Int. Journal of Refractory Metals and Hard Materials 57 (2016) 24–30

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

journal homepage: www.elsevier.com/locate/IJRMHM

Influence of surface topography on early stages on steel galling of coated WC-Co hard metals

T. Klünsner [a,*], F. Zielbauer [a], S. Marsoner [a], M. Deller [b], M. Morstein [c], C. Mitterer [d]

[a] Materials Center Leoben Forschung GmbH, Roseggerstraße 12, 8700 Leoben, Austria
[b] Fritz Schiess AG, Feinschnitt Stanzwerk, Floozstrasse, 9620 Lichtensteig, Switzerland
[c] PLATIT AG Advanced Coating Systems, Eichholzstrasse 9, 2545 Selzach, Switzerland
[d] Department of Physical Metallurgy and Materials Testing, Montanuniversität Leoben, Franz Josef-Straße 18, 8700 Leoben, Austria

ARTICLE INFO

Article history:
Received 10 November 2015
Received in revised form 25 January 2016
Accepted 3 February 2016
Available online 17 February 2016

Keywords:
Galling
WC–Co hard metal
AlCrN hard coating
Post-treatment
Blasting
Roughness

ABSTRACT

Galling, i.e. the transfer of workpiece material to tool surfaces, is an important factor known to influence both wear behaviour and loading conditions of metalworking tools such as deep-drawing, blanking or fine blanking punches or dies. The current study investigates very early stages of galling of mild steel on WC–Co hard metals coated by AlCrN-based hard coatings. Repeated dry-sliding contacts with virgin steel material were physically simulated by a ball-on-disc test setup with a virgin contact area on the ball in each lap. Special attention was paid to the influence of coating surface topography produced by coating post-treatment and the resulting distinct differences in galling behaviour. Galling initiation is illustrated by cross-sections of micrometre-sized features of transferred steel, showing their nucleation sites to be microscopic surface asperities. A layer-by-layer material transfer mechanism is indicated by the galling features' internal layered structure. The current work demonstrates a clear connection between the ratio of peaks to valleys on coating surfaces and the kinetics of the early stages of galling. A reduction of this ratio, e.g. by coating post-treatment via blasting with diamond-containing elastomer particles, leads to a reduced tendency for steel transfer to coated WC–Co hard metal surfaces.

1. Introduction

The economic competitiveness of many industrial metalworking processes crucially depends on factors such as short cycle time, high material removal rate and long tool lifetime. For many applications such as milling or turning, tools made of WC–Co covered with thin hard coatings are the well-established standard solution to these requirements. The importance of coated WC–Co hard metals is increasing due to the fact that also in production processes traditionally dominated by coated or uncoated high-strength steels, there is a trend to substitute the tool steel material by WC–Co hard metals. The driving force behind this trend is the desire to avoid localized plastification caused by cyclic tool loads that lead to a buildup of tensile residual stresses close to cutting edges. These tensile residual stresses foster fatigue crack growth that can trigger fracture before major tool wear takes place. The locations of the emerging localized tensile residual stresses can be correlated with the origins of tool failure close to the cutting edge of e.g. blanking [1] or milling tools [2,3]. In general, it is therefore beneficial for tool life to avoid localized plastic deformation by application of high strength tool materials such as WC–Co hard metals. They provide roughly two times higher resistance to plastic deformation compared with high-strength steels [4] and a higher wear resistance than steels [5].

Another source of tool loading components in tension and shear detrimental to tool life particularly in forming, deep drawing, blanking or fine blanking processes is friction between the tool surface and the workpiece. In many tooling applications there is a tendency of the workpiece material to adhere to the active tool surface. This process is referred to as adhesive wear or galling [6] and is associated with an increase of friction between the sliding counterparts [7]. In many cases, galling acts in combination with abrasive wear damage leading to blunting of cutting edges, which results in an increase of cutting forces and consequently accelerated tool damage. Also the tensile surface load components arising in sliding contacts [8], e.g. between a fine blanking punch and the workpiece, rise due to increased friction [9]. This is of relevance to tool lifetime since the failure behaviour of brittle materials [10] such as hard coatings and especially WC–Co hard metals is very sensitive to tensile load components under monotonous [11] and cyclic loading conditions [4].

