WEAR AND BLANKING PERFORMANCE OF AN ALCRN PVD COATED PUNCH

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Blanking of sheet steels is one of the most frequently used processes in the manufacture industry. During blanking processes, the wear of punch occurs due to the cycled contact of opposite surfaces. Therefore, the punch is exposed to high stresses and requires high resistance against wear. When worn tools are used, the tool surface directly affects the quality of sheet products and causes some surface defects. PVD coating of punch with a surface layer of improved hardness and low friction may reduce wear. The aim of this study is to characterize tool wear of AlCrN coated punch used for sheet steel blanking. The worn punch surfaces were examined by scanning electron microscopy. Results showed that wear take place due to abrasion, adhesion, and delamination along sliding flank surfaces. Edge rounding and fracture of cutting edges were also observed. After blanking tests, the tool wear volume of punches and burr height of blanked parts were also measured. The wear volumes were determined by means of profile measurements of the worn punch carried out after completion of a large amount of blanked parts.

Keywords: *Blanking, punch, tool wear, PVD coatings, wear measurement, burr height.*

The research into wear resistant coatings is continuously developing in many applications like punching, blanking and trimming tools. The development of wear resistant surfaces by hard coatings arises from the need of increasing tool life and performance. In a blanking tool, the wear of punch and die directly affects the quality of parts by causing some defects during blanking [1, 2]. It is well known that the errors in the produced parts caused by blanking are: dimensional, positional, form and surface errors [3]. However, the most common errors are form errors, such as edge draw-in, depth of crack penetration and burr height [1, 3, 4]. Therefore, the form errors should be prevented to improve the quality of sheet products.

As is well known, PVD coatings are now available to increase the tool wear performance. According to experimental studies on punchability of ultra high-strength steels and tool wear carried out by Högman [5], wear can be reduced by PVD coating of the punch. They further established that cutting edge and punch corner are critical worn areas during blanking process. The mechanical and thermal conditions near the coating surface determine the location of wear. Klocke and Raedt [6] have studied the PVD coated tools and determined that the highest mechanical stress appears on the cutting edge and the coating surface, where the tribological conditions of blanking lead to temperatures around 400°C and contact pressures of more than 3000 MPa. The numerical simulations of Vaz and Bressan [7] have also shown that the maximum shear stresses occur near the punch corner.

It should be noted that the type of coating layer is also crucial. The TiN coating is used especially for machining tools [8]. However, blanking is a cold working process and the high temperature durability is not necessarily required. Therefore, AlCrN coating with higher toughness properties are preferred to obtain higher resistance to wear [9].

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Industrial trials and test results by Wang et al. [10] showed that the tool life of AlCrN coated punch was more than 2.5 and 5 times longer than that of TiN-coated and uncoated punches respectively.

The PVD coatings are applied to the punch tools in sheet steel blanking operations. The wear of punch tools and the appearance of form errors can be delayed by AlCrN coatings through PVD deposition. The purpose of the present study is to characterize tool wear of AlCrN coated punch used for sheet steel blanking.

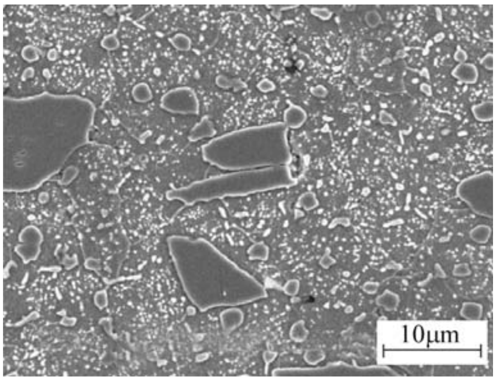

Fig. 1. SEM micrograph showing microstructure of X155CrVMo 12-1 punch tool (×2500).

Materials and methods. In the experiments, DIN 1.2379 (X155CrVMo 12-1) cold work tool steel was used as a punch material. As work piece material, 1 mm thick and 75 mm wide cold-rolled DIN 1.0037 (S235JR) low-carbon steel strip was used. The chemical composition (wt.%) of punch and strip steels is as follows: X155CrVMo 12-1 punch (1.55 C; 0.30 Mn; 0.25 Si; 12.0 Cr; 0.70 Mo; 1.0 V); S235JR strip (0.1 C; 0.20 Mn; 0.40 Si). Punches were hardened and then tempered to get a core hardness of 60 HRC. Microstructure of the punch consists of primary and secondary carbides of Cr, Mo and V in fine tempered martensitic matrix, as shown in Fig. 1. After heat treatments, the punches were grinded to reach a surface roughness (R_a) of ±0.2 μm.

