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Experimental simulation of high temperature sliding contact of hot rolled steel

H. Torres [a,*], M. Varga [a], F. Widder [a], U. Cihak-Bayr [a], O. Viskovic [b], M. Rodríguez Ripoll [a]

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

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ABSTRACT

Wear plates are used for the alignment of sheet metal during hot rolling of steel. Conditions found during the process, such as the high temperature contact with sheet metal and high sliding speeds are responsible for severe plate wear. Damage characterisation of worn alignment plates showed in particular the onset of microstructure changes beneath the wear grooves and the formation of a mechanically mixed layer in the contact region.The aim of this work is the development of a material selection map for cost-efficient steel grades by means of a new high temperature sliding wear testing. As a result, significant differences in wear behaviour were found between the investigated material classes.
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1. Introduction

The proper alignment of sheet metal during the hot rolling of steel is carried out by means of a set of guiding plates (also called wear plates), usually of low alloyed steel, which may be adjusted to contact the incoming slabs, as shown in Fig. 1a. Environmental conditions during hot rolling are quite severe, as the temperature of the sheet metal remains high and relative sliding speeds between both tribo-components are also high. Sliding speeds and sheet metal temperatures show a wide range of variation depending on the steel grades under production. Also, due to the large scale of present-day steelmaking, wear plates may contact during service a total sheet length in excess of several hundred kilometres.

For all the previous reasons, the lifetime of wear plates is limited, making frequent maintenance and facility downtime necessary, with significant economical costs for steel manufacturers. Any potential new material to be implemented in the real field application thus has to show a high degree of wear resistance under high temperature (HT) sliding contact. In an effort to extend the lifetime of the guiding plates used for the alignment of sheet metal during hot rolling of steel, a new procedure was developed for high temperature wear testing under conditions representative of the real field application (high sliding speeds and elevated temperatures) [2]. For the present work, sliding wear tests were carried out using an ASTM G65 tester [3] adapted for high temperature performance. The test rig was further modified in order to operate at speeds representative of the real field application, as their role in wear processes has been attested in the existing literature [4,5].

HT sliding wear testing has been regarded as a process involving significant material transfer between the samples [6,7]. Additionally it has been reported to produce marked subsurface plastic deformation on the samples [8], with an observed temperature dependence on wear rate which has been in turn linked to the formation of protective oxide layers limiting metal to metal contact and thus severe wear during sliding testing [9,10].

Any configuration chosen for lab-scale testing must be able to reproduce the dominant wear mechanisms as identified during characterisation of the real field application [11]. Additionally, frictional heating at sliding speeds similar to those found in hot rolling has been reported to produce significant temperature increase in the tribosystem and thus oxidational wear [4,12]. Frictional heating can also lead to microstructural changes beneath the contact surface, especially when the materials within the tribosystem are prone to phase transformations and high temporal gradients in temperature occur [13]. Thus, plate temperatures as well as sliding speeds representative of the real field application were considered to be important for the simulation of wear mechanisms and both had to be implemented in the lab-scale testing of alternative materials.

Despite its technological relevance, research in the field of HT wear of materials is still sparse as stated in [7], partly due to the required highly specialised testing equipment. The present study is

* Corresponding author. Tel.: +43 2622 81600 190.
E-mail address: torres@ac2t.at (H. Torres).

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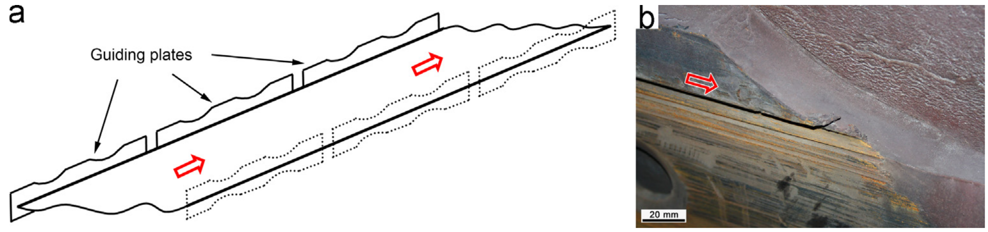

Fig. 1. (a) Overview of the alignment procedure performed on sheet metal during the hot rolling of steel and (b) detail of a damaged guiding plate after prolonged operation (cf. [1]).

an attempt to provide further insight into the wear mechanisms which occur under the HT conditions present in hot rolling plants. The main goal was the development of selection maps for materials suitable for HT applications by the development of test routines representative for real field applications. These maps are intended to increase the lifetime of wear plates and thus reduce material consumption as well as maintenance downtime.

