Surface & Coatings Technology 205 (2011) 4198–4204

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Performance of CrN radical nitrided tools on deep drawing of advanced high strength steel

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ARTICLE INFO

Article history:
Received 3 February 2010
Accepted in revised form 6 March 2011
Available online 11 March 2011

Keywords:
Radical nitriding
Deep drawing
Advanced high strength steel
AHSS
Adhesion
Coating

ABSTRACT

The performance of CrN film coating to reduce adhesion in the forming process of advanced high strength steel (AHSS) sheets was investigated. Radical nitriding prior to CrN film coating was used to increase the bond strength between the thin film coating and the tool steel substrate. Electron probe microanalysis was used to characterize nitride diffusion into the tool steel. Scratch testing was carried out to evaluate the bond strength between film coatings (CrN, TiN radical nitride and CrN radical nitride) and the substrate. Ball-on-disk testing was carried out to determine the friction coefficient. Deep drawing experiments with non-coated and coated tools were performed on SPFC 980Y steel sheets. JIS-SKD11 tool steel and TiN-coated tools exhibited high friction under dry sliding with SPFC 980Y sheet material. Moreover, severe adhesion was observed in deep drawing experiments using these mating materials. CrN film showed no adhesion to SPFC 980Y sheet material. The bond strength between a CrN film and the substrate can be increased by a nitride layer before coating.

1. Introduction

The demand for advanced high strength steel (AHSS) has significantly increased for use in automotive industries. A major problem in forming of AHSS material is galling, which is a type of adhesive wear [1]. Hard thin film coatings on tool material are effective in reducing wear and improving the tribological characteristics when sliding against AHSS material. In the metal forming industry, chemical vapor deposition (CVD) and physical vapor deposition (PVD) processes are commonly used to coat various types of film on tool surfaces. Several researchers [2–5] reported that adhesion and galling depend on the type of work material and level of contact pressure [1].

For stainless steel workpiece material, carbon-based coating provides the best protection against work material transfer. Forming of aluminum and titanium alloys requires nitride type coatings, such as TiN [2]. MoB-based cermets, cemented carbide and diamond-like carbon (DLC) films exhibit excellent anti-galling performance for aluminum and stainless steel forming [5–8]. Tungsten-doped DLC coating exhibits outstanding galling resistance on forming of hot dip galvanized steel [9]. CrN and TiAlN PVD coatings reduce the adhesion between copper alloys and die material in a cold drawing process [10]. It has been reported that TiCN CVD film has good anti galling properties when forming high strength steel (HSS) [11]. A TiCN PVD coating was effective in reducing galling in the forming of galvanized AHSS grade DP 980GI [12]. However, nitriding combined with a CrN film coated showed better performance when forming HSS grade SPFH 590 than TiCN PVD film and DLC film [13].

Previous studies revealed that CVD coating is preferable when forming under high contact pressure or severe conditions [14,15]. A high galling tendency during AHSS forming is observed under severe conditions [1,12,16]. However, the CVD process utilizes a high deposition temperature, which affects tool softening and causes structural changes. The tool geometry after CVD coating can be slightly changed, thus reducing part accuracy. Therefore, PVD coating is a more attractive technique for industrial applications. The main objective of this study was to select a suitable PVD film coating for forming of AHSS. The classic TiN and CrN film coatings, which are effective in many applications, including machining, molding and metal forming, were selected. The benefit of radical nitriding prior to PVD coating is explored.

2. Experimental procedures

2.1. Tool and workpiece material

Cold work tool steel JIS-SKD11 was selected as the tool material. The tool was hardened to 60 ± 2 HRC prior to hard film coating. An AHSS

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doi:10.1016/j.surfcoat.2011.03.010

Table 1
Chemical composition and mechanical properties of the tool (JIS-SKD11) and workpiece material (JIS-SPFC980Y).

Symbol [JIS]	Tensile strength [N/mm^2]			Yield strength [N/mm^2]			Elongation [%]		Hardness [HV]	
SKD11	–			–			–		720	
SPFC 980Y	1002			712			16		332	
SKD11	Chemical composition [%]									
	C	Si	Mn	P	S	Cr	Ni	Mo	W<	V
	1.014	1.268	0.310	0.024	0.004	4.946	0.092	1.751	0.020	0.194
	Nb	Ti	Cu	Al<	Co	Fe	Sn	B	As	
	0.185	0.019	0.120	0.003	0.014	bal.	-	-	-	
SPFC 980Y	Chemical composition [%]									
	C	Si	Mn>	P	S	Cr	Ni	Mo<	W	V
	0.183	0.472	2.500	0.018	0.002	0.022	0.025	0.001	0.010	0.003
	Nb	Ti	Cu	Al	Co<	Fe	Sn	B	As	
	0.004	0.034	0.022	0.034	0.001	bal.	0.003	0.001	0.005	

cold rolled sheet of 2 mm in thickness, grade SPFC 980Y (JIS), was used as the workpiece material. The chemical composition and mechanical properties obtained from electrospectrometer, micro-hardness and tensile tests are listed in Table 1.