The experimental study was done in AlCrN coated and uncoated condition of 1.2379 tool steel. The AlCrN coating was deposited using a Balzers Rapid Coating System (RCS) deposition machine. Fig. 2 shows the AlCrN coating with thickness of ca. 2 μm with hardness of 3200 HV0.05.

The blanking tests were carried out using a blanking test machine with 250 kN eccentric shaft press. The punch speed was 70 rpm and the maximum strokes were around 65000 for uncoated punch and 120000 strokes for the AlCrN coated punch. All of the blanking tests were carried out under dry cutting without using any lubrication materials. The distance between blanks was 5 mm and the dimensions are schematically shown in Fig. 3. Scanning electron microscope (SEM, JSM-6060) was used to observe the microstructures from cross sections and worn surfaces.

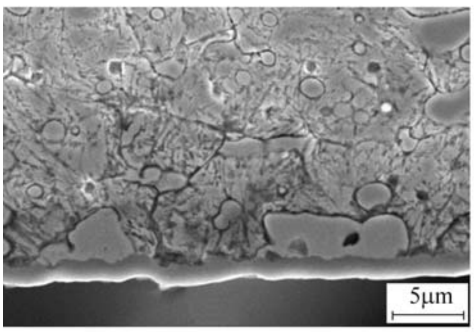

Fig. 2.

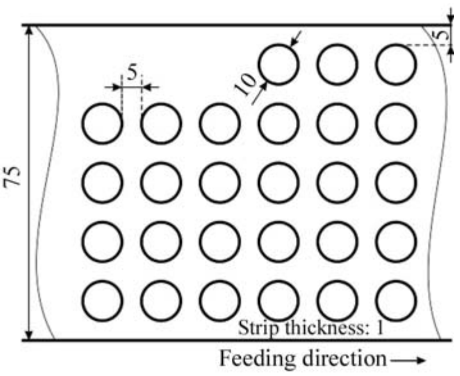

Fig. 3.

Fig. 2. SEM micrograph of cross section of AlCrN coated X155CrVMo 12-1 punch tool (×4000).

Fig. 3. The strip dimensions and punching arrangement (all measurements in mm).

The clearance Cl (%) was calculated from the expression below as a percentage of the strip [3, 11]:

$$Cl = \frac{D-d}{2t} \times 100\,, \tag{1}$$

where D and d are the die and punch diameter, and t is thickness of the strip. The die and punch diameters were 10 mm and 9.9 mm, respectively. As a result, the value of clearance considered here was 5%.

The tool wear volume of the punch and the burr height of the blanked strip were measured each 5000 and 1000 strokes respectively. The tool wear volume of the punch was derived from the measurement of wear radius using a stereo microscope and can be described as wear volume (V) [1]:

$$V = \frac{5\pi}{4}(r_{punch})^3 + \frac{3\pi}{2}R_p(r_{punch})^2\,,\ (\text{mm}^3) \tag{2}$$

where R_p is the punch diameter and r_{punch} is the punch cutting edge radius. An average value of four positions around the punch was measured to analyze the amount of volume wear after every 1000 strokes. On the other hand, the burr height was measured from the cross sections of blanked parts using a light microscope (LM). Five blanked parts were taken in order to determine the burr height after every 1000 strokes. The measurements were performed using LM.

Results. Fig. 4 shows the cutting edge and flank surface of the AlCrN coated punch before the blanking tests. A sharp cutting edge was observed before use. Moreover, it can be seen that the coating surface retains some droplets of the PVD coating process.

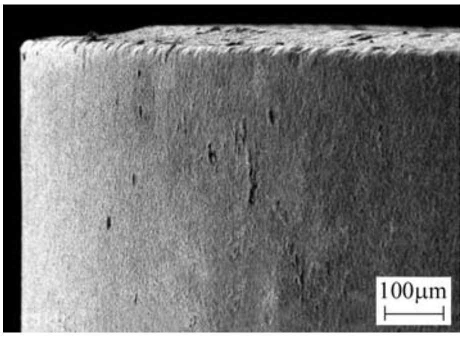

Fig. 4. SEM micrograph of the coated punch before blanking test (×150).

Cutting edge and flank wear. The cutting edge and the flank wear of AlCrN coated and uncoated punches were investigated using SEM after blanking tests. The worn surfaces were taken from the AlCrN coated punch after 120000 strokes and from the uncoated punch after 65000 strokes. In Fig. 5, it can be seen clearly that the wear is more severe on the uncoated punch, although the number of strokes was twice for the AlCrN coated punch. Fig. 5*a* indicates that AlCrN coating is worn slightly after 120000 strokes. Some micro-attrition and wear tracks were seen above the coating layer. Edge rounding also occurred due to wear. It is known that the edge rounding increases the tool radius and causes a burr height raise in the blanked parts [12]. In the uncoated punch in Fig. 5*b*, the edge rounding is more severe after blanking test with 65000 strokes. Edge fracture was also observed. The reason for edge fracture may be due to the repeated impact loads after edge rounding. Therefore, the loss of material is not uniform but strongly irregular along the cutting edge.

