The International Journal of Engineering and Science (IJES)
|| Volume || 12 || Issue || 1 || January || Pages || PP 22-27 || 2023 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Assessment of cutting tool wear by burr formation

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---***ABSTRACT***---
The objective of this paper is to investigate the effect of cutting tool wear on burr formation. When comparing machining, forging, and casting, shearing is mostly known in heavy industry for mass production as a very cheap and fast way to get the desired shape of the product. Recently, however, shearing has also been transferred to light industry to produce electronic components. The appearance of burrs on the cutting edge is usually unavoidable by cutting a part from sheet metal. Burrs not only reduce the accuracy of the product, but also cause further cost increases in the deburring process. In this paper, the effect of the cutting tool on burr formation is investigated by using the experimental approach. The experimental results show that the effect of wear on the functional parts of the cutting tool such as the shear and shearer have a great influence on the formation and size of burrs.
KEYWORDS; - *cutting,cutting gap, burr, wear*

Date of Submission: 01-01-2023 Date of Acceptance: 12-01-2023

I. INTRODUCTION

Recently, sheet metal has been extensively used in various industries such as electronics, automotive, aerospace, etc. Most commonly, shearing is used as the primary process to reduce the rolled sheet to a shape as close as possible to the desired product shape. Other manufacturing processes must be used to achieve the final shape of the product. In most cases, the most accurate dimensions and the shortest product manufacturing process are required, which has a favorable impact on the production costs and the usability of the product. During the shearing process, unwanted burr formation occurs on the shearing surfaces. The aim of every manufacturer is to produce semi-finished products with as few burrs as possible.[1]

Nowadays, the industry places various demands on components created by shearing. One of them is the requirement of a burr-free cutting edge, which allows better processing of components with a more economical result in the work process and their safer handling. Efforts are therefore being made to reduce burr formation to avoid subsequent deburring. Currently, this process is carried out in a further component processing step such as mechanical deburring [2, 3], belt grinding [4], sliding surface grinding [5], or burr pressing [6]. Material removal during the shearing process results in lower dimensional accuracy [7]. All these additional technical processes are labor, time and cost intensive.

The shear cutting process is one of the most economical separation processes since it combines high production rates with low costs. The quality of the shear cut edge depends on the material properties, material thickness, die clearance, cutting edge radius, tool wear and shear cutting strategy. [8]

The results of the shear cutting process are changes in the surface of the base material. These changes not only affect their geometric properties, but also change the physical, chemical, and mechanical properties of the surface (microstructural changes, cracks and microcracks, microhardness, corrosion resistance, etc.). All these changes are part of the concept of surface integrity, which is one of the basic aspects in terms of quality requirements, especially in structural elements for stator and rotor cores in electric motors, where these requirements are very high due to functionality and reliability. [9,10]

In general, the shearing surface of the materials that have undergone shear deformation due to the compressive stress of punch and die are composed of 4 parts: rollover, burnish zone, fracture zone and burr. An ideal shearing surface is created by 100% of the burnish zone, and without rollover, fracture zone or burr. At the beginning of the shearing process, elastic and plastic deformations usually occur, which subsequently produce rollover and burr. Burr after shearing process is the plastic deformity, which remains on the surface and lowers the products quality by influencing roughness and accuracy. In addition, burrs on the surface of inside or outside cut-outs can affect negatively to the cost efficiency of products and the safety of the workers.[11]

II. CUTTING PROCES

Rotating electrical machines are characterized by the variability of the magnetic induction flux. For this reason, the sheets used for their production must be isotropic. The material of stator and rotor made from electrical sheets should have an isotropic structure after final processing. However, the plastic deformation accompanying the cutting process worsens the magnetic properties of the finished electrical sheet products. The production of rotors by cutting electrical sheets is therefore always accompanied by the occurrence of an area with other magnetic properties.

A burr is formed (Fig. 1), the formation of which cannot be prevented during the cutting of electrical sheets, therefore the plates for the rotors and stators are sometimes subjected to an additional deburring operation. The influence of burr on the blades of rotors and stators, on the output characteristics of the electric motor is unfavorable.

