Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 1, 2012, vol. LVIII
article No. 1892

Radek ČADA*, Jan ZLÁMALÍK**

MATERIALS COMPARISON OF CUTTING TOOLS FUNCTIONAL PARTS FOR CUTTING OF ELECTRICAL ENGINEERING SHEETS

POROVNÁNÍ MATERIÁLŮ FUNKČNÍCH ČÁSTÍ STŘIŽNÝCH NÁSTROJŮ PRO STŘÍHÁNÍ ELEKTROTECHNICKÝCH PLECHŮ

Abstract

Paper concerns the comparison of functional materials parts of cutting tools used for the production of stator and rotor sheets in the electrical industry from point of view of their life. Alternatives and the properties of metal used for the production of stator and rotor components in electrical rotating machines are analysed. The main factors affecting the life of cutting tools of functional parts are analysed, one of the most important is the cutting tool functional parts material itself. Comparison of three variants of the cuttong tool funkcional parts material – 19 436 tool steel (chrome steel) according to the Czech State Standard 41 9436, 19 830 high speed steel according to the Czech State Standard 41 9830 and a special powder metallurgy product – ledeburite tool steel Vanadis 10. Useful lifes of the functional components of individual cutting tools performances can be calculated from the theoretical lifes by their multiplying the coefficients of the tool design and the cutting edges shape complexity.

Abstrakt

Článek se týká porovnání materiálů funkčních částí střižných nástrojů využívaných pro výrobu statorových a rotorových plechů v elektrotechnickém průmyslu z hlediska jejich životnosti. Je proveden rozbor variant a vlastností plechů využívaných pro výrobu statorových a rotorových komponent v elektrických točivých strojích. Jsou rozebráni hlavní činitelé, kteří ovlivňují životnost funkčních částí střižných nástrojů, přičemž jedním z nejdůležitějších je samotný materiál funkčních částí střižného nástroje. Je provedeno porovnání tří variant materiálu funkčních částí střižného nástroje – nástrojové oceli 19 436 (chromová) dle ČSN 41 9436, rychlořezné oceli 19 830 dle ČSN 41 9830 a speciálního produktu práškové metalurgie – ledeburitické nástrojové oceli Vanadis 10. Praktické životnosti funkčních částí jednotlivých provedení střižných nástrojů lze vypočítat z teoretických životností jejich vynásobením koeficienty provedení nástroje a složitostí tvaru střižných hran.

INTRODUCTION

Effective cutting tools utilization is subject to their sufficient life. Service life of cutting parts of the machine is in practice determined by the number of cuttings produced in the required quality.

* prof. Ing. Radek ČADA, CSc., VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Mechanical Technology, 17. listopadu 15, 708 33 Ostrava-Poruba, Czech Republic, tel.: +420 59 7323289, fax: +420 59 6916490, e-mail: radek.cada@vsb.cz

** Ing. Jan ZLÁMALÍK, VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Mechanical Technology, 17. listopadu 15, 708 33 Ostrava-Poruba, Czech Republic, tel.: +420 59 7323289, fax: +420 59 6916490, e-mail: jan.zlamalik.st@vsb.cz

The functional parts of the shear tool are considered worn out when they can no longer be sharpened or repaired. If the functional parts of cutting tool worn, it is possible to observe impaired quality of cutting area on cutted part.

Life of cutting tools for cutting sheets for the production of stator and rotor parts of electric rotating machines is evaluated according to burr, which is produced by cutting the sheet in the bottom of the cutting area. This burr must not exceed the allowable value of 10 % of cutted sheet thickness. For example, for sheet M400-50A EN 10106 (see 1) with depth of 0.5 mm the burr must not exceed 0.05 mm. Burr size affects the quality of compaction of the stator and rotor sheets complex of electrical rotating machines. If the burr at separate sheets is higher than 10 % of the cutted sheet-metal thickness, inadequate compaction of the stator and rotor sheets complex causes the electric rotating machine electromagnetic losses and thus its inefficient operation.

During the production value is achieved when cutting burr usually controlled comparison shop meter, a special magnifying glass workshop, workshop or micrometer.

There are two types of tool life:

a) the total life (the useful life, i.e. the total number of strokes to cutting tool wear),
b) partial durability (number of strokes between two over-sharpenings of the cutting tool functional parts).

