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Surface & Coatings Technology 200 (2006) 4654–4663

SURFACE & COATINGS TECHNOLOGY

www.elsevier.com/locate/surfcoat

PVD coatings for sheet metal forming processes—a tribological evaluation

P. Carlsson*, M. Olsson

MNT, Dalarna University, SE-781 88 Borlänge, Sweden

Received 15 October 2004; accepted in revised form 29 October 2004
Available online 16 December 2004

Abstract

The use of liquid-based lubricants in sheet metal forming mutually has a negative impact on the environment and on the whole economy, and, consequently, there is an urgent need to find a solution to make the forming processes dry or nearly dry. The deposition of a low-friction PVD coating on the forming tool has during the last years proved to be an interesting choice when it comes to create an "unlubricated" forming process. In the present study, five different PVD coatings (one CrN and four metal-carbide-doped DLC coatings) have been evaluated in sliding contact against hot dip Zn and 55% Al–Zn-coated steel sheet using a ball-on-disc test. From the investigation, it was found that all DLC coatings have potential to prevent material pickup during dry forming of hot dip Zn-coated steel. However, the as-deposited surface morphology, showing surface irregularities such as droplets and dimples, of the coatings will strongly influence the tribological performance, and, consequently, a polishing treatment or a running-in process, resulting in a smooth surface, will significantly reduce the tendency to material pickup. In sliding contact against 55% Al–Zn-coated steel, all PVD coatings display material pickup and high friction values, the only exception being a CrC-doped DLC coating in the as-polished condition. The CrN coating showed poor performance in sliding contact against both steel sheet materials due to a high tendency to material pickup. The study focuses on the tribo-induced changes of the surface condition of the PVD coating and the steel sheet surface during the sliding event. The changes in surface chemistry and topography of the tribo surfaces were characterised using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), Auger electron spectroscopy (AES) and light interference profilometry.

Keywords: DLC; Unlubricated forming; Running-in; Metal transfer; Zn; 55% AlZn

1. Introduction

Zinc and 55% Al–Zn-coated steel sheet have extensively been used in different types of applications, in particular in the automotive, building and household appliance industries. This is mainly due to a combination of high strength, excellent corrosion resistance and low cost. However, metal-coated steel sheet needs extensive lubrication during forming operations due to the strong tendency of the soft metal coating to adhere to the tool surface. After several successive forming cycles, the adhered material may result in scratches and eventually cracks on the formed product. This problem is often called galling [1]. Since the lubrication may deteriorate the workshop environment [2] and unhealthy degreasing agents are needed to remove the lubricant from the formed parts, efforts have been made to develop surface-engineered concepts which have the potential to form Zinc and 55% Al–Zn-coated steel sheet under dry conditions. One such concept is to apply a low-friction/high-wear resistant PVD coating on the tool. PVD coatings are preferable to use on tool steels since the low deposition temperature will not result in softening and reduced mechanical properties.

In the literature, basically two different types of PVD coatings, CrN and diamond-like-carbon (DLC)-based coatings, have shown promising results when used in those metal cutting and forming applications where pickup of work material on the tool surface should be avoided.

CrN coatings offer high thermal stability and oxidation resistance [3], high corrosion resistance [4], high wear resistance [5] and a low adhesion to some engineering work

* Corresponding author. Tel.: +46 2377 86 26; fax: +46 2377 86 01.
E-mail address: pca@du.se (P. Carlsson).

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doi:10.1016/j.surfcoat.2004.10.127

Table 1
Steel sheet materials included in the tests

Materials	Coating thickness (μm)	Strip thickness (mm)
55% Al–Zn-coated steel sheet	20	1
Hot dip Zn-coated steel sheet	20	1

materials such as Cu. Furthermore, the relatively low intrinsic stress state [6] and the relatively low deposition temperature make it possible to deposit relatively thick CrN coatings (possible to polish, resulting in a very smooth surface) on most steels without any risk for thermal softening [7].

