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Aluminum transfer buildup on PVD coated work rolls during thermomechanical processing

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ABSTRACT

A hot rolling tribo-simulator was used to examine material transfer and adhesion from Al-Mg alloy samples to various PVD coatings deposited on AISI M2 steel rolls. The coatings applied to the work rolls included Cr, TiN and TiCN, which were compared with an uncoated M2 steel work roll after 1, 10 and 20 lubricated hot rolling passes. The average surface roughness (R_a) of the work rolls was 0.17 μm. Material transfer to the work rolls was examined after 1, 10 and 20 passes. Scanning electron microscopy (SEM) and focus ion beam (FIB) microscopy were used to investigate material transfer and adhesion to the surfaces of the work rolls. Aluminum and magnesium transfers were observed on all work rolls' surfaces from the 1st hot rolling pass. Material transfer was most severe on the uncoated M2 steel work roll through the rolling schedule, while the PVD coated work rolls displayed better mitigatigation against aluminum adhesion during both the initial and final stages of the hot rolling schedule. The material transfer on both Cr-coated and uncoated M2 steel rolls contained more magnesium than aluminum after the 1st and but after the 10th rolling pass the trend was the same only for the uncoated M2 steel work rolls. The aluminum transfer covered a larger percentage area than the magnesium transfer on the nitride coatings throughout the rolling schedule.

1. Introduction

The surface quality of rolled aluminum products is influenced by the surface morphology of the work roll. It has been established that the rolled aluminum sheet surface morphology is a reflection of the work roll surface topography. The topography of the work roll is responsible for inducing shingles, grooves and rolling ridges on the rolled aluminum surface. In addition, the work roll surface morphology is essential in influencing the rolling lubrication conditions as well as for drawing the work piece into the roll bite. It should be noted that the material transfer from the work piece to the work roll surface intensifies as the work roll roughness increases and that this material transfer can limit tool life through galling and excessive heat generation, which can lead to a poor surface quality of the finished product [1–4]. In turn, aluminum transfer, roll wear and fatigue fracture are a few of the key factors that highly impact the morphology of the work roll [5].

Transfer from the aluminum work piece, commonly called pickup, occurs regardless of the roll topography and the applied load, while the thickness of the transfer is determined by the size of the oxide fragments covering the work piece surface and the stage of the rolling process [1,3,5]. As the aluminum transfer builds up on the work roll surface, it forms a coating on the work roll [1,5]. Since the roll coating affects the work roll surface morphology, it has a direct impact on the surface evolution of the rolled material and its surface quality [5–7]. Yoshida et al. [6] pointed out that a comparatively smoother and finer rolled aluminum surface was produced with a thinner roll coating. During the hot rolling process, the roll coating eventually becomes unstable and can transfer back to the aluminum surface [3,8,9]. The back transfer of the roll coating and defects in the roll coating have a noticeable influence on the rolled sheet surface quality, such as inducing pickup defects on the rolled surface [3,4,8,9]. Tripathi [3] proposed two mechanisms for generating roll coatings: (i) micromechanical interlocking of plastically deformed metal on the rough profile of the work rolls; and (ii) the tribochemical generation of a polymeric film from the oxidation of the lubricant, which can adhere to the work roll surface and entraps wear particles within it. The development of a roll coating is thus influenced by such factors as the surface topography of the work roll, rolling force as well the work rolls' rate of cooling [3,10]. The work rolls' rate of cooling is principally affected by the emulsion, as such lubrication plays an important role in roll coating buildup [3]. It has been shown that unlubricated rolling produces thick and continuous roll coatings, while lubricated rolling would result in the generation of coatings that are patchy and discontinuous [9].

It has been established that the rolling emulsions play an important role in the composition of roll coatings, although one of the functions of