During winding of the coil and during electric motor operation, the insulation may be broken, the winding may be short-circuited, and the rotor of the electric motor may burn out. Then, it is necessary to cut these sheets with the smallest possible burrs, of course, while maintaining the conditions of economy of production. At the same time, the requirements for electric motors stipulate that the size of the burr of the cut sheets, for stators and rotors, in small and medium-sized electric motors, should not exceed 10% of the nominal thickness of the sheet used. [12]

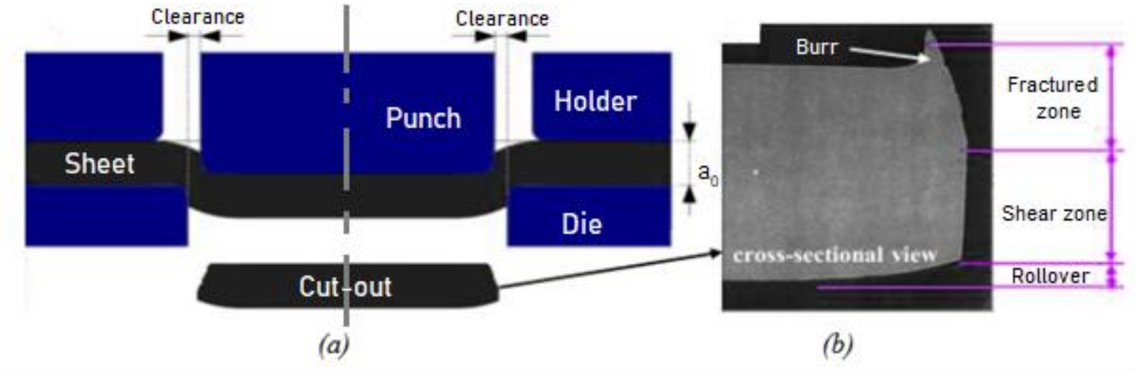

Fig. 1: Schematic of the cutting process and different zones of the cutting edge

III. MATERIAL

The subject of the experiment, which was carried out in order to observe the wear of the functional parts of the shearing tool depending on the occurrence and size of the burr, were sheets of electrical steel from U.S.Steel Košice.

Experimental research was carried out on two types of isotropic cold rolled sheets. The sheets were marked with letters A and C. The chemical composition and mechanical properties of the samples are given in Table 1 and Table 2.

Tab. 1: Chemical composition of the sample material

Chemical composition [%]	**C**	**Mn**	**Si**	**P**	**S**	**Al**	**N**
Sample **A**	0,030	0,350	1,100	0,090	0,009	0,155	0,007
Sample **C**	0,030	0,260	2,620	0,004	0,008	0,487	0,006

Tab. 2: Mechanical properties of the sample material

Mechanical properties	**Thickness [mm]**	**Re [MPa]**	**Rm [MPa]**	**Re/Rm**	**A_{80} [%]**	**Hardness [HV-5]**	**Hardness [HV-10]**
Sample **A**	0,66	248	383	0,648	34,0	130	120
Sample **C**	0,66	394	414	0,950	27,5	158	151

In terms of wear resistance, Alloy cold-work tool steel X210Cr12 (1.2080, EN) has proven to be the most advantageous of the traditional materials to produce the functional parts of the shear tool. Its chemical composition is given in the Table 3.

Tab. 3: Chemical composition of the Alloy cold-work tool steel

Chemical composition [%]	**C**	**Mn**	**Si**	**Cr**	**V**
X210Cr12	1,2 - 1,45	0,15 - 0,40	0,15 - 0,35	11,0 - 12,0	0,7 - 0,9

IV. METHODOLOGY OF EXPERIMENT

The nominal diameter of the cut-out holes is 50 mm. Prior to the experiments, the geometric dimensions of the punch and die were measured at four locations, which are shown in Figure2. The measured values are recorded in Table 4.

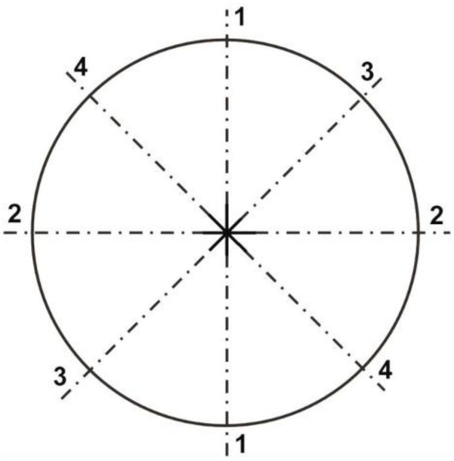

Fig. 2: Punch and die diameter measurement locations

Tab. 4: Diameters of the active parts of the cutting tool

Measurement location	**Diameter [mm]**		**Cutting gap [mm]**
	Punch	**Die**	
1 - 1	50,028	50,035	0,007
2 - 2	50,029	50,035	0,006
3 - 3	50,027	50,032	0,005
4 - 4	50,025	50,030	0,005

When cutting out, a burr is created at the edge of the cutting surface. The formation of a burr is a concomitant of shearing and is virtually impossible to prevent it.Burr on the cut-out for the stator harness adversely affects the characteristics of electric motors.

