Investigation of ironing process depending on applied tool materials and coatings

Preiskava procesa stanjševalnega vleka v odvisnosti od uporabljenih materialov za orodja in prevleke

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Abstract: Friction has significant influence, both on geometrical, kinematic and dynamic conditions of metals forming execution and on tool life; in that way, it influences the continuity of production. One of the methods for enabling the reduction of friction resistance (and in that way the influence on product quality) is the selection of properties of outer layers of the tool. Unlike machine elements, where it is possible to select a wide range of contact couples materials, in the case of ironing process one of contact couples elements – strained material – is determined in advance. The only thing that can be changed here, in certain limits, is tool material (die and punch) or various thermochemical procedures can be applied, as well as hard coatings etc., by which chemical content of surface layers is changed. In this paper, we will present the experimental results obtained by modelling ironing process by application of proper technological lubricants, use of anti-adhesion coatings on tools (coating TiN and hard coating Cr), selection of suitable type of tool materials (tool steel, hard metal) etc. The obtained results indicate that friction resistance can be reduced to a large extent, which will also minimize tool wear.

Izvleček: Trenje ima velik vpliv tako na geometrijske, kinematične in dinamične pogoje preoblikovanja kovin kot tudi na trajnostno dobo orodij

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Preliminary notes

in s tem tudi na kontinuiteto proizvodnje. Ena od metod, ki omogoča zmanjšanje trenjskega upora (s tem tudi vpliva na kvaliteto izdelka), je prava izbira površinskih plasti orodja. Nasprotno od strojnih elementov, ki jih lahko izbiramo iz širokega nabora materialov, pa je pri postopku stanjševalnega vleka eden od materialov, ki je v kontaktu, to je materal, ki se preoblikuje, določen vnaprej. Z določenimi omejitvami lahko pri stanjševalnemu vleku spreminjamo material, iz katerega je narejeno orodje (matrica in pestič), ali pa uporabimo različne termokemijske postopke, kot tudi trde prevleke itd., pri katerih se kemijska sestava površinskih plasti spreminja. V tem prispevku so prikazani eksperimentalni rezultati, ki so bili dobljeni pri modeliranju postopka stanjševalnega vleka z uporabo ustreznih tehnoloških maziv, z uporabo prevlek, ki so protiadhezijske (oplaščanje TiN in trda prevleka Cr), z izbiro ustreznih materialov za orodja (orodno jeklo, trdnina) itd. Dobljeni rezultati nakazujejo, da je mogoče bistveno zmanjšati trenje in s tem tudi obrabo orodja.

Key words: ironing, coatings, friction, wear, tools
Ključne besede: stanjševalni vlek, prevleke, trenje, obraba, orodja

INTRODUCTION

High intensity of tool wear in metal forming (MF) is the reason why tool life problem is getting the increasing attention. Together with the advancement of tool wear process, which mainly reflects the change of dimensions and form, the product quality deteriorates, and the obtained products have major dimensional deviations, worse surface quality and even visible errors in the form of notches and nodes. [1] Tool life also influences the reliable functioning of the machines or forming systems. Frequent replacements of tools lead to unavoidable standstill of machines which also influences pro-

ductivity decrease, and therefore the production costs. Tool wear process is very complex, and, and tool fracture can be caused by several reasons which act together. Tool wear process is influenced not only by friction appearance, but also by other processes, such as: fatigue (thermal and mechanical), corrosion and oxidation. Therefore, tool wear for MF will be the result of the superposition of all physical processes which act upon the tool; consequently it will be more intense than it would have been if it were influenced only by friction process course.[2]

In tools intended for cold MF, the following types of wear are dominant:

- adhesive,
- abrasive and
- fatigue (crumbling).

However, abrasive wear is considered as the significant process which determines tool life for MF.

