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The role of load on wear mechanisms in high temperature sliding contacts

H. Torres [a,*], M. Varga [a], K. Adam [b], M. Rodríguez Ripoll [a]

[a] AC2T research GmbH, Viktor-Kaplan-Straße 2 C, 2700 Wiener Neustadt, Austria
[b] voestalpine Stahl GmbH, voestalpine-Straße 3, 4020 Linz, Austria

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ABSTRACT

The role of contact pressures in high temperature, high speed sliding wear has been studied in the context of alignment plates for the hot rolling of steel. To this end, a lab-scale simulation of the process was performed under varying normal loads, using several iron-based materials to be implemented in the real field application. The resulting wear rates and friction coefficients were compared, and it turned out that applied loads exerted no discernible effect on wear rates at room temperature, while leading in some cases to significant wear decrease at temperatures equal or higher than 500 °C. This was attributed to a tribolayer formation influenced not only by sample temperature but also by applied load. Running-in stage duration was also observed to be related to decreased wear rates for several of the materials.

1. Introduction

The effect of load on the wear of metallic materials during lab-scale testing has been well attested in the literature [1,2]. In particular, the severity of sliding wear [3] and fretting [4] has been reported to respond to nominal contact pressures. Similar dependences have been found in the available literature for mechanisms such as three body abrasion [5], adhesion and material transfer [6,7], and even for the formation of protective tribolayers [8–11]. This remarks the necessity of assessing the range of nominal contact pressures found during lab-scale wear testing [12].

However, most of the references found in the literature are restricted to room temperature (RT) testing. Only a handful of scientific papers concerning the role of both temperature and applied loads in wear processes have been found by the authors among the available literature. A study dating back to 2008 [13] reported the effect of both normal loads and frictional temperature increase in tribotesting. However, the chosen interval of contact pressures ranged between 3.3 and 8.8 MPa, lower than the values found for the majority of metal forming processes. Wang et al. [14] studied the wear behaviour of cast steel for several different microstructures under varying normal loads up to 400 °C, being the most comprehensive paper found so far. The perceived scarcity in available experimental data for a broad set of materials led the authors to perform a systematic approach to the problem, studying the wear behaviour of ferrous alloys under temperatures and contact pressures as close as possible to those found in real manufacturing applications of interest like metal forming. This set of processes has in common the onset of severe tool damage at high temperatures (HT) [15–17], raising significant concerns due to the required frequent maintenance. It is also noteworthy that within this context, wear of mechanical components may lead to changing contact conditions and thus nominal contact stresses varying during operation time [12] even under constant applied loads.

As described in a previous paper [18], a lab-scale testing method relying on HT wear tests was developed for simulating the damage experienced by the alignment plates used during hot rolling of steel (as sketched in Fig. 1a), and subsequently utilised for the screening of HT-wear resistant materials. To that end the maximum achievable load of 130 N was chosen, as it made it possible to reproduce several key wear mechanisms observed in damaged guiding plates, such as the micro-scale ploughing seen at the wear tracks. It additionally allowed for material transfer from the counter body during a single test (the real process takes place only through multiple sheet metal passes). However, hot rolling process parameters such as sheet metal thickness or the forces applied during the alignment process may lead to different stresses at the sliding interface, thus influencing the overall plate lifetime. Additionally, increasingly conformal contact and changes in contact geometry due to the formation and growth of wear grooves may also lead to decreased pressures. This process may be ideally approximated to a hertzian contact featuring the following

* Corresponding author.
E-mail address: torres@ac2t.at (H. Torres).

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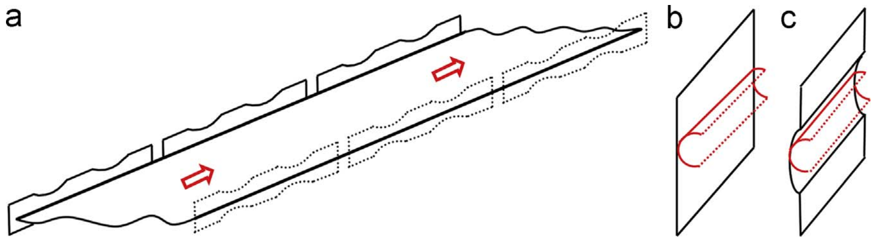

Fig. 1. a) Schematics of the alignment procedure performed on sheet metal during hot rolling [cf. 18], with a detail of the wear process experienced by the alignment plates, starting from b) the initial, unworn state, and leading to the formation of c) an inner cylinder–cylinder contact between the wear groove and the edge of sheet metal.

configurations: initially a plane (an unworn plate, Fig. 1b) against a cylinder (edge of the sheet metal), evolving into an inner cylinder (a wear groove, Fig. 1c) against a cylinder as the guiding plate gets worn off.