Normal cutting tool functional parts can be grounded up to twenty-five times. Number of grindings depends on the sizes of the functional parts of the shears or cutting tool, cutted part dimensions and cutting tool design [2].

Tool wear is caused by material loss on the functional surfaces of cutting elements. The wear occurs at the gradual penetration of the punch to the cutted sheet. The peripheral fibers of the sheet material when the punch is entering the cutted sheet lengthen, thereby strengthening the material sheet occurs. On the cutting edges of tool the high pressures arise, that cause wear of adhesive or abrasive character. Adhesive wear is characterized by pulling the tool edge material elements due to adhesion micro welds between the tool and molded material. It arises mainly on cutting and working tools. Abrasive wear is caused by the penetration of solid particles between the square edge of the tool and the sheared material. These particles cause material loss on the functional areas of cutting tools. It arises primarily at stamping operations, at cutting operations it occurs less.

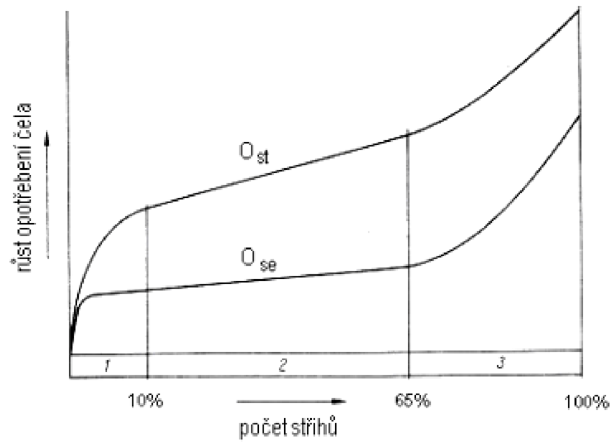

Fig. 1 Wear growth curve of the cutting tool front, depending on the number of cuts, respectively on life percentage (O_{st} – punch wear, O_{se} – die wear) [2].

The increase of cutting tool course is not linear, but general (see Fig. 1). On the curve three zones with different slope of the curve are seen. In zone 1 there is a rapid wear of the new cutting tool sharp blades. In zone 2 the wear rate decreases because the cutting tool edge area increases and by that the pressure per area unit decreases. In the zone 3 the cutting tool wear is accelerating due to the change of shear deformation on the cutting edge. In addition, with cutting also the extrusion of cut part through die exists. With wear increasing the size of the shear force increases [2].

1 SHEETS USED FOR THE PRODUCTION OF STATORS AND ROTORS OF ELECTRIC ROTATING MACHINES

For the production of stators and rotors (Fig. 2) in the electrical industry the sheets from isotropic dynamo steel are widely used. The sheets are supplied either in the final processing or in the pre final where the material is in development state. For the production of static electrical machines, mainly transformers, transformer steels are used with oriented structure, which is characterized by the minimum watt losses in the longitudinal direction. At the production of plates for inductive position sensors and for generators it is useful to choose sheets and strips material from isotropic dynamo steels for electrical engineering cold-rolled in the final processed state.

Fig. 2 Stator and rotor packets of position induction sensor.

Fig. 3 Roll of the strip of isotropic electrical steel M400-50A according to EN 10106 with thickness of 0.50 mm, which was used for comparison of the cutting tools functional parts life.

According to the requirements on the electrical rotating machines production and also customers requirements like the most suitable material for the life of cutting tools comparison the sheet M400-50A according to EN 10106 (Tab. 1.1), which is isotropic for electrical steel sheet with a maximum specific losses p = 4, 00 W/kg at 1.5 T and 50 Hz, with a nominal thickness of t = 0.50 mm supplied in heat-processed state, was selected

The sheets are supplied in bundles, strips in rolls (Fig. 3). Sheet has on its one side the finish in the form of paint with brand name Backlak that allows bonding of individual plates, on its other side it has finis in the form of organic paint Remisol. Paint thicknesses are 3 mm. Coatings reduce losses resulting from eddy currents in the stator and rotor windings. Coatings are resistant to temperatures up to 230 °C. Coils weight is dependent on the width of metal, usually m = 5000 kg in the sheet width 1000 mm. Coils can be used without insulation or with insulation on one side or the other side of sheet-metal.

Tab. 1.1 Properties of dynamo sheets for production of electric machines with thickness of 0.65 mm according to EN 10106 (highlighted material was used to evaluate the cutting tools functional parts life).