Due to its influence, conductive junctions are formed on the stator beam between the individual lamellas, which increase energy losses such as increased hysteresis and eddy current losses. Therefore, it is necessary to produce the stator lamella with the least possible burr, considering the economy of production.

The results so far, which have been experimentally obtained by measuring the losses, show that the amount of burr should not exceed 10% of the material thickness. Several foreign manufacturers of electric motors indicate a maximum burr height of 0.05 - 0.08 mm for a sheet thickness of 0.5 mm, some even more strict values of 0.02 - 0.04 mm.It can be said that as the magnetic stresses on the rotor and stator bundles increase, the tendency to reduce the maximum burr height will be enforced. The amount of burr that forms on the cuttings depends mainly on the amount of shear clearance, the degree of tool wear, the mechanical properties of the material to be sheared and the shearing speed.

The results obtained from the measurements show that the dependence of tool wear, which is expressed by the burr height h_i and the number of cuts x_i, can be expressed as an increasing function in the interval $x_i > 0$. Schematically, this dependence is expressed by a curve with an inflection point and three segments of significantly different steepness (Figure 3).

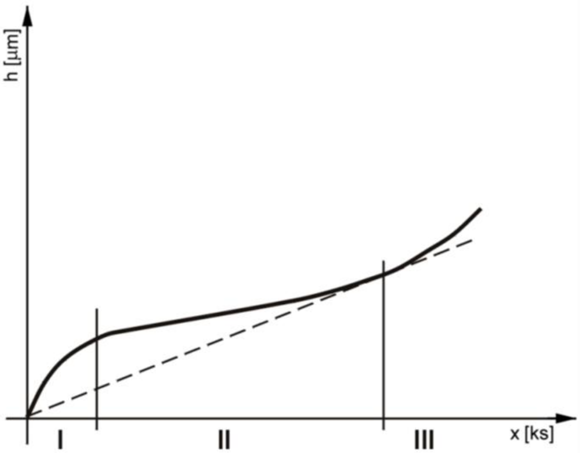

Fig. 3: Plot of the dependence of the burr h_i on the number of cut-outs x_i.

The direct measurement method was used to measure the burr height using a GRATMESSER IV burr measuring instrument manufactured by Dr. Schneider, Bad Kreuznach, NSR. The principle of measurement with this instrument is the optical measurement of the burr height.

The height of the burr is sensed by a mirror when illuminated by an external light source. Observation is made with a microscope. The measurement is visual using a calibrated plate placed in the eyepiece. The illumination bulb with lens is firmly attached to the microscope body. For the measurement, the microscope tube is placed on the cut-out near the burr and the burr appears as a dark band of irregular width in the eyepiece.

The scale division of the instrument used is in increments of 0,005 mm. The accuracy of the measurement is given by the manufacturer of the instrument as 0,0025 mm, which is sufficient for an objective assessment of the height of the burr.

Figure 4 shows the microscopic structure of the cutouts.

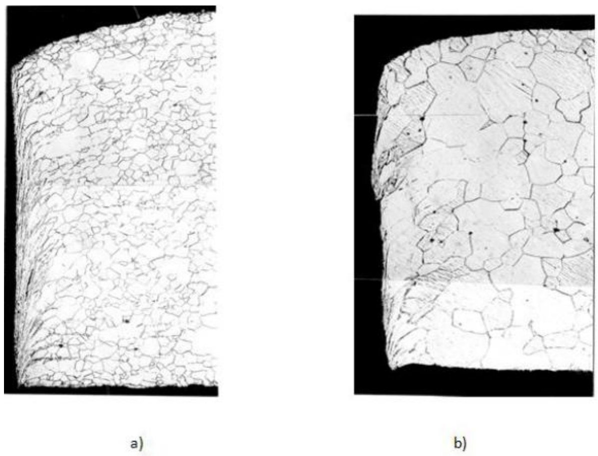

Fig. 4: Microscopic structure of the cut-outs: a) cut-out without burr, b) cut-out with burr

Figure 5 shows a graph of the dependence of the burr height on the number of cut-outs for material A in the 90° direction. The burr height is approximately the same up to a value of 40 000 cut-outs, from which point the burr height increases slightly. This is due to the fine wear of the shearing edgesof the functional parts of the shearing tool. A sharp increase in the burr height occurs from approximately 75 000 cut-outs.This can be expressed by the mathematical equation: $y = -6E-06x3 + 0{,}0044x2 - 0{,}2023x + 13{,}107$, $R^2 = 0{,}9883$.

