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ScienceDirect
Wear 265 (2008) 865–870
WEAR
www.elsevier.com/locate/wear

Effect of abrasive mineral on alloy performance in the ball mill abrasion test

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Received 18 June 2007; received in revised form 4 January 2008; accepted 8 January 2008
Available online 5 March 2008

Abstract

The ball mill abrasion test (BMAT) promises to offer accurate prediction of relative service lives of wear-resistant alloys for liners and grinding media in mineral grinding environments. Relative alloy performance depends strongly on the abrasive minerals present. Towards a greater understanding of factors controlling relative performance, BMAT data have been generated using several pure and blended minerals. The results show that very hard (above 630 HV) martensitic steels and white cast irons only offer large performance benefits when grinding relatively soft or weak abrasives (Mohs hardness less than about 6). This may alter the cost-benefit balance in favour of simple low-cost steels when grinding hard strong minerals, but even modest proportions of softer minerals in real ores can favour the use of more sophisticated hard alloys.

Keywords: Ball milling; Abrasion; Martensitic steel; White cast iron; High stress abrasion

1. Introduction

The ball mill abrasion test (BMAT) makes use of a conventional laboratory ball mill, which is a simple rotating barrel of similar geometry but smaller scale than typical industrial ball mills. Like their industrial counterparts, laboratory ball mills are devices for comminution of minerals or other granular solids. For this purpose they contain a charge consisting of steel or white cast iron balls (the grinding media) and the mineral to be ground, with or without water or other liquid. Laboratory ball mills are most commonly used to study matters of interest to operators of mineral processing plant such as the fracture characteristics of particular minerals or ores and factors affecting grinding efficiency. However, it has recently been shown [1,2] that laboratory ball mills can also be used to evaluate the resistance of metal alloys to high stress abrasion and other wear modes [3] relevant to industrial ball mill service.

In industrial ball mills, wear-resistant alloys are used not only for the grinding media but also for the replaceable liners which prevent damage to the structural components of the mill. Maximising the service life of both grinding media and mill liners is of considerable economic importance in comminution operations. Maximising liner life is of particular importance, since the cost of their replacement includes not only the cost of the replacement components but also the cost of lost production during change-out. Grinding media can usually be replaced without interruption to production, but the amounts consumed can be very large and constitute a major operational cost.

In mineral handling and transport operations it is often possible to minimise wear by means of engineering design modifications that reduce the intensity of interactions between abrasives and liners; but in comminution operations such modifications are usually impractical because comminution depends directly upon these interactions. For this reason, the main avenue available to comminution plant operators to maximise the life of wear components is selection of the best abrasion-resistant alloy. The relative performance of different candidate alloys, and therefore the cost-benefit balance governing alloy selection, depends strongly on the dominant wear mode. In particular, the

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doi:10.1016/j.wear.2008.01.008

degree of benefit to be gained by the use of very hard alloys and particle-reinforced composites varies widely as a function of wear mode. Major life increases are available from use of very hard alloys under low stress abrasion conditions, but only minor benefits are commonly to be gained under high stress abrasion conditions. These practical consequences of wear mode have helped to refine the understanding of the meanings of low stress abrasion and high stress abrasion [2].

In the BMAT, it is most convenient to use specimens in the form of balls or blocks which are introduced loose as part of the mill charge. These specimens function as part of the grinding media, but are distinguishable from the general ball charge by means of distinctive shape, size or markings. It is also possible to fix the specimens to the mill shell in an attempt to more closely simulate the conditions experienced by liners, but to date we do not have evidence to indicate that the relative performance of alloys is strongly affected by the different specimen forms.

The BMAT has not yet been standardised, but offers several advantages over standard laboratory abrasive wear tests. In particular, it has been shown to be a much better simulator of industrial ball mill service. In contrast to tests such as pin abrasion tests (PAT), the BMAT quite closely reproduces the abrasive particle and counterbody kinematics of industrial mills; can readily use actual ores; can accommodate a fairly wide range of abrasive feed particle sizes; and can produce quantitative alloy performance comparisons closely matching those in service [2]. Another advantage of the BMAT is that it naturally facilitates simultaneous exposure of multiple specimens, thereby reducing the sensitivity of alloy performance comparisons to small changes in abrasive conditions over time, and increasing the speed with which statistically valid data can be generated.