Brand according to ČSN EN 10106	**Thickness *t* (mm)**	**Maximum specific losses at 50 Hz**		**Minimum magnetic polarization in AC magnetic field at field intensity *H* (A/m)**			**Density *ρ* (kg · dm^{-3})**
		***p* 1.5 (W/kg)**	***p* 1.0 (W/kg)**	***J* 2500 (T)**	***J* 5000 (T)**	***J* 10000 (T)**	
M400-50A	**0.50**	**4.00**	**1.50**	**1.53**	**1.63**	**1.73**	**7.70**
M400-65A	0.65	4.00	1.70	1.52	1.62	1.72	7.65
M470-65A	0.65	4.70	2.00	1.53	1.63	1.73	7.65
M530-65A	0.65	5.30	2.30	1.54	1.64	1.74	7.70
M600-65A	0.65	6.00	2.60	1.56	1.66	1.76	7.75
M700-65A	0.65	7.00	3.00	1.57	1.67	1.76	7.75
M800-65A	0.65	8.00	3.60	1.60	1.70	1.78	7.80
M100-65A	0.65	10.00	4.40	1.61	1.71	1.76	7.80

2 ASPECTS AFFECTING CUTTING TOOLS FUNCTIONAL PARTS LIFE

The main factors that affect the durability of cutting tools functional parts are:

a) ***cutted length in material*** (it is given by the cutting technology, by the cutted sheet width and by kind of cutting blade bearings. For cutting the utilization of cutting with sloping shear blades is most advantageous, because at this way of cutting the sheet metal shear blades not penetrate sheared material at once, but gradually, which has a positive impact on their lifetime.),

b) ***cutted material type*** (for the production of stator and rotor plates of rotating electrical machines it is due to the character and use of sheet-metal in electrical engineering, according to practice a sheet with thickness of $t = 0.50$ mm with designation of M400-50A according to EN 10106 - see 1 was chosen),

c) ***cutting knives material*** (fundamentally affects the tool life, and in terms of susceptibility to shear knives cracking, their dull, and thus the number of over-sharpening. Blunt instrument is assessed by burr size on the bottom surface of shear cutting. This burr can reach a maximum value of 10 % of thickness of cutted sheet.),

d) ***type of shear knives placement*** (when using scissors with angled blades the shearing blades are placed at an angle to each other – see Fig. 4 and Fig. 5, which has a positive effect on the shear force, which is smaller than using scissors with parallel blades. Using smaller shear force has a beneficial effect on the longer life of cutting blades.),

e) ***possible number of cutting blades resharpening*** (it is given not only by the shear knives structure, but also by cutting tool construction. In practice the cutting tool construction which has all four edges for cutting, which allows each knife use effectively, is frequently used. Working height of knives into which it is possible to regrind the knife is 6 mm. Material removal at one grinding of shear knife edge is 0.1 mm, which means that when using all four cutting edges of knives it is possible the knives to use up to 240x, than they need to be replaced by new ones.),

f) ***cutting tool lubrication to reduce friction between the blades*** (in electrical engineering it is desirable, in order to avoid transferring the lubricant on sheared material. Materials that are contaminated by lubricant, would have to be technologically degreased, which would be costly and would be reflected on cut out more expensive stator and rotor plates of electrical rotating machines, and thus on rise the whole device price.).

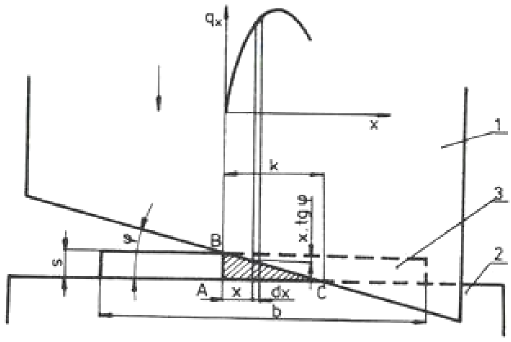

Fig. 4 Scheme of cutting by angled blades [5].

Fig. 5 Pneumatic scissors with angled blades.

3 MATERIALS OF CUTTING TOOLS FUNCTIONAL PARTS

For the production of cutting tools functional parts three types of tool materials – 19 436 tool steel (chrome) according to according to the Czech State Standard (ČSN) 41 9436 (see 3.1), high speed steel 19 830 according to to the Czech State Standard 41 9830 (see 3.2) and a special powder metallurgy product – ledeburite tool steel Vanadis 10 (see 3.3) can be used.

