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The tribological behavior of PVD coated work roll surfaces during rolling of aluminum

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ABSTRACT

The use of PVD coatings for the mitigation of roll wear caused by high friction and adhesion in the roll gap during hot rolling of aluminum has been investigated. A tribo-simulator with a roll-on-block configuration was used for rolling AA1100 blocks at 25 °C and 450 °C under dry and lubricated conditions respectively. Six types of coatings, TiN, TiCN, TiAlN, CrN, Cr and DLC, were applied to M2 steel rolls and their performances compared with an uncoated roll. The CrN coating displayed a good combination of low friction and good aluminum adhesion mitigation behavior. The Cr coating's coefficient of friction (COF) and its surface area fraction covered with transferred aluminum were among the highest. The TiAlN coating had the lowest COF under hot rolling conditions with evidence of an oxide layer that was observed to delaminate from the rest of the coating. The DLC coating displayed the highest COF during hot rolling but the lowest during cold rolling. It had one of the lowest aluminum transfers to its surface under both cold and hot rolling conditions. The high friction was attributed to the transfer of a carbonaceous layer from the DLC coating to the aluminum surface.

1. Introduction

The tribological aspect of the hot rolling of aluminum alloys has been the focus of research for several decades because of the complex interactions that occur between the roll and the alloy surfaces. The tribological system involves many parameters, such as; the work roll and its surface conditions, lubricant composition and conditions, work piece material and specifications, the rolling process parameters and the tribological conditions at the roll/work piece interface [1,2]. The tribological interactions that occur between the work roll and the work piece, which are both covered by their individual oxides, are influenced by the thermo-physical and mechanical properties of the roll and work piece, such as yield strength, bulk hardness, shear modulus and density [1,3,4]. These properties thus impact the transfer of heat and stresses at the roll/work piece interface, which come into play in determining the surface quality of the final product [1,2,4].

Asperity contact between the surfaces of the roll and the work piece under lubricated conditions is a result of the high shear stresses experienced during hot rolling [2,5]. As such, the frictional condition between the roll and the work piece is of particular interest; in fact friction is considered one of the main parameters influencing the rolling process [2,5–7]. Consequently, it is generally accepted that the measurement of the coefficient of friction (COF) and the effects of the tribological factors influencing the rolling process are vital to the evaluation of the tribological behavior at the interface between the roll and the work piece [2,8]. The friction in rolling involves several material and processing parameters, which include; the lubrication condition, work roll roughness, roll speed, normal load, temperature, forward speed and reduction [2,9]. In addition, friction has been reported to be affected by the oxide layers on aluminum work piece surfaces and to increase along the length of contact and with larger reduction of the work piece [1,5,9]. However, friction is one of the main compressive forces responsible for the motion and thickness reduction of the work piece between the rolls [5].

Friction is also affected by the transfer of aluminum to the work roll surface. This transfer from the work piece induces a coating on the roll surfaces and occurs regardless of the roll topography and the applied load [2,3]. However, aluminum transfer increases with roll roughness and can impede high production rates through galling and may reduce the surface quality of the finished product [3,10]. The increase in rolling force is also known to influence the occurrence of friction pick-up [8]. The thickness of the transferred aluminum coating to the roll is determined by the size of the oxide fragments covering the work piece surfaces, which must be very small [3]. The roll coating could also reduce the COF, acting as a barrier for further aluminum transfer by weakening the adhesion tendency of aluminum to roll surfaces during subsequent rolling passes [11]. It is therefore argued that the roll coating may positively affect the work roll performance [12]. The roll coating

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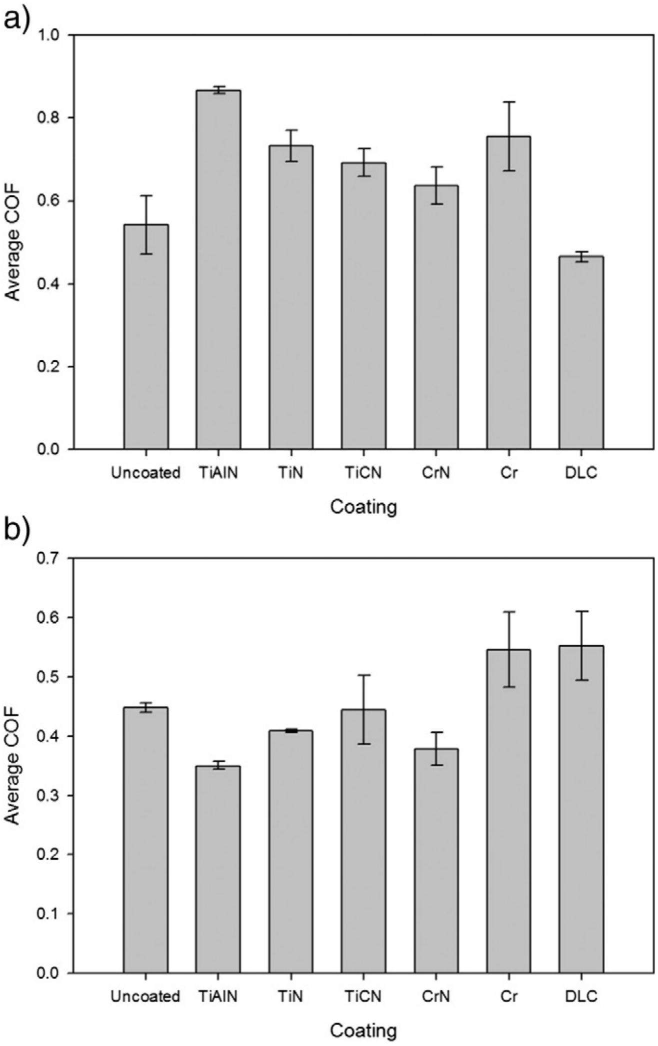

Fig. 1. Average COF values for coatings during (a) dry cold rolling and (b) lubricated hot rolling of AA1100 at 450 °C.

has a large impact on the effect the surface morphology of the roll has on the surface evolution of the rolled material [2]. Lubricants have been used to reduce aluminum adhesion to work roll surfaces, friction as well as wear to the work roll [3,8,10,13].

