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DESCRIPTION OF PUNCH WEAR MECHANISM DURING FINE BLANKING PROCESS

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Abstract: *Fine blanking is used to produce details with demanding quality. The process enables to create precision parts with straight edges showing little or no die break and superior finishing. In order to achieve better quality die clearance is very small, usually around 0.5% of the material thickness [1]. Therefore the tool components are under high contact stress and they have to work in extreme wear conditions resulting in poor tool lifetime. It is possible to increase tool lifetime by using tool reinforcing technologies, the right oiling conditions and adjusting cutting speed. Initially the wear mechanism has to be determined. Current article presents a simplified case for punch tribological system meaning that the influence of opposite punch and the v-ring is not considered.*

Laboratory tests, such as Rockwell coating adhesion test, and industrial experiments have been conducted with different coating compositions and punch surface roughness. Industrially the punches were used in automotive applications in fine blanking of cold-rolled steel strip.

Current article divides wear mechanism of punch into three phases. In first phase abrasive wear is the main mechanism of wear resulting in reduced surface roughness of punch. Therefore lubrication deteriorates and adhesion between coating and sheet metal occurs in second phase. In third phase intensive adhesion between the punch substrate material and sheet metal takes place and intensive stress causes fatigue wear.

Key words: fine blanking, punch wear mechanism, thin hard coating, adhesion

1. INTRODUCTION

The expanding use of high strength steels in fine blanking has brought out a new challenge – tool resistance and lifetime is not satisfactory any more. Whereas the blanking material has a direct influence to wear and tool endurance [2-4] the need for alternative and more resistant tools is therefore a topical issue.

Wear models for description of frictional and wear processes in fine blanking have several inputs. One input for these models are mechanical, physical and chemical properties of the coatings, especially mechanical behavior of coatings as micro-tribological processes are mostly governed by the coating properties.

Young's modulus of the coating has a big influence on the stresses developing within the coating during contact and lower modulus can decrease the amount of tensile stresses and therefore potentially increase the life of the coating.

Brittleness as the resistance to crack development should be high in a coating. The H/E (hardness / elastic modulus) parameter may be used to predict the wear resistance of a coating, where higher H/E ratio generally corresponds to higher wear resistance [5].

Another input of wear models is the tribological conditions of surface, for example roughness and lubrication. With insufficient lubrication, strong adhesive wear of the punch will occur and tool life is decreased because the adhesion leads to alternating stresses in tool surface resulting in tool fatigue near the surface. Cracks develop, grow and unite and tool material breaks out.

2. EXPERIMENTAL AND MATERIALS

2.1. Method for evaluating the wear of punches

For evaluating wear 16 industrial punches with different surface roughness were used. Punches were made from Böhler steel S390. The heat treatment was carried out at OY Bodycote using a vacuum furnace and obtained hardness was 65 HRC.

The surface grinding treatment (after heat treatment) of the tip was varied, which resulted in different surface roughness H and M. In fig. 1 the un-coated punch is shown, the tip and grip of the punch are pointed out.

Fig. 1. Un-coated industrial punch

Two types of hard coatings were used on the punch tips – TiCN and AlCrN. TiCN coating was deposited without pre-treatment of the tool. With AlCrN micro blasting as surface preparation was used. The coating thickness was 1.4 µm with AlCrN and 3 µm with TiCN, measured using ball-cratering method Kalomax and microscope Zeiss Axiovert 25.

For evaluation of wear eight punches were used in production at the same time in fine blanking of 4.0 mm soft annealed sheet metal C60E. The punches analysed were located in eight different positions in two parallel lines. The state of stress in blanking material was somewhat different in each punch position due to the variations of deformation in the sheet metal. In order to diminish this effect the punches were distributed evenly on the layout.

For wear amount analysis the worn areas of all punches were measured with Omnimet Image Analyse System software along with stereomicroscope ZEISS Discovery V20. Punches with greater surface roughness, H, (table 3) had nearly two times smaller wear area. Results are shown in table 1.

Coating type	**Area, mm^2**
TiCN H	1.94
TiCN M	4.00
AlCrN H	2.15
AlCrN M	4.20

Table 1. Worn surface area of punches

2.2 Method for determining the coatings coefficient of friction

Coefficient of friction was determined with tribometer Wazau SVT500 using ball-on-disk method. The specimens were stationary and load was applied to the sliding ball. Steel ball was used in order to mimic the actual friction pare between punch and stamping material.