3.1 Tool chrome steel 19 436 (X210Cr12 EN 96-79)

It is a high chrome alloy steel with high hardenability, which has a high wear resistance by metal, but also mineral materials. It has also good cutting properties, very high compressive strength and good dimensions stability during heat treatment. The disadvantages are difficult abrade, difficult hot formability and somewhat more difficult machinability in annealed condition.

From this steel the tools functional parts for cold cutting are made – all kinds of long-life tools for cutting at presses and punching of materials with smaller thicknesses and high strength materials (especially intricate shape cutting tools for cutting of dynamo and transformer sheets and sheets from stainless steels), knives for plate shears for sheet-metal and strips (sheared material to a thickness of about 4 mm), knives for cutting of wires, etc.

Tab. 3.1 Chemical composition of tool steel 19 436 (X210Cr12 EN 96-79) according to the Czech State Standard 41 9436.

19 436 (X210Cr12 EN 96-79)							
Chemical composition (weight %)	C	Mn	Si	Cr	Ni	P	S
	1.80 ÷ 2.05	0.20 ÷ 0.45	0.20 ÷ 0.45	11.00 ÷ 12.50	max. 0.50	max. 0.030	max. 0.035

3.2 High speed steel 19 830 (HS 6-5-2 EN 96-79)

High speed steel 19 830 (HS 6-5-2 EN 96-79) is a powerful high-speed steel with improved toughness and easy machinability at grinding. Compared with other high speed steels it is susceptible to decarburization.

It is used for greatly stressed tools for working of materials with medium and higher strength, especially for tools that require particularly good toughness as are powerful cutters, drills, taps, reamers, machine knives for gear, etc.

Tab. 3.2 Chemical composition of tool steel 19 830 (HS 6-5-2 EN 96-79) according to the Czech State Standard 41 9830.

19 830 (HS 6-5-2 EN 96-79)									
Chemical composition (weight %)	C	Mn	Si	Cr	W	V	Mo	P	S
	0.8 ÷ 0.9	max. 0.45	max. 0.45	3.8 ÷ 4.6	5.5 ÷ 7.0	1.5 ÷ 2.2	4.5 ÷ 5.5	max. 0.035	

3.3 Ledeburite tool steel Vanadis 10

Vanadis 10 is a Cr-Mo-V tool steel ledeburite produced by powder metallurgy for which the following properties are characterized: extremely high wear resistance, high compressive strength, very good hardenability, good toughness, very good dimensional stability after hardening and tempering, a good tempering resistance.

The main alloying element in this steel is chromium, which makes various types of more or less stable carbides. These carbides are easily dissolved in the austenite, which is then saturated with carbon and alloying elements. The high content of alloying elements in austenite ensures good material hardenability.

Other alloying element in this steel is vanadium, which has a high affinity to carbon and forms very stable hard MC carbides. Their presence on the one hand deteriorates machinability, on the other hand improves the wear resistance. Vanadium is used in tool steels as an alloying element to increase hardenability. Steels containing vanadium are resistant to grain coarsening during austenitizing, which positively affects the mechanical properties after heat treatment. Braking effect of MC carbides at the austenite grain coarsening can be explained by their size and thermal stability.

Structure and properties of ledeburite steels depend on the matrix character and the type, quantity, size and distribution of carbide phases. Properties of tool steels are given by the superposition of the matrix and carbides influence. For example, hardness in the state after soft annealing is closely related to the type and amount of carbides. The matrix is ferritic and resultant steel hardness does not significantly affect. After austenitizing and hardening the matrix is composed of martensite and its hardness significantly affects the resulting hardness of steel. Without presence of carbides in the material and their dissolution during austenitizing the sufficient hardness matrix after heat treatment cannot be obtained. Carbides, which are not subject to dissolution, then prevent grain coarsening and increase resistance to wear of steels.

Standard heat treatment of Cr-V ledeburite steels consists of the following steps: austenitizing, the battery temperature to dissolve a certain amount of carbides and austenite homogenization, cooling at room or negative temperature and multiple tempering, usually on the secondary hardness. After these processes the hardness reaches more than 60 HRC.