DLC coatings for tribological applications have extensively been investigated for the last 10 years. DLC coatings consist basically of a mixture of diamond (sp^3) and graphite (sp^2) and are generally divided into hydrogen-free tetrahedal amorphous ta-C DLC coatings and amorphous hydrogenated a-C:H coatings. In the tribological applications of interest in the present study, mainly a-C:H DLC coatings doped with metals or metal carbides have shown promising results due to a combination of high wear resistance and low friction (low adhesion to some engineering work materials) [8–12].

Podgornik et al. [13] have investigated the galling properties of four different PVD coatings: TiN, TiB_2, TaC and a tungsten–carbide-doped DLC coating (WC/C) in sliding contact with austenitic stainless steel. The results showed that the deposition of a DLC coating of the WC/C type may result in excellent protection against pickup of work material. However, to reduce the pickup tendency of work material, the coated surface should be as smooth as possible.

Vercammen et al. [14] have investigated different state-of-the-art DLC coatings in a comparative study. The results showed that the tribological properties of the DLC coatings vary strongly, depending on coating composition/configuration and processing conditions (techniques). In summary, it was found that the observed differences in performance was related to differences in intrinsic properties of the coating such as mechanical properties, roughness, coating thickness and internal stress state.

Murakawa et al. [15,16] and Taube [17] have investigated the potential of using DLC-coated dies in deep-drawing of aluminium. The results showed that the DLC-coated dies exhibit excellent antisticking properties for aluminium under oil-lubricated conditions. In another work by Murakawa et al. [18], the tribological properties of amorphous hard carbon films in deep-drawing of zinc-plated steel sheet were investigated. It was found that the DLC coatings showed excellent deep-drawing performance against zinc under dry forming conditions.

In a previous work by the present authors [19], it was found that a tungsten–carbide-doped DLC coating (WC/C) exhibited a low friction coefficient and no material pickup in dry sliding contact with Zn. However, the low friction/no material pickup characteristics were only obtained after a running-in procedure.

In the present study, the friction characteristics and material pickup tendency of a number of PVD coatings (one CrN and four DLC coatings) in sliding contact with Zn and 55% Al–Zn have been investigated using ball-on-disc testing. The work focuses on the influence of chemical composition and surface topography on coating performance. To increase the understanding of the friction and wear mechanisms controlling material transfer at the sliding interface, the worn surfaces were subjected to a careful characterisation using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX) and Auger electron spectroscopy (AES).

2. Experimental

2.1. Materials

Two different types of continuously hot-dip-coated steel sheet manufactured by SSAB Tunnplåt were included in the tests (see Table 1). The PVD coatings evaluated included a CrN and four different types of metal-carbide-doped hydrogenated (Me-C:H) diamond-like carbon (DLC) coatings (see Table 2). All DLC coatings display a multilayered structure of MeC and C (i.e., WC/C [12] or CrC/C [20]). The coatings were deposited on ball bearing steel balls (diameter 8 mm) using commercial PVD processes. It should be noted that the DLC III coating is deposited on a (Ti,Al)N coating, resulting in a dual-layer design, and that a thin (0.05–0.1 μm) interlayer of Cr was deposited to improve the adhesion of the DLC coatings to the steel substrate. The PVD coatings were tested both in the as-deposited and the as-polished, using 1-μm diamond, surface conditions.

2.2. Test procedure

The tribological properties of the PVD coatings were evaluated under unlubricated sliding conditions using a ball-on-disc test equipment. The normal load was set to 20 N, and the sliding speed was 0.05 m/s. All tests were performed at 21±1 °C in laboratory air (35–40% relative humidity). The tangential (frictional) and normal forces were continuously recorded during the tests. A new spot on the ball was

Table 2
PVD coatings included in the tests

Coating	Coating thickness[a] (μm)	Vickers hardness[a]
CrN	5–6	2000
DLC I (WC/C)	2.0–2.5	1500
DLC II (WC/C)	2.0–2.5	1200
DLC III (WC/C)	2.0–2.5[b]	1000
DLC IV (CrC/C)	2.0–2.5	2500

[a] As given by the coating supplier.
[b] Deposited on a 4–5 μm (Ti, Al) N coating.