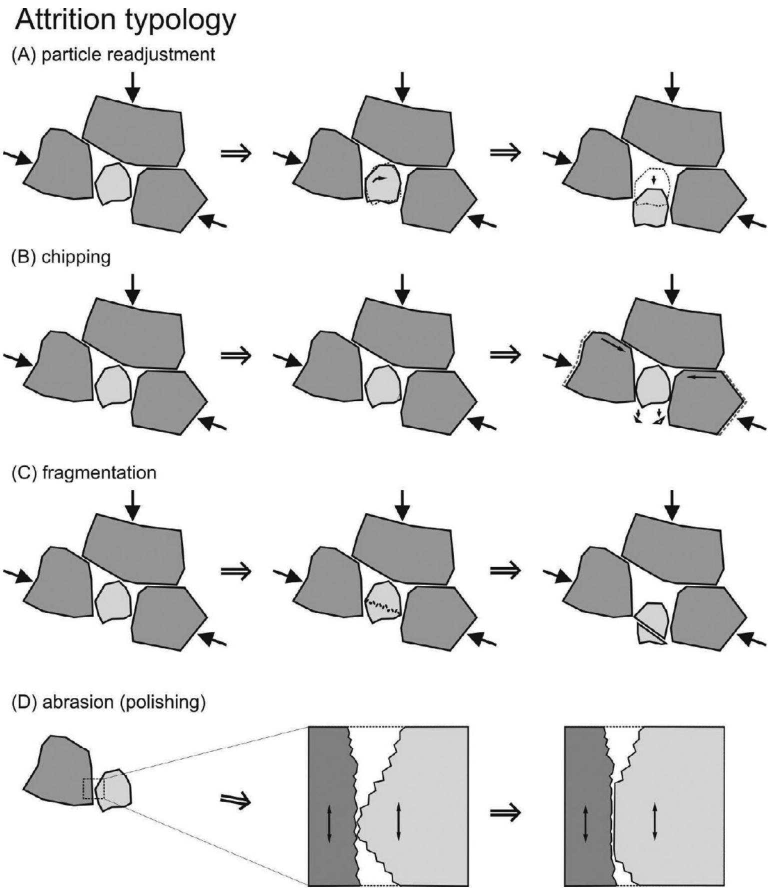

Fig. 1. Attrition typology.

As there is no feasible way to decrease the load level acting upon the ballast layer, the frequency of maintenance such as tamping and ballast cleaning is governed by the ballast quality. It is thus obvious that high quality ballast can reduce life cycle costs.

1.2. Traditional quality control

In order to ensure good ballast quality, quality standards need to be defined and, based on this, appropriate test procedures and sufficiently dense test intervals have to be selected. The European ballast quality standards are usually subdivided into those covering geometrical, and those covering mechanical requirements.

Concerning particle geometry, highly angular particles are desired. An extremely high angularity, however, will inevitably lead to excessive chipping of the exposed edges. A modest contingent of non-cuboidal particles increases interlocking and thus prevent relative movements between neighbouring particles. A very high proportion of elongated and/or flat particles, however, will result in increased fragmentation (see Fig. 2(b)). Most railway companies demand a percentage of 5–30% of elongated particles. The fines content is also closely specified and is usually limited to between 2% and 5%. All parameters are checked biannually at the quarry and, additionally, on site (typically; one test being performed for every 5000 tonnes of delivered ballast) (see ÖBB (Austrian Railways) – Infrastructure Department, 2007).

One of the common test methods for the estimation of the mechanical properties of railway ballast is the Los Angeles test, or LA test. Most railway company quality assurance systems specify that the tests be performed biannually for every quarry. For further details see ON EN 1097-1 (2004), ON EN 1097-2 (2006), ON EN 13450 (2004).

Such quality control systems exhibit specific shortcomings: Test intervals for mechanical properties are fairly wide. Ballast of inferior quality may leave the quarry for many weeks or even months on before being detected – or, worse, may not be detected at all (see Fig. 3). Geometric test results are available after some days and those for the abrasion tests after one or two weeks. In most cases shipping of samples to the lab, carrying out test procedures and report generation are all quite time-consuming. Meanwhile, production and delivery of ballast remains unaffected. As a result of the coarse grain size of railway ballast, lab test sample sizes need to be large in order to ensure representativeness, which makes ballast tests both arduous and expensive.

To overcome the disadvantages of the existing biannual material inspections the present paper introduces an innovative statistical monitoring system for railway ballast. The proposed statistical monitoring not only allows for on-going control of material compliance between the two regular material inspections, it also provides insight into the evolution of material quality over the course time. In addition, results can be used for assigning material to different areas of operation depending on the material quality needed.

1.3. Statistical monitoring – virtual testing

The statistical monitoring described below is based on samples drawn at frequent intervals from the delivered railway ballast. Similar to regular material inspection, geometric properties, the petrographic composition and the mechanical properties are determined. However, in contrast to the regular material inspection, the major geometric properties of these samples are measured **automatically** using the Petroscope®. This device also provides reflectance spectra of the sampled particles, mainly in the visible light range. To avoid the

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