It has been shown [2] that the ratios of wear rates of key alloy classes can be used to characterise wear modes. Importantly, abrasion mode and associated alloy performance ratios are determined not only by the mechanical conditions (such as contact forces, sliding velocities and presence or absence of rigid counterbodies) but also by the nature of the abrasive mineral. The latter fact ought to be well understood from established reference works such as that of Zum Gahr [4] but, despite this, most ASTM standard laboratory tests utilise idealised abrasive media such as quartz sand or commercial bonded garnet abrasive cloth.

The very limited BMAT literature to date shows alloy performance data for only a small number of minerals. The current work explores alloy performance responses in the BMAT using a variety of pure and mixed abrasive minerals. This is of both industrial and theoretical significance. Real ores are typically mixtures of several minerals. For example, the BHP-Billiton Cannington mine ore used in reference [2] was a mixture of Pb and Zn sulphides in a gangue of silica, CaFe silicates and FeMn silicates. Despite the presence of a substantial proportion of relatively pure silica, BMAT tests using this ore gave alloy performance ratios more suggestive of low stress abrasion (as might be expected from the softer minerals) than of high stress abrasion (as occurs when pure silica sand is used as the abrasive). In order to gain a greater understanding of the factors controlling wear rate, and to develop intelligent methodologies for materials selection and predictive maintenance scheduling, it is necessary to expand the available data sets—both for a larger number of well-characterised pure minerals and for systematically varied mixtures of minerals.

2. Materials and methods

The BMAT apparatus used was a 300 mm diameter, 300 mm long laboratory ball mill. A conventional graded ball charge (diameters 9.5, 12.0, 15.5, 18.5, 24.4, 28.1, 32.7 and 37.5 mm) was used, weighing 30 kg in total. To this ball charge, a total of 7 kg of block-shaped specimens were added. The specimens had dimensions typically 55 mm × 23 mm × 14 mm and weighed on average 130 g each. A total of 53 such specimens were simultaneously exposed in the BMAT, comprising 13 materials typically in quadruplicate.

The 13 materials (actually ‘alloy/heat treatment combinations’) were made up from three alloy classes, namely:

- Cast low-alloy high-carbon pearlitic steels (AS 2074 grade L2B or L2C). Such steels are commonly used for the liners of larger ball mills and semi-autogenous grinding mills.
- Wrought low-alloy medium-high-carbon martensitic steels. Steels of similar composition are commonly used for forged grinding balls in high-impact mills.
- Cast high-Cr-Mo white irons. Such irons are often used as liners in fully autogenous grinding mills and smaller ball mills.

Three examples of pearlitic steels were used. The specimens were cut from commercial grinding mill liners and were used in the as-received (normalised and tempered) heat treatment condition. The hardnesses of the three alloys were 300, 329 and 346 HV.

Five examples of high-Cr-Mo white cast irons were used. In four of these the specimens were cut from investment cast test plates poured from 70 kg or 150 kg melts, while in the fifth case they were cut from sand cast test plates poured from a commercial production melt. All were given conventional destabilisation treatments (typically 980 °C for 4 h and air cooled) resulting in a fully martensitic matrix. The different alloy compositions resulted in hardnesses of 633, 663, 700, 788 and 894 HV.

A single wrought low-alloy medium-high-carbon steel (Böhler K245) was used, but given five different heat treatments to produce a range of hardness values. After austenitising at 840 °C and oil quenching, they were tempered at 700, 550, 400 or 240 °C or used as-quenched, resulting in hardnesses of 257, 397, 540, 727 and 817 HV respectively.

In order to discern the effect of abrasive mineral on relative performance of different alloy classes, it was useful to group the above 13 materials into four generic classes, as follows:

(a) pearlitic steels, average hardness 320 HV;
(b) heavily tempered martensitic steels, average hardness 370 HV;
(c) as-quenched or lightly tempered martensitic steels, average 770 HV; and