Intensive tool wear in ironing processes results from the fact that the entire work surface of the tool is in constant contact with the material being formed. From that reason, wear intensity is higher when compared with other tools. Wear cases for this kind of tools can be divided into following types:[3]

- adhesive wear which manifests as the appearance of adhesive particles ("bulges"),
- micro and macro cracks,
- crumbling and
- the appearance of material loss in the form of ring, which is the effect of abrasive wear.

The most influential type of wear for this kind of tools is the appearance of so called annular damage on work (conic) surface for compression, which eliminates the conditions for normal forming and causes the appearance of additional friction resistance and significant increase of drawing force.[1]

Such mechanism of tool wear is the consequence of material flow kinetics and distribution of pressures in cone for compression. The material being compressed achieves the largest strain-ing in the entrance cone zone, which is why the highest unit pressures are created there. Furthermore, all impurities, oxides etc. remain on work edges at the entrance into the cone tool part; those impurities can act as abrasives which cause abrasive wear characterised by high intensity; therefore the contact of partly formed material of released oxide and tool material occurs in the central part of the cone.

The increase of tool life for MF can be accomplished by:[3]

- replacement of tool steels used so far with materials with better resistance properties, which are also much more expensive,
- application of properly selected methods of surface forming which enable the obtaining of desired surface layer properties, especially higher resistance to wear,
- application of suitable technological lubricants.

The deficit of alloying elements and, particularly, their high price are the reasons why high-alloyed steels are applied only in special cases and for heavily loaded tool elements. That is why effective and efficient increase of tool durability can be accomplished by surface forming. By using this solution for the problem of short durability of productive tools, friction and wear processes, as well as processes of fatigue, oxidation and corrosion are mainly localised on surface layers, so they are

the only ones required to have higher resistance to wear, thermal fatigue, oxidation, corrosion etc.; thus, it is not necessary that the entire tool has those properties.

In the course of searching for optimal properties of surface layers, nowadays we have at our disposal several forming methods which enable accomplishment of useful contact couples properties. In addition to the mechanical forming where the improvement of tribological properties is achieved, mainly, as the result of increase of outer layers hardness (e.g. pressing procedures), in other cases one of the important goals of surface forming is the change of chemical content (e.g. by enriching with ingredients, such as: carbides Cr, carbides B, nitrides Al, Ti, Cr, Mo, V etc.) due to which a significant increase of resistance to abrasive wear is accomplished. It has been determined, as the result of many investigations, that finely-dispersed hard phases (e.g. carbides, nitrides etc.) are the most resistant to abrasive wear.[4]

Galvanic forming represents a special group of surface layers modifications. It includes the procedures such as: hard chromium-coating, phosphating etc.[5]

Coating obtained by hard chromium-coating is characterised by relatively high hardness (1000–1200 HV), as well as by characteristic grid which represents natural canals for lubrication. The result of such surface layers forming is the significant increase of resistance to wear.

With the aim of obtaining good tribological properties, both at room and at increased temperature, plasma technologies were developed which involve applying coatings of hard soluble metals such as: Cr, W, Co, Ti or their compounds TiN, TiC etc.[6]

The group of methods for surface forming which are also worth the attention also includes also electro-polishing and chemical polishing. The result of polishing is the removal of defective surface layers made at preceding forming (e.g. forming by cutting) and new surface layers are obtained which are characterised by significantly less roughness and lower or very low levels of their own stresses. Surface layers obtained as the result of these processes are characterised by considerably smaller friction coefficient, increase of resistance to abrasive wear and to corrosion.[7]

EXPERIMENTAL INVESTIGATIONS

Experimental investigations in this paper were conducted on the original model of ironing, which is characterised by a double sided simulation of the contact zone with the punch and die.[8]

This model enables realization of the high contact pressures and respects the physical and geometrical conditions of the real process (die and punch materials, topography of the contact surfaces, the die cone angle (α) etc.). The scheme of the mentioned model is shown in Figure 1.

The dies are placed in holders, where the left hand holder is fixed and the right hand holder is moving together with the die. The punch consists of the body 3 and the front 4, which are mutually connected by the pickup with the strain gauges 5.