Vanadis 10 is suitable for high-performance tools and a large series of cuttings, where abrasive wear is a dominant problem. It is an alternative for tools from the materials that are prone to edges chipping or arising of cracks (e.g. tungsten carbide). It is used for the production of cold-work tools (forming, machining, etc.). Material is used where high hardness and wear resistance while maintaining sufficient strength are required. Mentioned properties can be improved by using special finish – PVD layer. Because during operation the large burden of this layer can occur due to its fragility and risk of destruction, the layer with higher hardness than the hardness of the matrix, which is created by plasma nitriding, is used under it.

Tab. 3.3 Chemical composition of ledeburite tool steel Vanadis 10.

Vanadis 10						
Chemical composition (weight %)	C	Mn	Si	Cr	V	Mo
	2.9	0.5	1.0	8.0	9.8	1.5

4 EVALUATION OF THE CUTTING TOOLS FUNCTIONAL PARTS LIFE ACCORDING TO THEIR MATERIAL

Evaluation of the functional parts of cutting tools separate design which functional cutting parts were made from three variants of materials – tool steel 19 436 (chrome steel) according to the Czech State Standard 41 9436, high speed steel 19 830 according to the Czech State Standard 41 9830 and a special powder metallurgy product – ledeburite tool steel Vanadis 10 (see 3) was carried out at joint-stock company TES VSETÍN. A cold-rolled dynamo sheet M400-50A according to ČSN EN 10106 with thickness of 0.50 mm and with protection insulating layer (see 1) was used as a trimmed material. Lifes of functional parts of separate cutting tools performances, i.e. the total number of strokes to wear, were determined for 10 % limit burr of plate thickness (when demand on smaller burr the life would be lower) for various sizes of cuttings. The cutting was carried out without lubrication of cutting tools.

The results are summarized in the table of expected life of cutting tools functional parts (see Tab. 4.1). This table does not include accidental destructions (crashes) of tools, such as dropping of the tool part into the machine working area, a foreign object in the tool, etc.

The practical life of functional parts of cutting tools separate performances T_P can be calculated from the theoretical life of T_C mentioned in the final, right column of the table, by its multiplying with the coefficients of the tool design and the cutting edges shape complexity:

$$T_P = T_C \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6 \text{ (pc)} \quad (4.1)$$

where are T_P – practical life of cutting tool functional parts, T_C – theoretical lifetime of cutting tool functional parts, K_1, K_2, K_3, K_4, K_5, K_6 – coefficients of the tool design and the cutting edges shape complexity, which can be selected as follows:

- cutted part shape: sharp corners, small bridges $K_1 = 0.90$,
  dovetails, small holes $K_2 = 0.85$,
- number of profile punches in casting: to 20 pieces $K_3 = 0.90$,
  to 50 pieces $K_4 = 0.75$,
- sheared material: tensile strength upper than 500 MPa $K_5 = 0.90$,
  Al content upper than 1 % $K_6 = 0.90$.

If any effect does not exist, the relevant coefficient $K_i = 1$.

The relationship can be used for the activities of adjuster and sedge of crimping tools.

From Tab. 4.1 follows that the best and most innovative material for the production of functional parts of cutting tools for cutting of stator and rotor plates used in electrical rotating machines is the product of powder metallurgy Vanadis 10.

Tab. 4.1 Expected life of the functional parts of cutting tools for cutting of cold rolled dynamo sheet M400-50A according to ČSN EN 10106 with thickness of 0.50 mm and with protection insulating layer, for the 10 % limit burr of plate thickness and cutting without lubrication of cutting tools.

Cutting tool design	Cutting tool functional parts material	Number of strokes for one sharpening *z* (pc)	Average removal from cutting part at sharpening *s* (mm)	Total shear parts working height *h* (mm)	Theoretical number of sharpening during the overall tool life	Tool life (number of strokes to total wear) T_C (pc)
Block tool with upper removing ø100 ÷ 1000 mm	ČSN 19 436	50 000	0.25	12	48	2 400 000
	ČSN 19 830	75 00	0.25	12	48	3 600 000
	Vanadis 10	150 000	0.25	12	48	7 200 000
Tool with simple shear blades for simple cutting	ČSN 19 436	70 000	0.10	6	60	4 200 000
	ČSN 19 830	310 000	0.10	6	60	18 600 000
	Vanadis 10	450 000	0.10	6	60	27 000 000
One row progressive tool 50 ÷ 300 mm	ČSN 19 436	80 000	0.25	12	48	3 840 000
	ČSN 19 830	150 000	0.25	12	48	7 200 000
	Vanadis 10	300 000	0.25	12	48	14 000 000
Diameter groove tool without tag	ČSN 19 436	50 000	0.10	6	60	3 000 000
	ČSN 19 830	240 000	0.10	6	60	14 400 000
	Vanadis 10	400 000	0.10	6	60	24 000 000