The main goal of the present study is to further investigate the role exerted on wear behaviour by the changing contact loads and stresses during prolonged HT sliding. To this end, a series of wear tests were performed at different loads using several iron-based materials. Special emphasis was given to the role of microstructure, including second phases, in tribolayer formation. The results were compared to obtain a comprehensive insight on the role of contact load and temperature in the resulting wear mechanisms.

2. Experimental

2.1. Materials

Three different iron-based alloys were chosen for testing, with their respective chemical compositions given in Table 1.

i) The low-alloyed, *ferritic/pearlitic steel* grade currently used for alignment plates was chosen as the reference material, its microstructure is shown in Fig. 2a. Its RT hardness was measured to be 151 ± 3 HV10.
   Additionally, two prospective iron-based hardfacings for future implementation in the application were investigated. Special focus was laid on the role of microstructure on sliding wear at HT. They were deposited by direct diode laser welding on a mild steel substrate.
ii) A *martensitic hardfacing* with fine and evenly distributed vanadium carbides (diameter < 5 μm) as seen in Fig. 2b. Its RT hardness was measured to be 812 ± 21 HV10.
iii) An *hypereutectic, chromium carbide-rich hardfacing* was also tested. Its RT hardness was 692 ± 18 HV10, and showed a ledeburitic matrix with large primary chromium carbides (Cr_7C_3), as seen in Fig. 2c.

Both hardfacings had in common their cost-efficiency due to localised applied wear protection and compatibility to low-alloyed steel.

2.2. Hot hardness measurements

HT hardness measurements (HV10) of the chosen materials were performed up to 700 °C, using a testing rig developed at AC2T research GmbH as described elsewhere [19]. This technique was expected to provide additional information on the HT tribological behaviour of the tested materials, especially abrasion resistance and ductility.

Table 1
Chemical composition of the tested materials, in weight %.

	C	Si	Mn	Cr	Mo	Ni	V	Fe
Ferritic/pearlitic	0.3	–	1.4	–	–	–	–	Balance
Martensitic hardfacing	2.8	0.7	1.1	5.7	1.7	–	12.5	Balance
Hypereutectic hardfacing	3.9	1.1	0.25	32.5	0.5	4.5	–	Balance

2.3. HT sliding wear testing

HT, high speed sliding wear tests were performed using a high temperature block on wheel configuration. The device, whose configuration is shown in Fig. 3, is based on an ASTM G65 abrasion tester modified to allow for inductive heating of the plate samples up to bulk temperatures of 700 °C. A detailed description of the test rig is found elsewhere [18]. No added abrasive was used for the tests. Sliding speeds representative of the real field application (12.1 m/s) were chosen for testing, and the wheel used as a counter body was manufactured from a representative steel grade commonly hot rolled at the application plant.

Test duration was set to 10 min for the ferritic/pearlitic steel grade as sheet metal in the real application may have total lengths in the kilometre range. However, duration had to be limited to 4 min for both hardfacings due to the lower thickness of the welded layers (~1 mm).

Due to the reported role of temperature in wear processes [19,20], temperatures representative of those measured in the real field application were chosen, namely RT, 500 °C and 700 °C. For details see [18] and Table 2.

As previously mentioned, the described test rig was able to successfully reproduce the observed wear mechanisms found during the high speed sliding contact between guiding plates and sheet metal in hot rolling of steel [18]. The present set of tests was designed to cast additional light into the effect of applied loads on HT sliding wear mechanisms by making use of three iron-based alloys with radically different microstructure. To this end, both the minimum and the maximum loads allowable by the test rig under the current configuration were chosen, namely 45 and 130 N. Estimates of the initial contact pressure during lab-scale testing were performed as follows: a hertzian contact was assumed between plate samples and the counter body. Young modulus and Poisson ratio for the steel wheel were chosen as 210 GPa and 0.29, respectively. For the plate samples, the effect of temperature on material properties had to be taken into consideration, as they were inductively heated. To this end, data for Hertz contact pressure calculation was taken from [21] for the intermediate testing temperature of 500 °C: a Young modulus of 110 GPa and a Poisson ratio of 0.30. Thus, a hertzian cylinder on plane contact under loads of 45 N and 130 N at HT returned initial maximum contact pressures of ~60 and ~100 MPa, respectively.

The entire set of parameters chosen for sliding wear testing is listed in Table 2. Every test was performed three times in order to ensure repeatability. Plate samples were subsequently characterised