The bent strip of thin sheet 7, in the U shape, (test-piece) is being placed on the "punch". The strip is being acted upon by "dies" 2 with force F_D. Test-piece is passing (sliding) between dies, by the action of the force F_{ir} on the punch front, when the sample wall is being ironed. During passing through, the external surface of the sample is sliding along the die surface, which is inclined for an angle α, while the internal surface of the sample is sliding over the plates 6, which are fixed to the punch body.

The device was made with the possibility for an easy substitution of the contact – pressure elements (die 2 and plates 6), easy cleaning of the contact zones and convenient placing of samples.

Plates 6 and dies 2 can be made of various materials, as well as with various
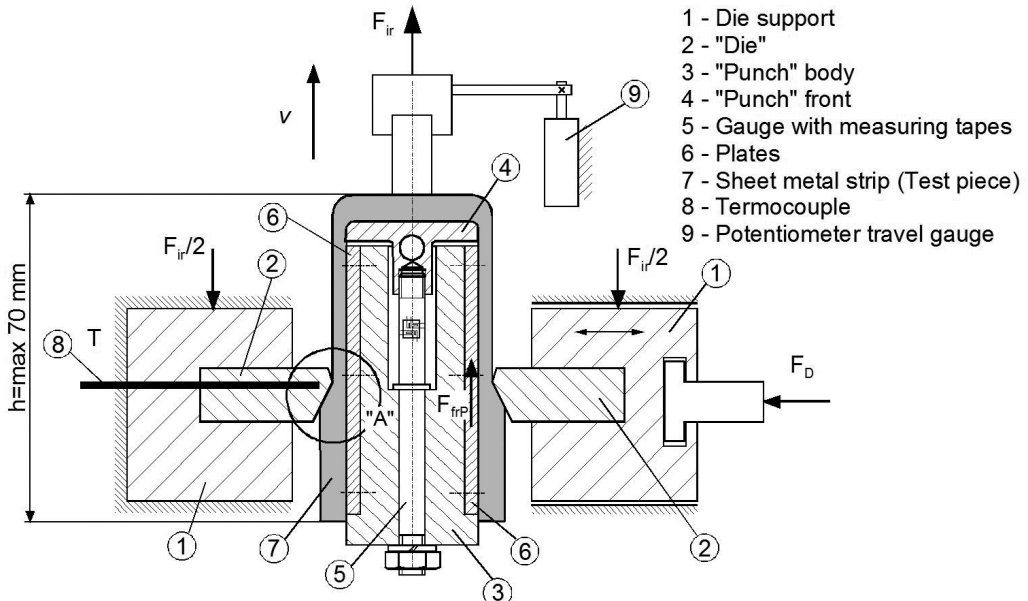

1 - Die support
2 - "Die"
3 - "Punch" body
4 - "Punch" front
5 - Gauge with measuring tapes
6 - Plates
7 - Sheet metal strip (Test piece)
8 - Termocouple
9 - Potentiometer travel gauge

Figure 1. Scheme of model used in this paper

roughnesses, while dies can have various slope angle α.

The total ironing force F_{iz} represents the sum of the force of friction between punch and work piece, F_{trI} and force which acts upon the test piece bottom F_z, i.e.:

$$F_{iz} = F_{trI} + F_z \qquad (1)$$

Force F_{iz} is measured on the device itself, and the friction force on the punch side F_{trI} is registered by means of gauge with measuring bands.

The friction coefficient on the punch side, taking into account that it changes according to *Coulomb*'s law, can be calculated on the basis of the following expression:

$$\mu_I = \frac{F_{trI}}{2 \cdot F_D} , \qquad (2)$$

and friction coefficient on die side by the expression:

$$\mu_M = \frac{F_{iz} \cdot \cos\alpha - 2 \cdot F_D \cdot \sin\alpha}{F_{iz} \cdot \sin\alpha + F_D \cdot \cos\alpha} , \qquad (3)$$

Knowing the dependency of forces F_{iz} and F_{trI} on sliding path h, it is possible to determine the friction coefficients (μ_M and μ_I) in function of sliding path on the basis of previous expressions.

