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High temperature wear behavior of the surface-modified externally cooled rolls

Ali Günen[a,*], Erdoğan Kanca[b], Mustafa Serdar Karakaş[c], Vahdettin Koç[d], Mustafa Sabri Gök[e], Yusuf Kanca[f], Ahmet Çürük[a], Mehmet Demir[b]

[a] Department of Metallurgy and Materials Engineering, Faculty of Engineering and Natural Sciences, Iskenderun Technical University, 31200 Hatay, Turkey
[b] Department of Mechanical Engineering, Faculty of Engineering and Natural Sciences, Iskenderun Technical University, 31200 Hatay, Turkey
[c] Department of Metallurgical and Materials Engineering, Faculty of Engineering, Selçuk University, 42130 Konya, Turkey
[d] Department of Machine and Metal Technologies, Vocational School of Technical Sciences, Adıyaman University, 02000 Adıyaman, Turkey
[e] Department of Mechanical Engineering, Faculty of Engineering, Bartın University, 74000 Bartın, Turkey
[f] Department of Mechanical Engineering, Faculty of Engineering, Hitit University, 19030 Çorum, Turkey

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ABSTRACT

Externally cooled rolls of a steel plant were coated using three different surface modification techniques, namely titanizing, boronizing and borotitanizing. The grown coatings were examined using optical microscopy, scanning electron microscopy, microhardness measurements, X-ray diffraction and Raman analysis. Depending on the coating technique, a wide range of coating thicknesses and microhardness values were obtained; the highest microhardness was obtained in the titanized sample, while the greatest coating thickness was obtained in the borotitanized sample. Wear tests were performed on the untreated and coated specimens using a ball-on-disc wear tester under two different loads (1 N, 3 N) at three different temperatures (25 °C, 250 °C, 450 °C). The average friction coefficient values decreased at elevated temperatures, and increased under increased load. Temperature had a significant effect on the wear mechanism. At room temperature the effective wear mechanism was delamination, while at 250 °C and 450 °C oxidative wear was observed. All of the surface modification treatments improved the wear resistance. The highest wear resistance was observed in the borotitanized sample.

1. Introduction

1.1. Rolling mills and rolls

The process of plastically deforming a material (hot or cold) by passing it between rolls with compressive forces is known as rolling. When carried out at temperatures above the recrystallization temperature the process is known as hot rolling. Hot rolling processes are commercially and technologically important in the steel industry. New techniques to improve properties are constantly being made due to competition and reduced profit margins [1,2]. Consequently, new applications inevitably require steel sheet having preferably less thickness and higher strength with low surface roughness [3,4]. Since rolling mills have a great influence on these properties, it is crucial to improve the properties of roll materials. Important properties for roll materials include surface roughness, wear resistance, toughness and thermal fatigue [2–5].

Cooling beds are a series of rolls where the material leaving the hot rolling mill is cooled to obtain the desired mechanical properties and conveyed to coil winding (Fig. 1). The rolls can be internally or externally cooled. The number of rolls in the cooling bed of a rolling plant depends on the production speed and the thickness of the steel sheet. In externally cooled rolls (ECRs), there are water jets, located underneath and in between the rolls of the cooling bed to provide cooling for the passing material. The main reason for the use of internally cooled rolls (ICRs) is the simultaneous measurement of the surface quality, thickness and width of the sheet. To obtain accurate readings from the electronic measuring equipment in ICRs, water should not be present [1,6].

Cooling beds are engine-actuated and operate at high speeds. However, because the thickness of the material to be rolled is variable, the rotation speed of the rolls is also variable and subject to change. The rolls also need to be lightweight for low energy consumption: to decrease weight the rolls are made hollow with load-bearing bearing supports. To prevent ingress of seepage water into both stationary and moving components, the rolls need to have very low clearance values.

* Corresponding author.
E-mail address: ali.gunen@iste.edu.tr (A. Günen).