The tests were carried out with and without lubricant (the same oil which was used in industrial experiments) and the results are shown in table 2. Friction was found to be nearly 3 times smaller with all coatings when lubrication is used.

Coating type	**Coefficient of friction**	
	Dry	**Lubricated**
TiCN H	0.33± 0.04	0.10± 0.02
TiCN M	0.28± 0.04	0.10± 0.02
AlCrN H	0.34± 0.05	0.10± 0.02
AlCrN M	0.27± 0.03	0.12± 0.02

Table 2. Coefficient of friction between steel ball and coatings with and without lubrication

2.3 Method for determining the surface roughness of punches

For measuring the surface roughness Ra of punches a profilometer MAHR concept and contact method was used. The results are shown in Table 3.

Coating type	**Marking**	
	Rz	**Ra**
TiCN H	4.34	0.57
TiCN M	1.75	0.16
AlCr H	2.55	0.33
AlCr M	1.57	0.22

Table 3. Coating type and surface roughness (µm) of punches after coating deposition

2.4 Rockwell adhesion test

Rockwell adhesion test CEN/TS 1071-8 was used to study the adhesion between punch substrate and coating [6] and adhesion was determined according to 4 classes: “0“; “1“; “2“ and “3“. Where “0” is very good adhesion (no cracking or delamination of coating) and class “3” refers to the poorest adhesion (full delamination of the coating).

The results show that both studied coatings have similar adhesion, although in case of lower surface roughness (type M punch) somewhat better adhesion (class 1) was observed compared to class 2 in case of higher surface roughness (type H punch).

3. RESULTS AND DISCUSSIONS

The wear of the punch cutting edge leads to poor quality of blanked parts: formation of burr; shape distortion of detail surface caused by chipping of the tool cutting edge; cracking of cut surface [1].

The industrial punches used in current experiments are sharpened after 80 000 running cycles. The reason for regular maintenance is the wear of cutting edges and burr on cut surfaces.

The usual mechanisms for wear of punch are abrasive, adhesive and fatigue. These three mechanisms are related to each other and they often take place simultaneously however usually the wear is dominated by one mechanism. In different phases of the wear cycle the mechanism is not identical.

3.1 Abrasive wear

The amount of material removed by abrasive wear (V_{abr}) may be characterized by equation 1 [7].

$$V_{abr} = n^2 \frac{P_y E W^{\frac{3}{2}}}{K_{1C} H^{\frac{3}{2}}} L \qquad (1)$$

where E is elastic modulus, H is the hardness of the softer material, W is the normal load, L is the sliding distance, K_{1C} is the fracture toughness, n is the work-hardening factor and P_y is the yield strength.

3.2 Adhesive wear

Adhesive wear is influenced by the materials electronic structure, crystal structure and orientation, cohesive strength, hardness, melting temperature, oxide layers, lubrication conditions [7-8].

As a result of adhesion the material is separated from one surface and adhered on to the other causing uneven lubrication, higher contact stress and breakage of tools due to excessive grip [8-9].

Wear in lubricated friction pairs is different from dry wear conditions because the stress is partially transmitted to the lubricant. The main parameter characterizing the wear in lubricated friction pairs is the effective distance between surfaces λ (lambda ratio) which may be found with equation 2.

$$\lambda = \frac{h}{\sigma} \qquad (2)$$

where h is the lubricant thickness and σ is the square root of the surface variance (asperities) [7].

The value of λ will decrease when increasing stress and surface roughness or decreasing speed of movement or viscosity of lubricant.

If the lambda ratio is larger than 3 then metal to metal asperity contact is insignificant and adhesive wear is not possible. However if lambda is less than 1 then the operating regime is consider to be boundary lubrication and some adhesive and fatigue wear would be likely [7].

3.3 Fatigue wear

Fatigue wear is dependent of structure, cohesion strength, yield strength, residual stress and strength of material.

At the punch surface layer cyclic change of temperature occurs during fine blanking. Temperature of tool rises and compressive stress will form in the surface layer when sheet material is being cut, after which fast cooling is applied causing tensile stress.

Repeating this cycle fatigue cracks in the surface layer of punch are formed.