On the mentioned device it is also possible to simulate consecutive (multi-phase) ironing, when one sample is passing between the contact pairs several times.

The device for ironing is installed on a special machine for thin sheet testing ERICHSEN 142/12.

For experimental investigations in this paper, the low carbon steel sheet, tempered by aluminium, Č0148P3 (WN: 1.0336; DIN: DC 04 G1/Ust 4, Ust 14) was chosen. It belongs into a group of high quality sheets aimed for the deep drawing and it has properties prescribed by standard SRPS EN 10130:2004.

For the die and punch material, the alloyed tool steel (TS) Č4750 (WN: 1.2601; DIN17006: X165CrMoV12; EN: X 160 CrMoV 12 1) was selected, while one set of dies was made of the hard metal. In order to improve the surface, a certain number of dies and of punches – their working surfaces – were coated by chromium (Cr) or titanium nitride (TiN). In experiments, pairs of dies and punches made of the same materials were always used, e.g., D-TS/P-DS or D-TS + Cr/P-TS + Cr, with exception of the hard metal die, which was always used with the punch made of tool steel.

The special attention was devoted to material characteristics in the sheet rolling direction (0°), since the tested

Table 1. Properties of tools and test piece materials

		Material	Mechanical properties
Tool	Die (D)	TS* TS + Cr plate TS + TiN plate HM**	TS Hardness 60÷63 HRC HM Hardness 1200 HV30
	Punch plate (P)	TS* TS + Cr plate TS + TiN plate	
Test-piece		Č0148P3 (WN: 1.0336; DIN: DC 04 G1/Ust 4) Thickness: 2.0 mm width: 18.6 mm	R_p = 186.2 MPa R_m = 283.4 MPa A_{80} = 37.3 % n = 0.2186 r = 1.31915
* - TS – Tool steel, Č4750 (DIN17006: X165CrMoV12) ** - HM – Hard metal, WG30 (DIN4990: G30)			

samples were cut in that way, (SRPS C.A4.002:1986) which was applied using specimens in rolling direction. Material characteristics for test-piece were determined. Values are shown in Table 1. Tests have been performed under laboratory conditions (v = 20 mm/min, T = 20 °C).

RESULTS AND DISCUSSION

The investigations performed on tribo-model of the ironing process made it possible to estimate the influence of surface tool layers (die and punch) on the progression of ironing process (drawing force, friction coefficient on die and punch, wall tension stress etc.).

The change of mean value of drawing force in dependence on blank holding force at various surface states of the tool is given in Figure 2. The increase of blank holding force leads to the increase of the mean value of drawing force similarly for all the states. Application of both the tool without coating (TS) and with chromium coating (TS + Cr) leads to similar values of drawing force, which are somewhat smaller than the ones obtained by tools with coating TiN (TS + TiN) and hard metal (HM). These results suggest somewhat lower compatibility between tools, both with the coating TiN and hard metal with mild steel sheets, compared to the tools with Cr coating and tool steel. Using the tool with TiN coating on the surface of mild steel sheets led to the small scratches at first, which sometimes grew into rough cuts on the metal sheet surface. The higher forming degree there was (bigger holding force and bigger angle of die gradient), the more frequently those rough cuts appeared on the metal sheet

surface. This can be also confirmed by greater differences in mean ironing force in those conditions.