Galling of metallic materials sliding against coated surfaces has been characterized by various test setups in which the sliding counterparts are flat surfaces on one another [12], round-shaped objects on flat surfaces [7,13] or cylinders on cylinders [7]. A measure for the galling tendency can be the sliding distance at which the friction coefficient rises significantly for test setups with constant applied load. Test setups

* Corresponding author.
E-mail address: thomas.kluensner@mcl.at (T. Klünsner).

http://dx.doi.org/10.1016/j.ijrmhm.2016.02.002
0263-4368/

with increasing loads allow for the definition of a critical load for galling initiation [7,12]. From the mentioned kind of tests it can be concluded that galling can be diminished by: (*i*) increasing the yield strength of the counterpart materials [14], (*ii*) avoidance of elevated levels of contact pressure and temperature [15], (*iii*) the use of certain counterpart material matches [7,14], (*iv*) the use of lubricants [16], (*v*) by avoiding macroscopic surface grooves or scratches as preferred sites of material transfer [7] and (*vi*) by surface polishing that results in a reduction of surface roughness values, e.g. quantified in terms of the average roughness R_a [16]. Polishing of coatings was found to be more effective than substrate polishing in the case of steel substrates [16]. The need for further research regarding which aspects characterizing surface topography are suitable to describe galling tendency on e.g. blasted surfaces is emphasized in the literature [12]. In general, most results on galling available in the literature deal with rather advanced stages of galling. For example, percentages of surface covered with macroscopic material transfer are used as a measure of galling tendency [7].

In many cases, the shaping of tool steel or hard metal tools of complex geometries requires the use of electrical discharge machining with subsequent dry or wet blasting [17]. Up to now, the galling tendency of these surfaces is not well understood, especially when hard coatings are applied. Therefore, wet blasted hard metal surfaces are used in the current work as substrates for hard coatings to study possibilities to reduce their galling tendency. For complex-shaped tools as used in the applications mentioned above, conventional surface polishing methods are not applicable to reduce surface roughness due to economic reasons or general feasibility. For both reasons there is a need for alternative surface post-treatment methods to reduce surface roughness and therefore galling tendency of electrical discharge machined coated hard metals.

The current work thus investigates the influence of blasting of an AlCrN-based coating deposited by cathodic arc evaporation with different media on the coating surface topography and its influence on the very early stages of galling of mild steel. Along with common parameters describing average roughness such as R_a, the role of the ratio of surface peaks to valleys is studied as an important factor influencing galling kinetics.

2. Experimental methods

The investigated samples were cylindrical discs with a diameter of 32 mm and a height of 4.1 mm made of WC–Co hard metal with 11.8 wt.% Co binder and 1 μm average WC grain size. The surface of all investigated discs was initially polished to a mirror-like finish and afterwards wet blasted. This served to produce surfaces with topography similar to electrical discharge machined and subsequently wet blasted WC–Co tool surfaces. Immediately after this treatment, an approximately 2 μm thick AlCrN thin film was deposited on the discs by means of cathodic arc evaporation in a Platit π^{411} industrial deposition system, using a combination of lateral and central cylindrical rotating arc cathodes fitted with pure Cr, Al, and $Al_{0.7}Cr_{0.3}$ targets. The process was carried out at a coating temperature of 480 °C in a 99.999% pure nitrogen atmosphere at a pressure of 4 Pa and a bias voltage of −40 V. The physical properties and compressive strength of this AlCrN coating are described in [18].