2. Experimental

2.1. Reference material

Wear plates used for the alignment of sheet metal during hot rolling are currently manufactured from low alloyed, grade 1.0050 structural steel due to its economical cost. The base material has a lamellar ferritic/pearlitic microstructure, as seen in Fig. 2a, with hardness values of 161 ± 7 HV10 at room temperature (RT). The chemical composition includes a Mn-content of 1.4 wt%, with a maximum C-content of 0.3 wt%.

A damage analysis of guiding plates after prolonged operation (Fig. 1b), was performed to identify the predominant wear mechanisms. The surface characterisation of wear grooves was carried out using 3D optical profilometry. Cross and longitudinal sections were also prepared and analysed by means of optical microscopy (OM) in order to determine their microstructure. Additional measurements were performed by means of a scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) for microstructural and chemical analysis of the samples, especially at the transferred/mixed layers formed during HT tribocontact between sheet metal and the alignment plates (cf. [1,2]).

2.2. Alternative materials

Three different materials were chosen for comparison with the reference steel grade currently employed in guiding plates. The chemical compositions are given in Table 1. The study was focused on Fe-based materials due to their outstanding cost-efficiency performance:

i) *Grey cast iron* was chosen due to the reported formation of protective tribolayers from graphite flakes during dry sliding [14,15]. Its microstructure is shown in Fig. 2b, featuring a ferritic/pearlitic substrate with graphite lamellae and ferrite in their vicinity. RT hardness prior to testing was measured as 125 ± 12 HV10.

ii) An *abrasion resistant, martensitic steel grade* commonly used for the manufacture of wear protection plates was chosen for evaluation, featuring a martensitic microstructure without large hard phases, as shown in Fig. 2c. A small fraction of retained austenite/ferrite could also be seen in the form of brighter regions, probably softening the martensitic substrate. RT hardness was measured to be 524 ± 5 HV10, and its chemical composition is listed in Table 1.

iii) A *Fe–Cr–V-based hardfacing* was deposited by direct diode laser welding on an austenitic steel substrate, and its RT hardness was measured as 665 ± 28 HV10. The microstructure is shown in Fig. 2d as seen by SEM (back-scattered electron mode), featuring a martensitic matrix with fine, dispersed V-carbides whose diameter ranged between 1 and 5 μm. Its chemical composition is given in Table 1. The thickness of the deposited hardfacing was ~2 mm. This material was selected because of its HT-resistant martensitic microstructure. The deposition of hardfacing layers on industrial components has also been reported [16] as an efficient alternative for bulk materials for applications where high wear resistance is crucial.

2.3. HT sliding wear testing

The High Temperature-Continuous Abrasion Test (HT-CAT, [2]) was chosen for the lab-scale simulation of the main wear mechanisms observed in the real field application. The HT-CAT is based on a standard ASTM G65 [3] test rig, modified to allow the heating of the plate sample up to temperatures of 700 °C. The test configuration is illustrated in Fig. 3. A flat sample with dimensions $70 \times 25 \times 10$ mm^3 simulates the guiding plate and is pressed with a constant normal force against a sliding wheel representing the as-rolled sheet metal. As counter body material, a single sheet metal grade with a RT hardness of 159 ± 3 HV10 was used, which is one of the most representative steel grades found during hot rolling. One steel wheel was used, without reworking after testing. No third body abrasive was used during testing, because in the real field application only the oxide layer formed at the sheet or at the guiding plate may act as an abrasive. The test configuration was regarded as representative to the conditions found during the alignment of sheet metal because it does not encourage the retention of wear debris.

The lab-testing load of 130 N was selected to match typical contact pressure values found under real application conditions. This load corresponds to an initial maximum hertzian contact pressure of ~110 MPa, assuming an unworn 1.0050 grade steel plate loaded against a low-alloyed steel wheel with a diameter of 232 mm and thickness of 3 mm. The initial maximum hertzian pressures were expected to decrease during the formation of the wear track as the contact became more conformal. For the real field application, an exact maximum contact pressure cannot be defined since the thickness of sheet metal varies continuously during hot rolling according to production needs. Thus, contact pressures in the wear plates vary widely depending on sheet geometries. However, assuming a hertzian contact pressure and a cylinder – plate contact situation for unworn plates, the measured edge radii of commonly used sheet metal resulted in maximum contact pressures within the same order of magnitude as those calculated for lab-scale testing.

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