The change of mean value of drawing force in dependence on die gradient an-gle, when tool material is the parameter, is given in Figure 3. Drawing force increases with the increase of die gradient angle. At smaller die cone angles, that increase is more intensive than at bigger angles.
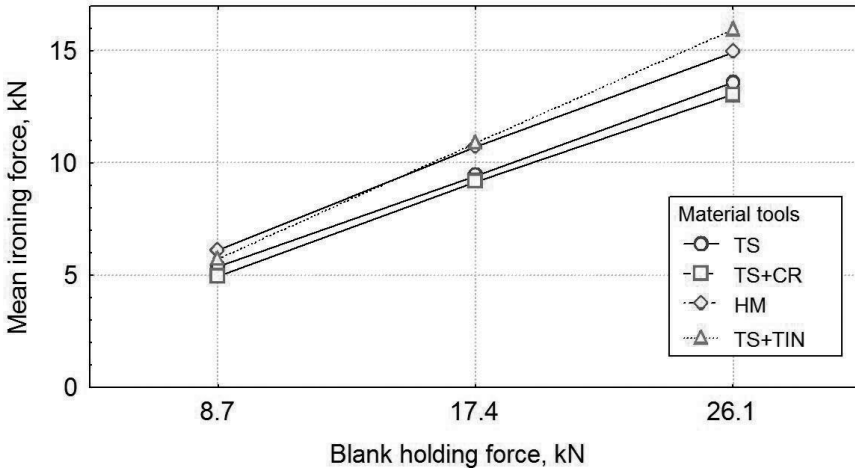

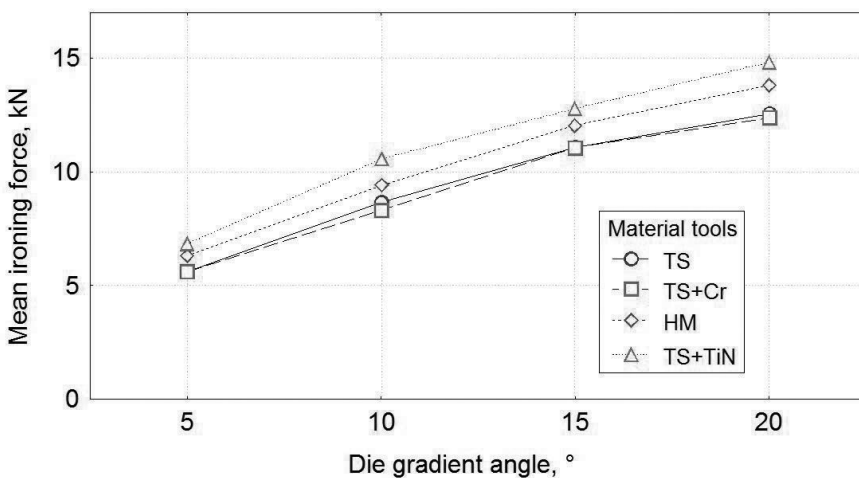**Figure 2.** The change of mean value of drawing force in dependence on blank holding force at various tool materials

Figure 3. The change of mean value of drawing force in dependence on die gradient angle for various tool materials

Mean values of drawing force for various tool materials are given in Figure 4. The tool with hard chromium coating (TS + Cr) proved to be the best (the smallest value of drawing force). Somewhat worse results were obtained by using the tool of alloyed tool steel (TS), hard metal (HM) and coating TiN (TS + TiN), respectively.