After coating deposition, three variants of manual post-treatment procedures were chosen. The first post-treatment technique involved manual wet blasting with corundum particles with 360 mesh grit size. The second post-treatment technique, referred to as mild aerolapping, involved manual dry blasting with polymeric carrier particles with incorporated diamond particles [19]. The third post-treatment technique, referred to as aerolapping, differs from the second by a more thorough treatment.

The topography of the resulting surfaces was characterized in the disc specimens' centres by means of contact mode atomic force microscopy (AFM) [20]. All determined roughness parameters represent values containing averaged information from three AFM images with dimensions of 86 × 86 μm including 512 scan lines. The considered roughness parameters were R_a and R_z [21] describing the respective arithmetical mean roughness and the maximum vertical distance from the highest surface peak to the lowest valley [21]. In addition, the profile bearing length ratio or Abbott-Firestone curve [22] was used to determine R_k, R_{pk} and R_{vk}, which quantify core roughness, surface peak height and surface valley depth, respectively [23].

Ball-on-disc tests were performed in ambient air at room temperature under unlubricated conditions. In these tests, the circular contact path diameter was 14 mm and the relative displacement velocity 0.04 ms^{-1}. The balls had a diameter of 6.35 mm and were made of mild ferritic carbon steel with a yield strength $R_{p0.2}$ of about 300 MPa; the applied load was 10 N. The contact situation between ball and disc was analysed via finite element (FE) simulation. Elastic–plastic material behaviour of substrate material [4] and ball material was considered via stress–strain curves attained experimentally in uniaxial compression and tensile tests, respectively. Contact surfaces were assumed to be smooth, neglecting peaks of contact pressure at surface asperities present on technically rough surfaces. Under a load of 10 N the contact region was predicted to have a diameter of 180 μm with a nominal contact pressure of 600 MPa.

In many metalworking processes such as milling, drilling, blanking and fine blanking, tool surfaces are in contact with virgin workpiece material bare of hard (oxidized) particle debris stemming from the frictional contact. To resemble this aspect of tribological contact situations, a common ball-on-disc test was modified by manually replacing the contact area on the ball with a virgin one after each lap on the disc. This measure was found to be necessary to avoid the modification of very early stages of material transfer or even its removal by hard particles, e.g. oxide debris, accumulated in the contact zone between ball and disc. This modification to the ball-on-disc test facilitates the consideration of this aspect of tribological contact while maintaining the commonly available test assembly.

The lap start direction and start location were the same for all steel balls used. The friction coefficient between ball and disc was recorded for 300 consecutive laps with a data acquisition rate of 100 Hz. The resulting wear track was investigated at a position close to the lap's end after 300 laps by means of scanning electron microscopy (SEM). At the end of the tribotest, focused ion beam (FIB) milled cross-sections of approximately 20 μm in length and 20 μm in depth were prepared at the wear track centre close to the lap's end with planes tangential to the wear track path. Backscattered electron (BSE) contrast was used to illustrate the presence of iron in the SEM micrographs, while secondary electron (SE) contrast was applied to show very fine structural features. The chemical composition of transferred material was analysed by energy-dispersive X-ray spectroscopy (EDX).

3. Results

The roughness parameters of the investigated coated specimens along with an uncoated reference substrate are summarized in Table 1, evidencing that the compared post-treatment techniques lead to significantly different coating surface morphologies. Note that the roughness of the wet-blasted uncoated substrate is very similar to the wet-blasted coated specimen. Coating post-treatment by mild aerolapping resulted in very similar coating surface roughness compared to the wet blasting procedure. In particular, mild aerolapping did not reduce the ratio of peaks to valleys R_{pk}/R_{vk} on the coating surface. In contrast, the thorough aerolapping procedure significantly lowered the observed average roughness R_a and roughness peaks, as expressed by R_{pk}. Also, the ratio of peaks to valleys on the thoroughly aerolapped surface with an R_{pk}/R_{vk} value of 0.51 was significantly lower compared to the other investigated surfaces, which yielded R_{pk}/R_{vk} values above 1, see Table 1.