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Sliding abrasion resistance assessment of metallic materials for elevated temperature mineral processing conditions

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ABSTRACT

The multiplicity of harsh environments in mining, processing and transporting ore and related waste, cause severe wear, extremely high maintenance costs and lost production.

Elevated temperature processing is one of the conditions that influence the performance of possible materials of construction. This takes the forms of reduced hardness and strength, deleterious changes in the structure and properties of materials during protracted exposure and increased oxidation and corrosion.

Drag chain conveying of hot solids e.g. in smelting, typically results in three-body sliding abrasion and adhesive wear of connecting pins and hole surfaces in link assemblies and of moving paddles that impel the particulates in enclosed channels. Selected materials have been assessed for this type of service under reciprocating sliding abrasion contact conditions using an adapted Cameron-Plint TE77 wear rig at 20 °C and 350 °C. These include the current carburised low alloy steel, other steels, Cr white irons and Co-based alloys in bulk, overlay and surface treated forms.

Examination of wear scars, using scanning electron microscopy, identified the main wear mechanisms affecting the highly resistant powder metallurgical (PM) tool steels and HVOF coating as micro-scratching and as indentation leading to micro-fracture. Materials with lowest resistance displayed evidence of significant material removal by micro-ploughing. The formation of oxide layers on some samples during testing appeared to be beneficial.

1. Introduction

Abrasive wear is arguably one of the most damaging and costly issues for many industries, particularly mining and mineral processing, where severe interactions between equipment and hard solids, ores or waste products, result in very high maintenance costs and production losses. There is a wide array of components that are required to operate effectively in such extremely harsh environments. Conditions are often exacerbated by elevated temperatures, and the associated lower hardness and strength, as well as increased chemical attack and deleterious changes to a material's microstructure and properties during protracted exposure [1] often result in significantly increased wear and/or corrosion rates.

There have been many studies conducted to examine elevated temperature sliding wear behaviour of materials in both unidirectional [2–5] and reciprocating [6–12] motion, however, the influence of abrasives on sliding wear mechanisms is generally concentrated on unidirectional rotation, due to the difficulty of ensuring that the abrasive is always present in the area of contact. Limited studies have been conducted to examine the influence of abrasives on sliding wear mechanisms at elevated temperatures.

The presence of an abrasive and the generation of wear debris between sliding bodies may result in either two- or three-body abrasion, or a combination of both depending upon the relative hardness of the materials in contact, thereby increasing the complexity of the tribological system.

In many situations, the prevention or reduction of wear is achieved by the use of superior alternative materials or the application of coatings or other surface treatments. There has, however, been a significant amount of research conducted to examine the formation of oxide scales or 'glazes' during sliding wear and to establish the influence of such layers on the wear resistance of specific materials [13–15].

The drag chain conveying of hot solids in smelting operations is one particular problem where elevated temperature environments lead to rapid degradation of equipment (see Fig. 1). The link bore and pin combination, which hold individual chains together, experience a relative reciprocating movement and the ensuing wear rapidly results in an increase in bore dimensions and hence in the overall chain length. As the degree of slack in the chain increases, the efficiency of hot solids movement is reduced and the opportunity

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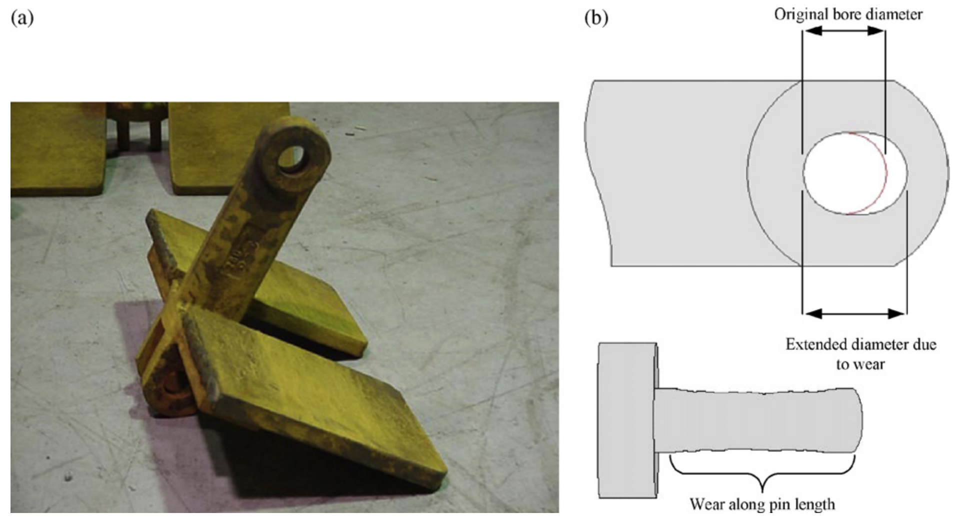