Figure 5 shows the change of friction coefficient on die side in dependence on blank holding force and die gradient angle at various tool materials. The smallest friction coefficient was obtained by using the tool with hard chromium coating at all angles of die gradient. Somewhat higher values were obtained with alloyed tool
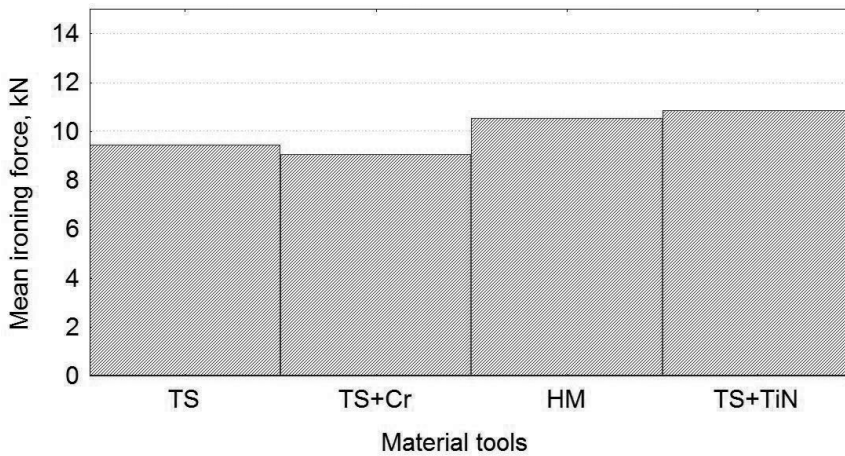
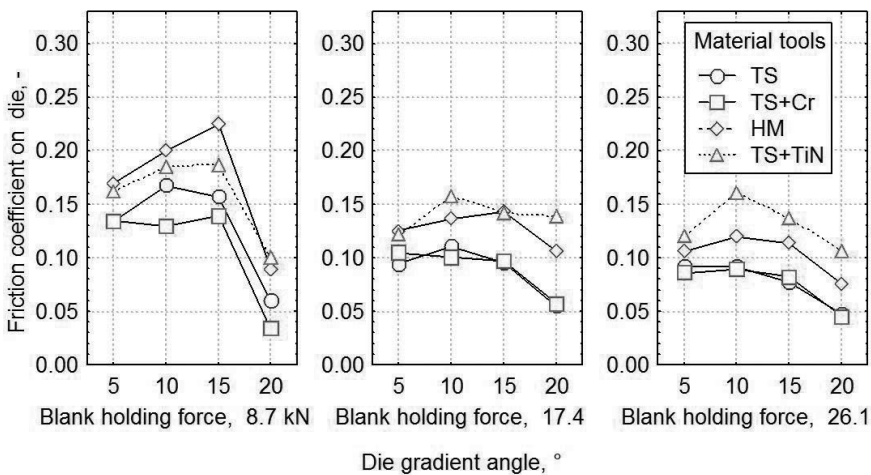**Figure 4.** Mean value of drawing force for various tool materials

Figure 5. Change of friction coefficient on die in dependence on die gradient angle and blank holding force for various tool materials

steel, and the highest values were obtained with tools of hard metal and titan-nitride coating. Changes in friction coefficient values on the die side varied a lot, from very low values of 0.05, up to significantly higher ones of 0.23.

The examples of change of friction coefficient on die side on sliding path at ironing with various tool coatings are given in Figure 6. Instability and higher friction coefficient on the slide path indicate to the occasional impairment of contact conditions.
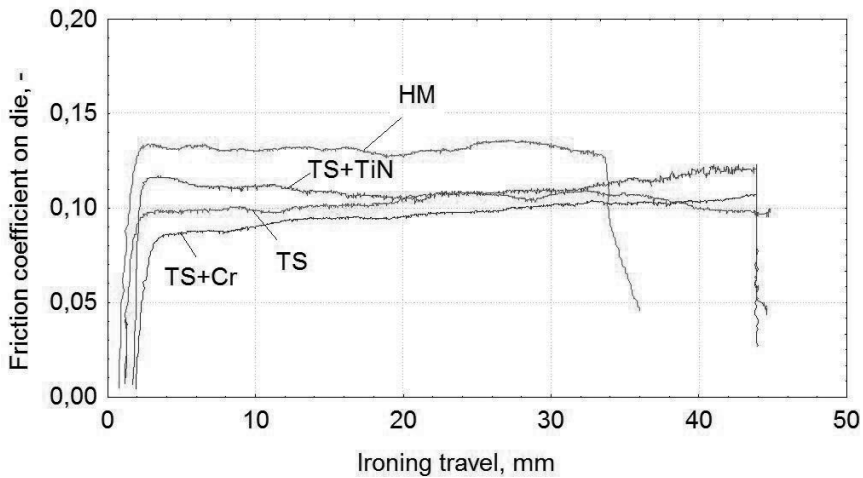