As can be seen in Fig. 6, the flank surfaces of the uncoated and AlCrN coated punches show adhesive and abrasive wear. The axial shear force is very large in punching process. It may cause wear of the punch flank surfaces during shear [13]. The flank surface close to the cutting edge presents some wear tracks (grooves and valleys) due to abrasion in Fig. 6. On the other hand, from Fig. 6*b*, adhered or welded layers were observed at flank surface of the uncoated punch. This indicates a typical adhesive wear.

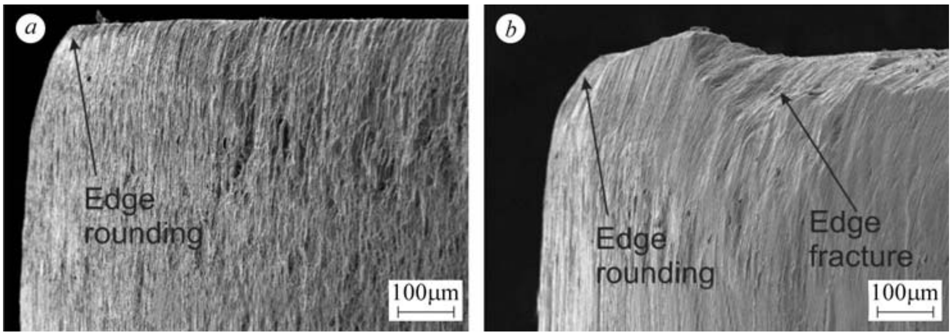

Fig. 5. SEM micrographs of the edge wear after blanking tests:
a – AlCrN coated after 120000 strokes; *b* – uncoated after 65000 strokes (×150).

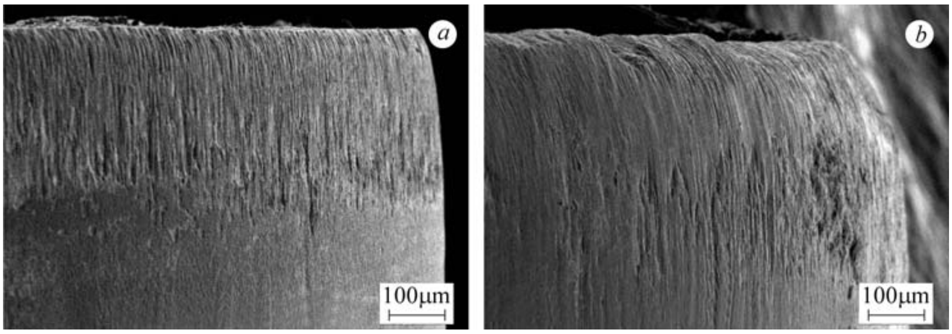

Fig. 6. SEM micrographs of the flank wear after blanking tests:
a – AlCrN coated after 120000 strokes; *b* – uncoated after 65000 strokes (×150).

Cross section of worn AlCrN coated tool. Another wear mechanism observed in the worn surface of AlCrN coated punch is delamination wear. Suh [14] has claimed that plastic deformation near to the worn surface region or large primary carbides with dislocation pile-ups may produce crack initiation. In Fig. 7, plastic deformation and fracture appeared near to the worn surface. This involves initiation of the surface and subsurface cracks, crack propagation and formation of wear particles. The cracks initiated in the subsurface region developed towards the surface.

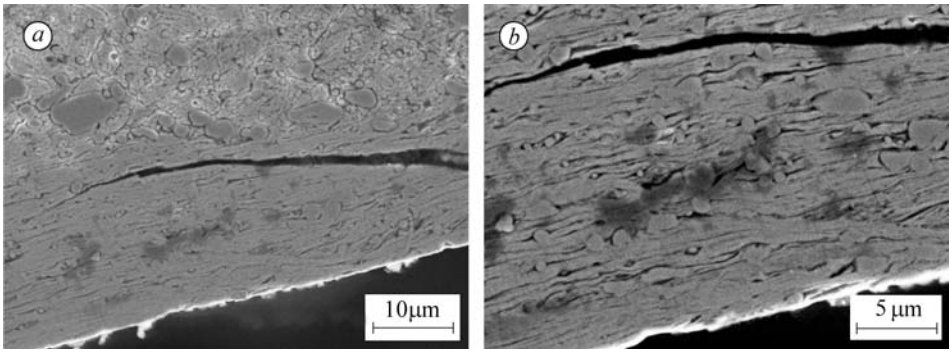

Fig. 7. SEM images of AlCrN coated punch surfaces after blanking tests:
a – AlCrN coated after 120000 strokes (×2200); *b* – uncoated after 65000 strokes (×4300).

