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Consumption of steel grinding media in mills – A review

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ABSTRACT

In this study, the current understanding of the factors affecting the consumption of steel media in comminution systems in mineral processing are reviewed, together with models predicting wear losses in grinding media. Media wear arises as a consequence of complex interaction between a range of variables related to processing conditions, the characteristics of the media, as well as the ores or slurries, and is not well understood as yet, despite extensive study over the last 50 years and more. The three basic wear mechanisms, impact, abrasion and corrosion, can simultaneously influence mass loss in grinding media. Present studies are difficult to compare directly, owing to imprecise information with regard to the composition of the media or grinding conditions. As a result, most current models do not account for varying conditions inside the mill and their use is restricted to conditions similar to those associated with their calibration. This may not always be possible and alternative modelling methodologies are discussed and demonstrated by means of a case study on simulated data.

Contents

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Nomenclature

A	surface area of grinding media in general, m^2
A_b	surface area of ball or sphere, m^2
A_i	abrasion index, –
A_{lball}	surface area of grinding ball in laboratory mill, m^2
A_{rball}	surface area of grinding ball in industrial mill, m^2
C	cost of grinding media per unit mass, \$/kg
CL	crop load, %
D_f	final diameter of grinding ball, m
D_i	initial diameter of grinding ball, m
D_0	initial diameter of mill, m
$E_{abr,i}$	energy dissipated owing to abrasion phenomenon i, J
$E_{imp,j}$	energy dissipated owing to impact phenomenon j, J
k'	wear speed or wear constant, $m^{3-n}\ s^{-1}$
k_d^E	energy specific wear rate constant, $m\ J^{-1}\ kg^{-1}$
k_m	mass wear rate constant, $kg\ s^{-1}$
k_d	linear wear rate constant, $m\ s^{-1}$
m	mass of grinding media, kg
$m_{abr,i}$	grinding media mass loss owing to abrasion mechanism i, kg
m_{corr}	grinding media mass loss owing to corrosion, kg
$m_{imp,j}$	grinding media mass loss owing to impact mechanism j, kg
Δm	change in the mass of the grinding media, kg
N	rotational speed of mill, s^{-1}
N_c	critical rotational speed of mill, s^{-1}
n	wear rate exponent, –
R	volumetric wear rate of grinding media, $m^3\ s^{-1}$
T	mass of ore milled, kg
t	time, s
v	velocity, $m\ s^{-1}$
W	mass loss of grinding media per unit surface area, $kg\ m^{-2}$
ρ	density of grinding media in general, $kg\ m^{-3}$
ρ_b	density of steel ball, $kg\ m^{-3}$
Ω_E	grinding media consumption based on energy usage, $kg\ J^{-1}$
Ω_M	grinding media consumption based on amount of ore ground, $kg\ kg^{-1}$
Ω_t	grinding media consumption based on operating time, $kg\ s^{-1}$

1. Introduction

Grinding circuit operators have long been aware of the significant impact of grinding media consumption on the cost of grinding. Comminution accounts for an estimated 30–50% of typical mining operating costs, and of these, liner wear and media consumption account for roughly 50% of the cost. According to Moema et al. (2009), in some instances, media wear can constitute up to 40–45% of the total cost of comminution. An estimated consumption of steel grinding media of around 600,000 tons p.a. in the 1980s already gives an indication of the scale of the problem (Malghan, 1982). Likewise, in the cement industry, as mills are supplied for ever increasing capacities, the ball size distribution and wear exact a tremendous effect on the profitability of producing finished cement. Improper size distribution or filling level of the ball charge can reduce the efficiency of grinding by 5–20%, amounting to losses of millions per annum for a mill with a capacity of 150 tons/h (Longhurst, 2010).

Apart from these cost factors, one of the major unsolved problems in the optimal design of ball mills concerns the equilibrium media size distribution in the mill, which is determined by the rate at which make-up media is added to the mill, as well as the rate at which these grinding media are consumed (Austin and Klimpel, 1985). Reliable prediction of grinding media consumption can therefore play an important role in the management and control of these costs, and the overall cost of mining operations.

The cost associated with grinding media is chiefly determined by two factors, viz. the price and wear performance of the grinding media. Different operating conditions can be compared with the effective grinding cost or the cost-effectiveness of the application (Sepúlveda, 2004). This is a challenging task, since different operating conditions in comminution circuits arising from changes in ore types, operational procedures and the properties and size distributions of the grinding media themselves all need to be accounted for when the cost of grinding media is calculated (Chenje et al., 2004; Lameck et al., 2006; Jayasundara et al., 2011).

The consumption of grinding media has been studied extensively in the mineral process industries, where steel balls and rods are mostly used to reduce rock fragments and ore particles to the fine sizes required for mineral liberation and further downstream processing. Apart from a better understanding of the phenomena involved in the wear of grinding media, many of these studies were also aimed at the development of models capable of predicting media consumption based on an understanding of the mechanisms involved in the process. In this paper, these studies are reviewed, starting with an overview of the properties of grinding media in Section 2, followed in Section 3 by consideration of the wear mechanisms on media consumption. This is followed by characterization of the grinding environment in Section 4, and measurement of grinding media consumption in Section 5. In Section 6, grinding media wear models are reviewed and in Section 7, a simulated case study is considered to illustrate the potential of alternative ap-