Fig. 1. (a) Single link/paddles assembly from a drag chain conveyor, (b) schematic showing location of wear for link bore and pin.

grows for increased ingress of abrasive process solids into contact zones between pins and bores.

The Cameron-Plint TE77 high frequency friction machine (*Phoenix Tribology Ltd., Newbury, UK*) is a well-established tool in the research of reciprocating sliding contact conditions [16–20]. For applications such as the drag chain conveyor, the rig has many advantages for assessing the compatibility of specific material couples. Currently, one principal material of choice for the linkage bar is a carburised low alloy steel casting, however, the thickness of the carburised layer is in the region of 500 μm and therefore offers only temporary protection. Due to the current unsatisfactory service life in the aggressive smelting environment, an investigation was undertaken to assess potential substitute materials to mitigate the wear of the pin and link bore during service. The need for improvement was also related to a plan to operate the system at higher temperature thus exacerbating the conditions.

The formation and comminution of wear debris within the contact area for sliding wear often adapt from two- to three-body abrasion. This additional debris component is considered likely to influence the formation of a compacted oxide layer [21]. This is a particularly important area of understanding for applications such as the drag chain link bore and pin where a third body, in the form of hot process solids, is present from the start.

The work reported herein describes an appropriate test procedure that has been developed for assessing materials for this application and examines several possible replacement options. These are in bulk form or as thickness dependent, surface treated layers or hardfacing deposits.

2. Experimental methods and materials

2.1. Test products

The materials which have been assessed are listed in Table 1. The choice was intended to both evaluate the capability of the test procedure and some of the influences on performance (e.g. original steel hardness) and to evaluate possible candidates for use in elevated temperature sliding wear environments. The former motive resulted in the inclusion of several materials not specifically intended for protracted high temperature service (e.g. quenched and tempered AR steels). A cross-section of wear materials classes was selected that offered some potential benefits in terms of high wear and softening resistance and low oxidation susceptibility.

The relative motion of the drag chain link bore and pin involves a reciprocating sliding action with entrainment of particles between components [22]. The Cameron-Plint TE77 is suitable for assessing such movement and a ‘horizontal cylinder-on-flat’ sample geometry was chosen to ensure a suitable uptake of abrasive into the space between the two contacting surfaces.

2.2. Test specimens

Flat sections with dimensions of 13 mm × 25 mm × 7 mm were ground to a 1200 SiC grit finish. The cylindrical ‘counterbody’ samples were prepared from hardened O1 tool steel (60 HRC) with a diameter of 6.35 mm and length of 20 mm. A 45° chamfer at both ends of the cylinder gave an initial line of contact of 18 mm and

Table 1
Materials assessed under reciprocating sliding abrasion conditions.

Sample	Material class	Description	Hardness—HRC
A	Existing drag chain conveyor material	Low alloy steel	47.0
B		As above + carburising treatment	62.0
C	AR steels	CMnB AR 400 steel	40.0
D		CMnB AR 600 steel	55.6
E	Tool steels	Powder metallurgy high alloy tool steel	69.2
F		Powder metallurgy high Cr tool steel	65.7
G	White irons	Hypoeutectic Cr white iron casting (~24–28% Cr, 2.4–2.8% C)	57.4
H		Hypereutectic Cr white iron casting (~30% Cr, 3.5–5% C)	60.5
I	Wrought Co-based alloys	Stellite 6B	37.6
J		Stellite 712	48.0
K		Tribaloy 400	53.7
L	Overlays/coatings	Chrome carbide bulk weld overlay (Nom. 28%Cr, 4%C)	54.7
M		HVOF sprayed WC-NiCoCrFeMo	73.8