Figure 6. Friction coefficient for various tool materials
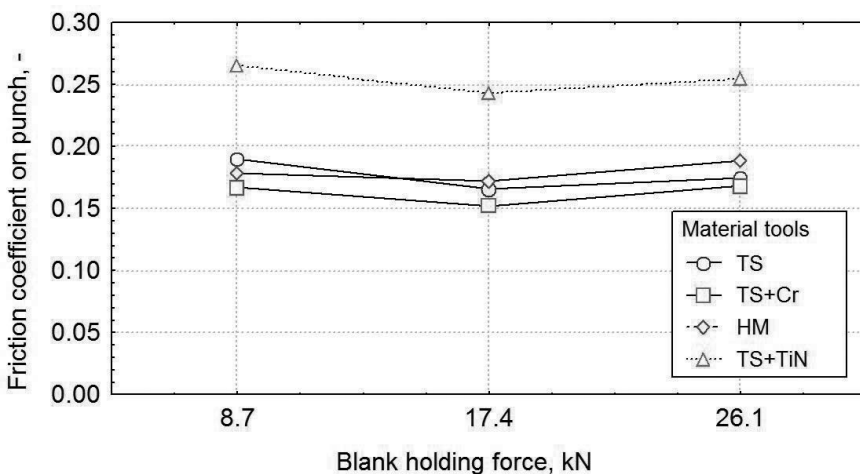

Figure 7. Chang of friction coefficient on punch in dependence on blank holding force at various tool materials

The change of friction coefficient on punch in dependence on blank holding force, for various tool materials, is shown in Figure 7. For steel samples, for all tool materials, friction coefficient will decrease in the beginning, with the increase of blank holding force, and then it will start increasing with further increase of blank holding force. The highest value of friction coefficient is obtained by using the tool with titan nitride coating (TiN).

The influence of tool material on friction coefficient on punch at various die gradient angles is shown in Figure 8.
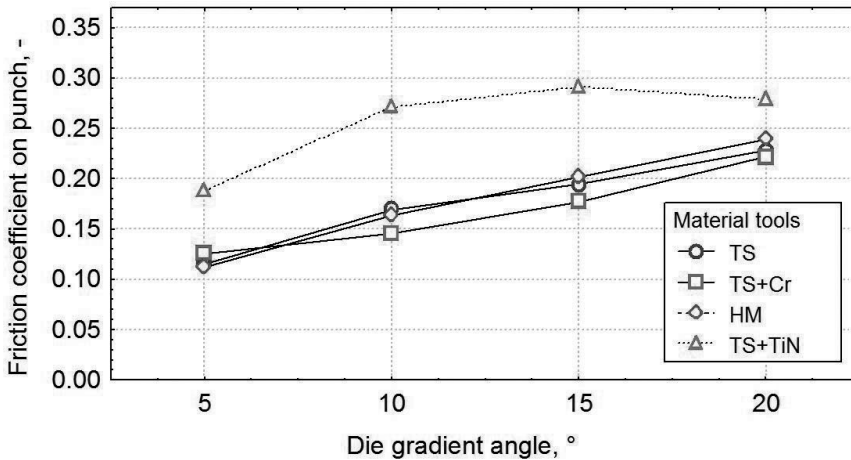