2.2. Deposition process

Film coatings of CrN and TiN, each approximately 3 μm in thickness, were deposited using the PVD technique with and without radical nitriding prior to hard film coating. The combination of radical nitriding and PVD coating provides increased peel off resistant for coatings [15]. In this process, the process was carried out under NH_3 (400 SCCM) and H_2 (200 SCCM) environment under deposition pressure of 57 Pa. The deposition temperature was set at 530 °C and the bias voltage was 500 V. After the radical nitriding applied, the dies were deposited by TiN and CrN coating film.

A TiN coating was deposited by cathodic arc ion plating with N_2 flow of 400 SCCM at 8 Pa in the pressure chamber. The deposition temperature was set at 400 °C and the bias voltage was 50 V. The average distance between substrate and target was 200 mm. A CrN coating was also deposited by cathodic arc ion plating with N_2 flow of 2000 SCCM at 4 Pa in pressure chamber. The deposition temperature and the bias voltage were 400 °C and 250 V. The average distance between substrate and target was 200 mm similar to TiN coatings.

2.3. Coating characterizing technique

The arithmetic mean roughness (R_a) of the die surface finish after coating was measured using a Taylor Hobson 2-series 2D stylus-type surface roughness measurement device. The stylus travelled on the surface at a constant speed of 1 mm/s over 12 mm tracing length with 0.8 mm cut-off. The hardness of film coatings was measured by JEOL-nanoindenter with a linearly increasing normal load (0–1000 μN) at a loading rate of 200 μN/s. A pyramidal (Vickers) indenter and a trigonal pyramidal (Berkovich) indenter were used. The properties of each surface are listed in Table 2. Electron probe microanalysis (EPMA) was performed to characterize the architecture of film coatings and the diffusion depth of the radical nitride.

Table 2
Properties of coated films.

Surface conditions	Surface roughness; R_a [μm]	Nano hardness [GPa]	Color
Non-coated (ball)	0.0502	–	Steel
CrN	0.0515	23.52	Silver
Radical nitriding + TiN	0.0693	23.60	Bronze
Radical nitriding + CrN	0.0694	23.34	Silver

2.4. Scratch test

The bond strength of each film on SKD11 substrate was characterized using scratch testing. A Rockwell diamond stylus was drawn over the coating surface for a linearly increasing normal load of 0–100 N at a sliding speed of 10 mm/min for a sliding distance of 8.6 mm. Specimens were cleaned with methanol prior to each test.

2.5. Ball-on-disk test

The friction coefficient between coated tools and AHSS was measured in ball-on-disk tests. The ball represents the forming tool

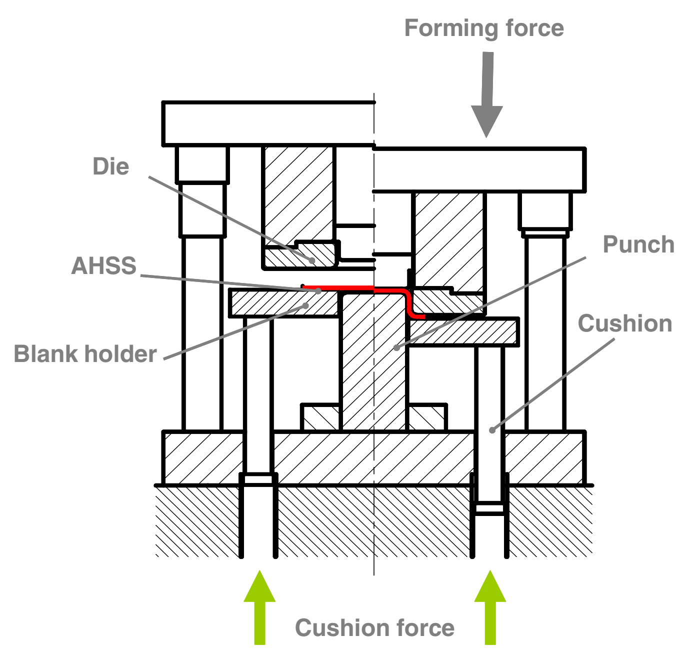

Fig. 1. Diagram of the deep drawing die.

Table 3
Tools condition for deep drawing experiments.

Items	Values
Punch diameter [mm]	59.4
Die diameter [mm]	64.2
Punch corner [mm]	5.0
Die corner [mm]	10.0
Die clearance [mm/side]	2.4
Punch speed [mm/sec]	20
Blank holder force [kN]	10
Deep drawing ratio	1.6
Lubricant	EM-7230
	Viscosity 60 mm/s^2 (40 °C)