9 CONCLUSIONS

Based on the analysis of sheet-metal used for the production of stator and rotor components for electrical rotating machines it can be stated that for position inductive sensors and for generators is useful to select as a material some from isotropic dynamo electrical steels for electrical engineering cold-rolled in the final processed state (see 1). According to the production requirements for electrical rotating machines the sheet-metal M400-50A according to ČSN EN 10 106 (see Tab. 1.1), which is isotropic for electrical steel sheet with a maximum specific losses p= 4.00 W/kg at 1.5 T and 50 Hz, with a nominal thickness of t = 0,50 mm supplied in heat-processed state (see 1) was selected as the most suitable material for the cutting tools life comparison.

In the paper the main factosr affecting the durability of functional parts of the cutting tools are described. One of the most important is the material of cutting tool functional parts (see 2).

From comparison of three variants of the cutting tool functional parts material – 19 436 tool chrome steel according to Czech state Standard 41 9436 (see 3.1), high speed steel 19 830 according to the Czech State Standard 41 9830 (see 3.2) and a special powder metallurgy product Vanadis 10 (see 3.3), which is summarized in Tab. 4.1 (see 4) follows that the best and most innovative material for production of functional parts of cutting tools for cutting of stator and rotor plates used in electrical rotating machines is the product of powder metallurgy – ledeburite tool steel Vanadis 10 (see 3.3).

Useful lifes of the functional parts of cutting tools separate performances can be calculated from the theoretical lifes by their multiplying with the coefficients of the tool design and the cutting edges shape complexity (see 4). The relationship can be used for the activities of adjuster and sedge of crimping tools.

REFERENCES

[1] ČADA, R. *Tvářitelnost ocelových plechů: odborná knižní monografie.* Lektorovali: L. Pollák a P. Rumíšek. 1. vyd. Ostrava: REPRONIS, 2001. 346 s. ISBN 80-86122-77-8.

[2] BOBČÍK, L. Střižné nástroje pro malosériovou výrobu. 1. vyd. Praha: SNTL, 1983. 213 s. Bez ISBN.

[3] NOVOTNÝ, J. a LANGER, Z. *Stříhání a další způsoby dělení kovových materiálů*. 1. vyd. Praha: SNTL, 1980. 216 s. Bez ISBN.

[4] ČADA, R. *Plošná tvářitelnost kovových materiálů.* 1. vyd. Ostrava: VŠB-TUO, 1998. 90 s. ISBN 80-7078-557-8.

[5] HRUBÝ, J., RUSZ, S. a ČADA, R. *Strojírenské tváření: skriptum.* 2. vyd. Ostrava: Vysoká škola báňská v Ostravě, 2006. 160 s. ISBN 80-248-1218-5.

[6] ZLÁMALÍK, J. *Návrh produktivní technologie vystřihování plechů rotorů a statorů pro generátory: bakalářská práce.* Ostrava: Vysoká škola báňská – Technická univerzita Ostrava, Fakulta strojní, 2009. 76 s.

[7] ZLÁMALÍK, J. *Návrh technologie výroby plechu rotoru a statoru indukčního snímače polohy vystřihováním a zakružováním: diplomová práce.* Ostrava: Vysoká škola báňská – Technická univerzita Ostrava, Fakulta strojní, 2011. 88 s.

[8] EVIN, E. Properties of steel-sheets with Fe-Zn coatings for automobile industry. *Zsesyty naukowe*, 2010, Vol. 16, No. 1, pp. 27-32. ISSN 1897-2683.

Results in the contribution were achieved at solving of specific research project No. SP2012/162 with the name *”Optimization of Flat and Volume Forming Processes with the Use of Physical Simulation and Finite Element Method”* (*„Optimalizace procesů plošného a objemového tváření s využitím fyzikálního modelování a metody konečných prvků“*) solved in year 2012 at Faculty of Mechanical Engineering of VŠB – Technical University of Ostrava.