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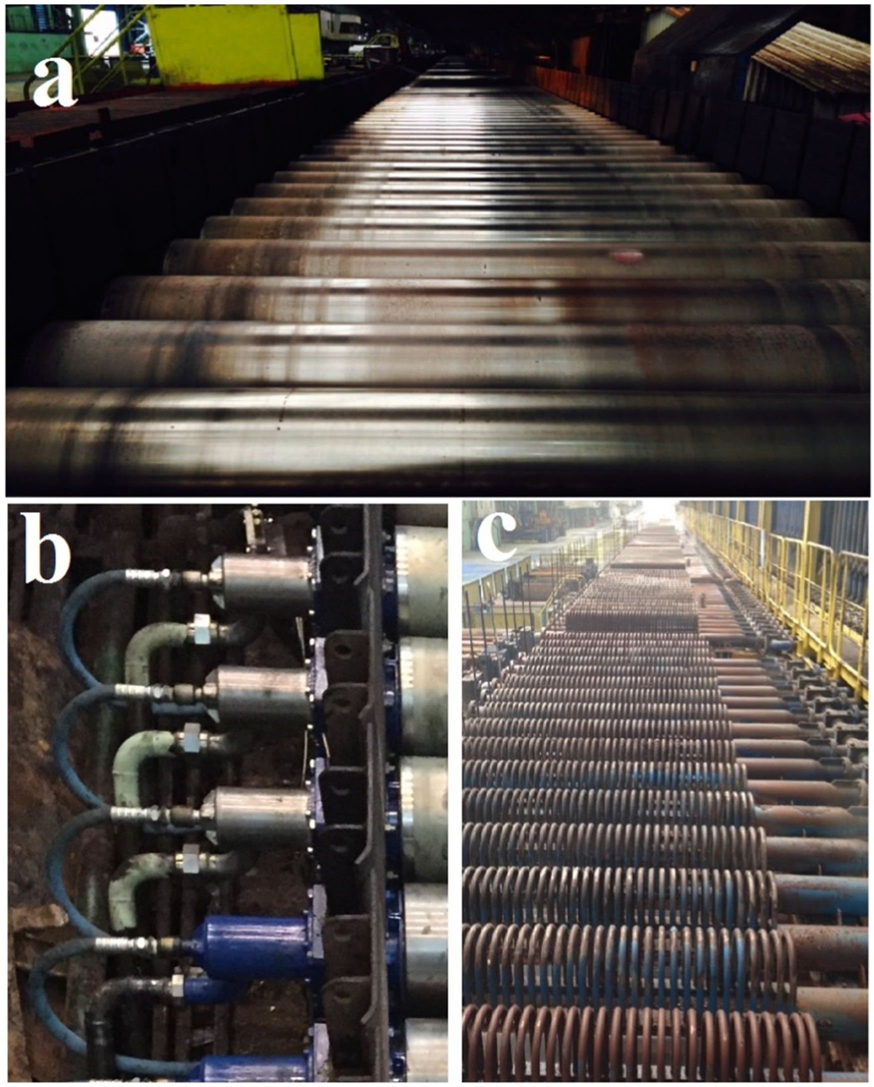

Fig. 1. (a) The appearance of the externally cooled rolls (b) internal cooling system and (c) upper cooling system in an industrial hot rolling mill.

Table 1
The chemical composition of STKM13A steel, in mass percent.

Material	Mn	C	Si	P	S	Fe
STKM-13A	0.9	0.25	0.35	0.04	0.04	Bal.

Table 2
The wear test parameters.

Test specimens	Ball: WC abrasive Disc: Untreated or coated STKM-13A steel
Revolution speed	0.3 m/s
Sliding distance	270 m
Applied load	1 N and 3 N
Temperature	25 °C, 250 °C, and 450 °C

Table 3
Properties of coatings used in the study.

Treatment	Thickness (μm)	Microhardness (HV)	R_a (μm)	R_z (μm)
Titanizing	3.6	2462 ± 15	0.40 ± 0.05	1.30
Boronizing	244.7	1417 ± 23	1.08 ± 0.15	3.25
Boro-titanizing	261.2	2388 ± 52	2.21 ± 0.2	6.65

There are both advantages and disadvantages to this. If adhesive forces in any preexisting coatings are weak, the rolls are easily affected by impact and high temperatures (especially in some plasma spray and high velocity oxy-fuel coatings) and low clearance regions rub against each other and obstruct the movement of the rolls. In addition, the leading ends of thick products leaving a set of rolls have front-end-curvature which causes them to impact every roll. During cooling the leading end hardens, and these impacts can cause failures on any existent surface coatings present on the rolls. These failures not only affect the rolls but also the quality of the product. Pinch rolls that follow are also affected in that blisters or markings are formed on the surface of the end product. This is highly undesirable in mass-production. When multiple rolls are used, troubleshooting also becomes problematic. In such events failure analysis studies also take a considerable amount of time and also result in production losses [1,6,7].

The cooling bed starts at the end of the rolling regime about 30 m beyond the rolling mill. The reason for this distance is thickness and surface quality inspections that are necessary before cooling. The rolls operating in this intermediate stage are subjected to temperatures of 250–450 °C due to heat transferred from the steel product. The surface scale that forms here cannot be removed due to the absence of water and this scale damages any existing coatings on the counterfacing rolls.