Measurement of burr height and wear volume. For the measurement of the burr height as a function of strokes, five blanked samples were taken at the end of intervals (each of 1000 strokes). The blanked samples were mounted in resin to the cross section and fixed to the polished surface for the metallographic investigation. The burr heights of different strokes were measured. Using LM micrographs of burr samples, the burr height on each blanked samples was measured by taking four specified points at the perimeters and then "the average burr height" was calculated. The values of burr height are given as % of the blanked sheet thickness.

The wear volumes of the uncoated and AlCrN coated punches were calculated according to Eq. (2). The measured burr height and wear volume can be seen as a function of strokes in Fig. 8. In the coated and uncoated punches, the burr height and wear volume increase with the number of strokes. Here it can also be seen that the wear volume of the uncoated punch is higher than of the coated one. The deviations of wear volume values of the uncoated punch depend on the inhomogeneous wear of the cutting edge (Fig. 5*b*).

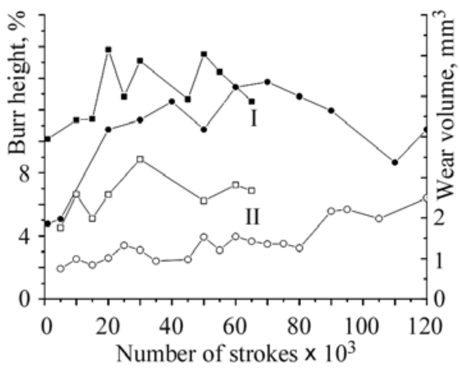

Fig. 8. Measured burr height (I) and wear volume (II) depending on the number of strokes: ●; ○ – coated; ■; □ – uncoated.

CONCLUSIONS

In this study, the blanking performances of the AlCrN coated produced by Arc PVD and the uncoated punches were evaluated in real work conditions for sheet steel blanking. The wear resistance of AlCrN coatings was investigated and compared to those of uncoated punching tools. The wear at the cutting edge and the flank of the punch proved to be reduced by AlCrN coating obtained by PVD. As for the wear mechanisms investigated using SEM, it was revealed that abrasion and adhesion are the main responsibles and result in edge rounding and fracture at the punch cutting edge. Evidence of delamination was also observed in the cross section of worn punch surfaces.

The measurement of wear volume and burr height also gave the conclusive results. The wear volume at the punch edge is linearly enlarged with increasing strokes. The wear volume is higher for the uncoated punch as expected. SEM investigations also indicate that wear of the uncoated punch causes some edge fractures at the cutting edges. The burr height seems to depend on the rounding of worn punch edges. The burr height is low at the lower numbers of strokes, especially for AlCrN coated punch, with increasing strokes above 10000 for uncoated and AlCrN coated punches and then continues to increase linearly.

РЕЗЮМЕ. Штампування листів сталі – один із найвідоміших процесів у виробництві, за якого штамп зношується через циклічний контакт протилежних поверхонь. Він зазнає впливу високих напружень і тому повинен володіти високою зносотривкістю. Під час використання зношеного штампа поверхня інструмента впливає на якість листових виробів та спричиняє поверхневі дефекти. Покриви на штампі, отримані за допомогою PVD, завдяки високій твердості та слабкому тертю, можуть зменшити зношування. Вивчено зношування штампа із AlCrN покривом, який використовують для штампування листів сталі. Поверхні досліджено за допомогою сканівної електронної мікроскопії. Встановлено, що зношування спричинене стиранням, адгезією та розшаруванням уздовж задньої поверхні ковзання. Визначено об'єм зносу штампа та висоту зазору штампованих частин.

РЕЗЮМЕ. Штампование листов стали – один из наиболее известных процессов в производстве, когда штамп изнашивается вследствие циклического контакта противоположных поверхностей. Он пребывает под воздействием повышенных напряжений и поэтому должен обладать высокой износостойкостью. При использовании изношенного штампа поверхность инструмента влияет на качество листовых изделий и обусловливает поверхностные дефекты. Покрытия на штампе, полученные с помощью PVD, благодаря

высокой твердости и меньшему трению, могут уменьшить изнашивание. Изучено изнашивание штампа с AlCrN покрытием, который используют для штампования листов стали. Поверхности исследованы с помощью сканирующей электронной микроскопии. Выявлено, что изнашивание вызвано стиранием, адгезией и расслоением вдоль задней поверхности скольжения. Определены объем износа штампа и высота зазора штампованных частей.

Acknowledgement. The author is thankful to Kocaeli University Research Fund for supporting this study under Project No. 2008/026.

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Received 02.04.2012