Figure 8. The change of friction coefficient on punch in dependence on die gradient angle at various tool materials
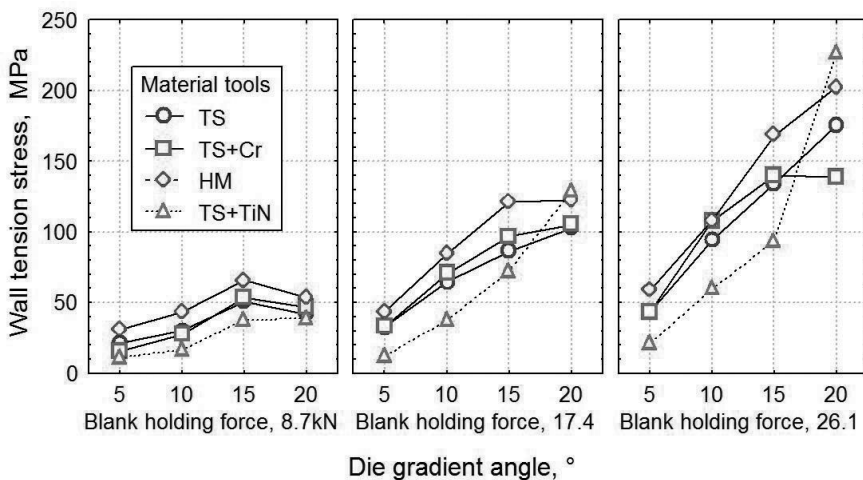

Figure 9. Change of wall tension stress independence on die gradient angle and blank holding force for various tool materials

By using the tool of tool steel (TS), with chromium coating (TS + Cr) and hard metal (HM) at the increase of angle α, friction coefficient constantly increases and that connection is almost linear. The values for TS and HM are almost identical, which is understandable, because the tool is marked with HM, i.e. HM/TS, i.e. Punch plate is made of tool steel. The tool with hard titan nitride coating (TS + TiN) gives significantly higher values of friction coefficient.

Figure 9 shows the change of wall tension stress in dependence on die gradient angle and blank holding force for various tool materials. The smallest values of wall tension stress are obtained with tools with TiN coating, and the highest values are obtained with tools of HM. Regarding aluminium alloy samples, the smallest wall tension stress is obtained by using the tool of alloyed tool steel (TS), and the largest one is obtained with tool of hard metal (HM).

The specified diagrams show that at small blank holding forces, with the increase of die gradient angle above 15°, the decrease of wall tension stress occurs. At larger blank holding forces and larger die gradient angles, stress differences become more significant compared with the ones obtained at small blank holding forces and small die gradient angles.

Contrary to the friction of die side which is damaging and which needs to be as low as possible, the friction of the punch is useful and its increase to a certain value is well justified. Higher values of the friction coefficient on the punch side lead to the decrease of wall tension stress, and in this way to the increased possibility of forming without damaging the material. According to all abovementioned, we can say that higher values of friction coefficient on the punch side, obtained using punch-tool with TiN coating were more beneficial than other conditions of punch surface.

Conclusions

One of the methods which enable the reduction of friction resistance (and in that way the influence on product quality) is the selection of properties of tool surface layers. However, it should be emphasised that, unlike machine elements for which it is possible to select the a wide range of contact couples materials, in the case of MF process, one of the contact couple elements – strained material – is determined in advance. The only thing that can be changed, in certain limits, is the tool material or various procedures of thermo-chemical forming, galvanisation etc. can be applied, which change the chemical content of surface layers.

The device presented in this paper can be used to assess the behavior of tool surface layers, dies and punch for ironing. It is sensitive enough for comparative examinations of compatibility between different types of ironing tools with formed metal sheet.

Through comparative examination of tool, die and extruder, made of tool steel (TS), tool steel with Cr coating (TS + Cr), hard metal (HM) and tool steel with titanium nitride (TS + TiN) during the ironing of mild steel, following conclusions were reached:

- The lowest ironing force was obtained while using the tool with Cr coating (TS + Cr). Using tool steel (TS), extrusion force was somewhat higher (about 5 %), whilst using hard metal (HM) led to even higher values (about 16 %). The tool with hard coating (AC + TiN) had the lowest compatibility. Obtained ironing force was about 20 % higher compared to the force obtained from the tool with hard Cr coating.

- Besides its dependence on the other parameters of forming process (angle of die gradient, forming degree, type of lubricant, roughness of the tool surface, etc), change in friction coefficient, both on the die and punch, also depends on condition of the tool surface layers and it is completely adequate to the change of ironing force.

Acknowledgements

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