Work roll wear is influenced by friction, load, sliding length and the presence of abrasive and corrosive particles in the lubricant [1,14]. It is important to note that although high friction can cause deterioration to the work roll topography, to the point that rolls need to be reground to restore the initial finish, low friction can also be detrimental, as this may cause slippage and excessive roll wear [1,12]. Wear of the rolls can occur uniformly on the contact surface or locally in deep wear bands [15]. This type of roll wear is due to the interactions between oxidation, friction and thermal fatigue, with damage mechanisms being attributed to abrasion (exerted by the oxide scale of the work piece), adhesion, thermal fatigue and oxidation [12,14,16]. Uniform wear has been attributed to abrasion and thermal fatigue causing micro-chipping and crack formation perpendicular to the roll surface [14,17]. Thermal fatigue caused cracks appear during the early stages of rolling and can trigger and develop other wear mechanisms [17]. Therefore, it can be said that the roll life is shortened by high temperature and high pressures at contact with the work piece, thus materials used in work roll manufacture require good thermal, mechanical and tribological properties [1,12,15,17].

Coatings can be used to mitigate adhesion and reduce friction, rolling force and roll wear [3,8,10]. Diamond-like-carbon (DLC) coatings have been identified as promising coatings with a high tendency for reducing aluminum adhesion [10]. The properties of DLC coatings are dependent on the coatings' bonding structure and hydrogen content. For example, the low friction of non-hydrogenated DLC (NH-DLC) coatings is attributed to the presence of water in the atmosphere [10,18]. Water dissociation to H and OH passivates the carbon bonds on the surface, allowing for friction reduction and adhesion mitigation [18]. On the other hand, interest in metal nitride coatings is growing rapidly because of the high wear resistance attributed to them [19]. TiN coatings are recognized for their tendency of low adhesion to molten aluminum [10]. The incorporation of aluminum into TiN improves the oxidation behavior and thermal stability of the coating, enhancing the oxidation resistance of the die [19]. However, the deposition of coatings on a die surface does not guarantee improved friction and wear resistance; the coating topography or morphology has a strong influence on this. A high surface quality of the coating is required to modify the tribological interactions between the coating and the work piece [20].

Hence, because of the complex tribological conditions that occur during hot rolling, the evaluation of tribological properties of the roll materials is vital to any rolling operation. The on-line assessment of these properties is quite difficult [12]. The measurements of rolling parameters (e.g. friction) are affected by rolling conditions, which are constantly changing with each pass and for each mill [4,15]. Temperature also varies during a rolling pass due to the plastic deformation which increases the temperature and contact with the roll and emulsion, which reduces temperature [15]. Laboratory simulation of hot rolling conditions remains a hard challenge for tribologists, with test configurations such as disc on disc, pin on disc and ball on disc, being employed to reproduce specific aspects of these complex tribosystems [1,21]. Friction measurements have included calculations using parameters such as torque and forward slip, as friction decreases with increasing roll speed [5,8]. Friction has also been estimated from the reduction or spread, the angle of contact (though inaccurately) and matching measured and calculated roll forces (Hill's formula) [5,22].

In this work, several types of PVD coatings (i.e. NH-DLC, Cr, CrN, TiN, TiCN and TiAlN) are examined to determine the possibility of the application of these coatings in extending the life time of work rolls in the hot rolling process. Adhesion and friction were used as the main criteria for the evaluation of the coatings in comparison to the uncoated steel roll. Tests were carried out first, under dry conditions at room temperature and then lubricated tests at high temperature were performed to simulate cold and hot rolling conditions using a tribo-simulator.

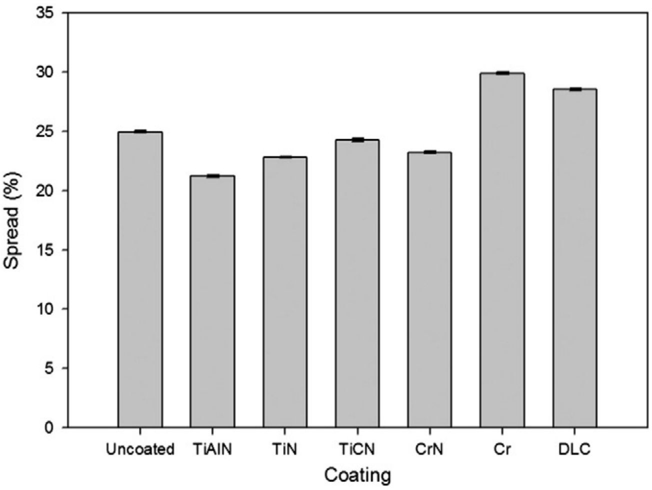

Fig. 2. Spread on AA1100 for uncoated and coated rolls after hot rolling at 450 °C.