3.4 Experimental results and different phases of wear

Equation 1 indicates that surface roughness should not influence abrasive wear resistance. With respect to equation 2 the lambda ratio should decrease when Ra increases leading to larger contact stresses and temperatures. In fact temperature in the contact area could reach up to 800…900 °C [10]. Fatigue wear is favoured by poor adhesion between coating and punch.

However industrial experiments showed better wear resistance with higher surface roughness.

At the tip of the punch working conditions are most severe and contact with the blanking material is the longest. The tip initially starts the cutting of the sheet metal and is pulled out of the cutting zone last. Therefore the tip of the punch is worn the most (fig. 2).

Fig. 2. SEM photograph of punch cutting edge (after 80 000 cycles). Figure 3 will show a close-up of the worn surface indicated in the white box

On the basis of fig. 3 it is possible to divide the wear of punch into three zones. The tip (in left at fig. 3) of the punch has reached pre-breaking stage where all of the coating is removed, fatigue cracks are formed and intensive adhesion of sheet metal has taken place.

In the middle zone coating is preserved, however Ra is small and lubrication has become worse leading to adhesion (somewhat milder than in the first zone).

In the right side of fig. 3 coating is maintained and wear is modest.

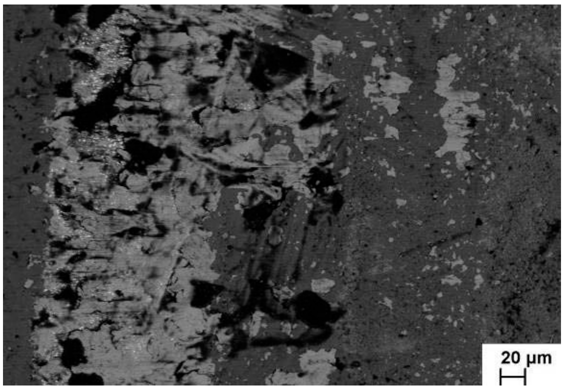

Fig. 3. The tip of the worn punch at greater magnification. The wear intensity is more intense at the tip (in the left)

The wear mechanism of fine blanking may be divided into three phases, where different wear types dominate.

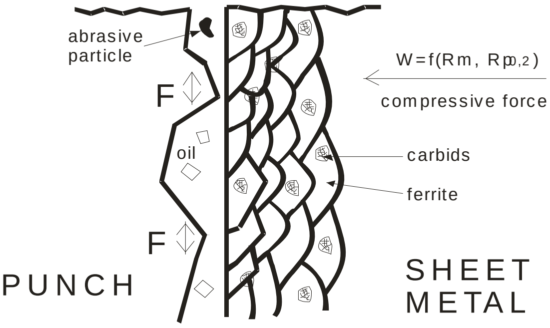

Fig. 4. Scheme of wear mechanism in the first phase

In the first phase the lubrication between the stamping material and the punch is sufficient and lambda ratio is situated somewhere between value 1 and 3. Partial contact between asperities of punch surface and sheet metal are taking place. Contact is not creating significant tensile stress, however stress would be higher when the strength properties Rm and Rp0.2 of sheet metal are increased thereby leading to severe wear.

Carbides and non-metallic inclusions of sheet metal and worn abrasive particles induce abrasive wear of the punch. In phase I the main mechanism of wear is abrasive due to good lubrication and few contact asperities. Adhesion and fatigue are not significant in first phase of wear.

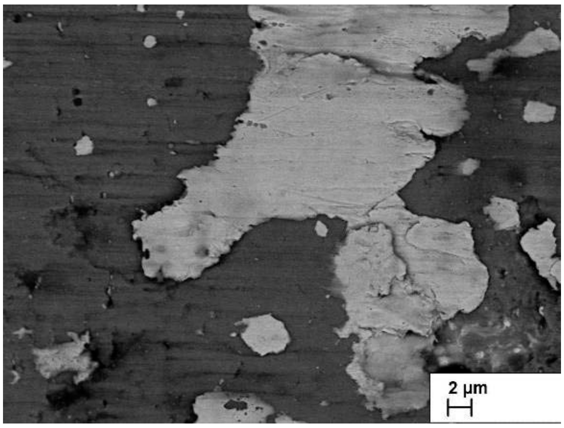

Fig. 4. Punch surface at second phase – many asperities of the surface have been “evened out” and consequently surface roughness has decreased