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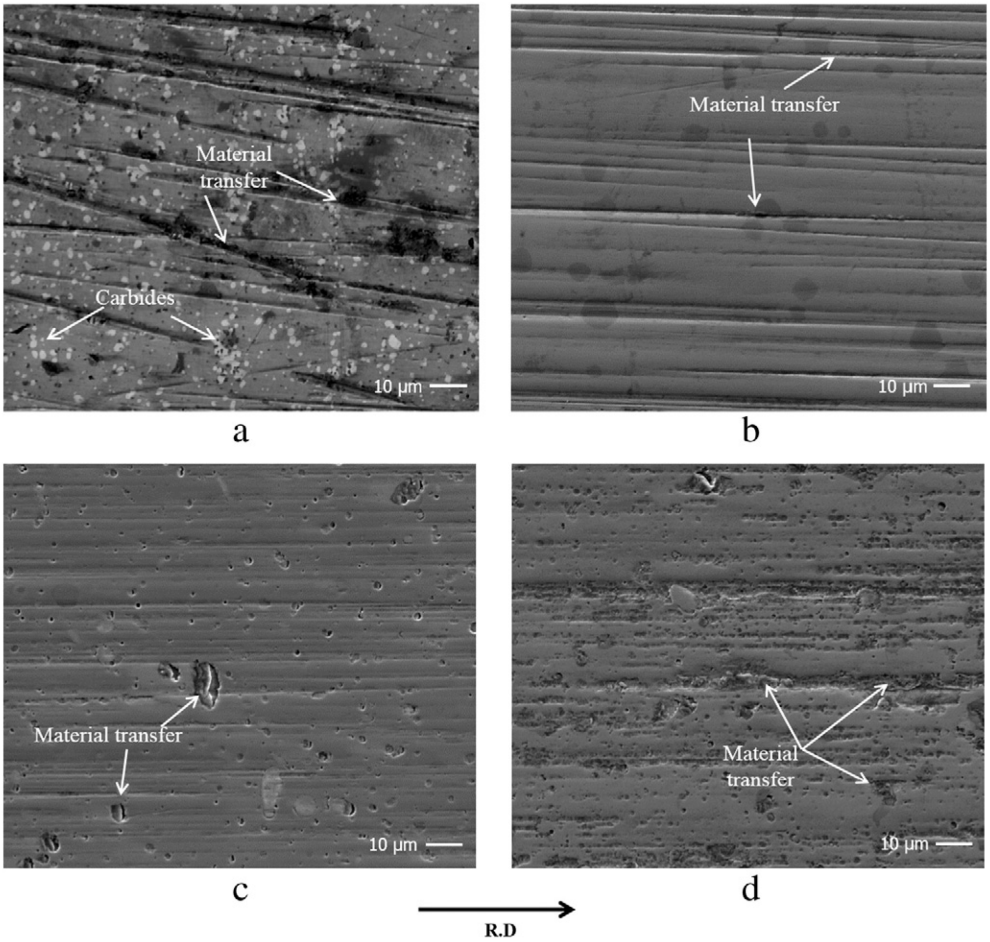

Fig. 1. SEM images displaying material transfer to the (a) uncoated, (b) Cr-coated, (c) TiN-coated and (d) TiCN-coated work rolls after 1 hot rolling pass against an Al-Mg alloy.

lubricants applied in rolling is to reduce aluminum adhesion to the roll as well as roll wear [1,2,6,10,11]. Yoshida et al. [6,11,12] observed that the thickness of the roll coating was directly related to the state (used or fresh), concentration and composition of the rolling emulsion. Therefore, the thickness of the roll coating is industrially used as an evaluation for the performance of the lubricant [3]. The roll coating, once developed, is also thought to act as a barrier, mitigating further aluminum adhesion by weakening the adhesion affinity of aluminum to the work roll surface on successive rolling passes [13]. Hence, it can be argued that the roll coating can be beneficial to the work roll performance, and its development on fresh work rolls is a part of the industrial rolling practice [3,14]. The effectiveness of the roll coating would be dependent on its thickness and continuity on the work roll surface [3].

Hard tribological coatings, typically used to mitigate adhesion and reduce friction, have been tested under lubricated and dry rolling conditions as a possible solution for reducing pickup and roll wear [1,2,10,15,16]. Howes et al. [9,15] examined roll coating buildup of commercial purity aluminum on work rolls made of several different materials. Dry tests at a rolling temperature of 300 °C revealed the greatest amount of aluminum transfer on the steel rolls and the least amount of transfer on the Si_3N_4 and Cr_2O_3 rolls [17]. They linked this material behavior to the influence of thermal conductivity and wettability (by molten aluminum) of the work roll material [17]. Howes et al. [18] subsequently heated the work rolls in-situ to eliminate the temperature difference between the work roll materials and the aluminum work piece. Under this condition, they reported thicker roll coatings formed at higher work roll temperatures and variations in the roll coating thickness between the different rolls were much less pronounced [18]. However, work rolls made of WC and Cr_2O_3 did not develop a continuous roll coating on their surfaces in comparison to the steel rolls, which possessed a continuous coating [18]. Under lubricated conditions, Howes et al. [15] detected the thickest roll coating on the Cr_2O_3 rolls and the least on the steel rolls, ascribing the aluminum transfer to the mechanical interactions between the roll and the aluminum piece. Gali et al. [16] compared aluminum adhesion to steel work rolls coated with various physical vapour deposition (PVD) coatings under dry cold rolling and lubricated hot rolling conditions. Their observations after 1 rolling pass revealed that aluminum adhesion was low on CrN and DLC coatings under dry cold rolling and lubricated hot rolling conditions. However, high aluminum adhesion was discovered on the Cr coating under similar rolling conditions [16]. It should be noted that the surface quality of the coating plays an important role in the coating performance, as it can improve the tribological interaction between the work roll and the work piece [19].

The present work examines the interactions between aluminum-magnesium (Al-Mg) alloys and a selection of PVD coatings under lubricated thermomechanical processing conditions to examine the buildup of roll coatings and potential benefits of PVD coatings in extending the work roll life. Aluminum adhesion was monitored through a typical hot rolling schedule, after the 1st, 10th and 20th rolling passes. This work aims at providing a better insight into the buildup of aluminum adhesion on dies during lubricated thermomechanical processes, as well as exploring the impact that PVD coatings would have on roll coating buildup.

2. Experimental procedure

Thermomechanical processing experiments were performed with a rolling tribo-simulator possessing a roll-on-block configuration, the