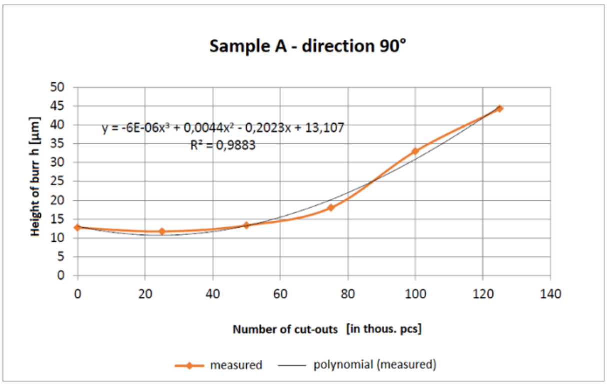

Fig. 5: Graphical dependence of the burr height on the number of cut-outs of the sample A – direction 90˚

Figure 6 also shows the dependence of the burr height on the number of cut-outs for material A, but in the 0° direction. At the beginning of the shearing process there is a slight decrease in the burr height up to a value of 25000 cut-outs. Thereafter, the burr height increases slightly up to a value of approximately 75,000 cut-outs. Above this number of cut-outs, there is a rapid increase in the size of the burr height. This phenomenon can be described by the mathematical equation: y = -3E-05x3 + 0.0101x2 - 0.52x + 15.628, R^2 = 0.9595.

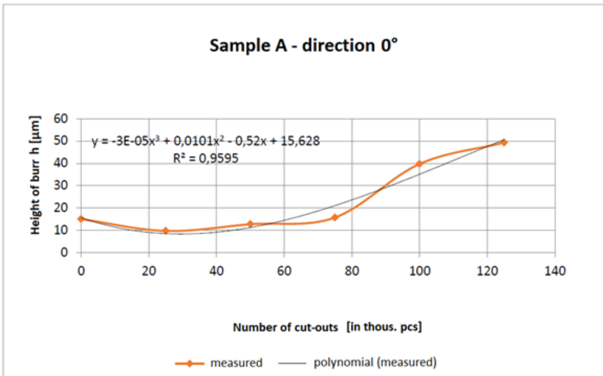

Fig. 6: Graphical dependence of the burr height on the number of cut-outs of the sample A – direction 90˚

The dependence of the burr height on the number of cut-outs for material C in the 90° direction is shown in Figure 7. The graph shows that the initial burr height for material C was already higher at the beginning of the shearing process than for the previous material A. Uniform values of the burr size were maintained up to approximately 25,000 cut-outs. From this number, up to 50000 cut-outs, there was a slight increase in the burr height values. This may have been due to the already slight wear of the shear edges of the die and punch. The burr height values gradually stabilized to around 175 000 cut-outs. Subsequently, the burr height increases rapidly up to values of 40 µm at a number of 220 000 cut-outs resulting in greater wear of the shear edges of the functional parts of the shearing tool. This phenomenon can be expressed by the relation: y = 9E-06x3 - 0,0029x2 + 0,292x + 13,863, R^2 = 0,9525.

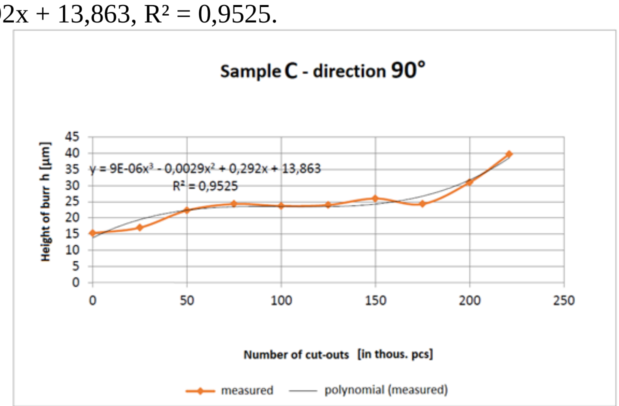

Fig. 7: Graphical dependence of the burr height on the number of cut-outs of the sample C – direction 90˚

V. CONCLUSION

From the measured values of the burr size, it can be concluded that the burr height does not exceed the permissible values when the size of the correct relative shear gap between punch and die is maintained. Type 'A' material is about 30 % less susceptible to burr formation than type 'C' material, which is due to the significantly higher yield strength of sheet 'A' than sheet 'C' and the high Re/Rm ratio (up to 0,95). The durability of the cutting edge when shearing the 'A' material samples was already lower at 75,000 cut-outs, when the size of the burrs started to increase substantially. When cutting material C, although the initial burr height was higher, it remained approximately the same until 175 000 cut-outs had been cut. It was only after this number of cut-outs that the burr height began to increase substantially, which only documents that shear edge wear was occurring.

ACKNOWLEDGEMENTS

This paper was written with the financial support of the granting agency VEGA within the project solution VEGA 1/0384/20 and KEGA 036TUKE-4/2021.

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