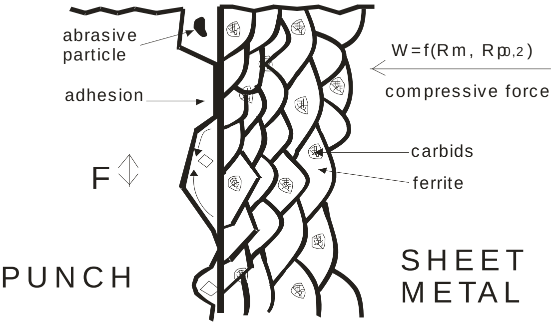

Fig. 5. Scheme of wear mechanism in the second phase

In second phase of wear lubrication conditions have changed due to decrease of coating roughness. Oil quantity between surfaces has decreased (λ is below 1).

Fig. 4 shows the SEM photograph of II phase and in fig. 5 the scheme for wear mechanism is brought. The adhesion of sheet metal to the punch is becoming dominant, which leads to greater stresses and higher contact temperature resulting from increased friction. In second phase the adhesion of coating to the punch substrate material, friction coefficient of punch and lubricants in oil become very important.

At the end of second phase the coating is fully removed from the punch revealing the substrate material (Böhler S390 steel) and as a result hardness, crystal structure and microstructure of the punch are changed. Intensive adhesion will appear even though surface roughness might increase.

In fig. 6 SEM photograph of wear in third phase can be seen and fig. 7 shows the scheme for III phase wear mechanism.

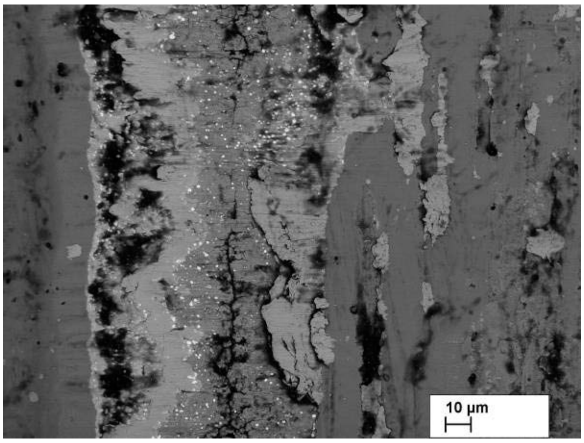

Fig. 6. Punch surface at third phase

During phase III the measurements of the punch may increase due to intensive adhesion. Therefore stresses and temperature might be elevated in the surface layer of the punch. The increase of force F might cause formation of a fatigue crack leading to chipping or breakage of the punch tip.

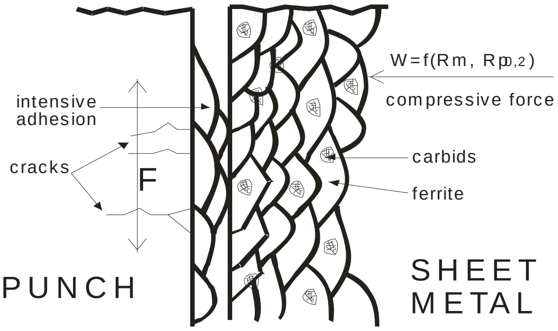

Fig. 7. Scheme of wear mechanism in the third phase

During fine blanking it is crucial to ensure the proper lubrication of surfaces and choose the proper surface roughness. However it is also important to prevent the amount of abrasive particles in sheet metal. For example wear can be decreased by using a stamping material with the same mechanical properties but with a lower carbon content and carbide amount.

4. CONCLUSIONS

The wear of punch in fine blanking is not connected to any specific wear mechanism therefore classical equations for evaluating wear can not be used.

Based on conducted experiments, the process of wear can be divided into three phases:

I – abrasive wear is dominant, adhesive wear is insignificant due to material asperities and lubrication between contact surfaces. Additionally adhesive wear is diminished by suitable crystal lattice structure and microstructure of the coating;

II – adhesion wear becomes dominant caused by the change in lubricating conditions. Wear becomes intensive;

III – the force and the stresses in fine blanking increase due to severe adhesion and change in punch measurements. Fatigue wear is becoming important and it may lead to cracking and breakage of the punch.

In order to improve the punch life-time it is important to avoid adhesive wear with the use of proper lubrication and decrease abrasive particles.

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