VISION ASSISTED CLEARANCE EVALUATION IN CUTTING PROCESS

Cezary JASIŃSKI [1], Łukasz MORAWIŃSKI [1]

[1]*Warsaw University of Technology, Warsaw, Poland, EU*
cjasins1@wip.pw.edu.pl, *l.morawinski@wip.pw.edu.pl*

Abstract

Cutting is one of the most frequently carried out metal forming processes. One of the basic parameters of this process is the clearance value. The clearance is the difference between dimensions of the punch and the die, usually related to sheet thickness. The amount of clearance affects on geometry and quality of the material cut surface. The cut surface can be divided into the area of rollover, burnish, fracture and burr. Of these areas, only rollover and burr is visible on the sheet surface. In this paper, the authors proposed a method allowing to determine the clearance based on the rollover area measurement. By means of the camera and experimental lighting, it was possible to measure the size of the rollover area without making sheet cross-sections. Proposed vision system allows fast measurements of the rollover area and determines the associated clearance. The experimental measurements were carried out on a deep drawing steel DC04 with a thickness of 1 mm and 2 mm.

Keywords: Cutting process, clearance, rollover area, vision system

1. INTRODUCTION

Cutting is one of the sheet metal forming processes. It allows to obtain a flat products of various shapes and holes with any dimensions and locations. Cutting could be carried out by means of different type of press equipped with tools in the form of punch and cutting plate with sharp cutting edges. Clearance is one of the basic parameters of cutting process. It is the difference between the radius of the hole in the cutting plate and the radius of the punch, usually referenced to the sheet thickness. Clearance affects on the quality of the cutting surface and sheet geometry in the cutting area [1,2] (**Figure 1**) and it increase with the wear of tools during cutting operations [3,4]. Usually, when the clearance increase, the quality of the cutting surface drop and the rollover area at the edge of the product increase. Depending on the product designation, the stricted clearance determination may be important.

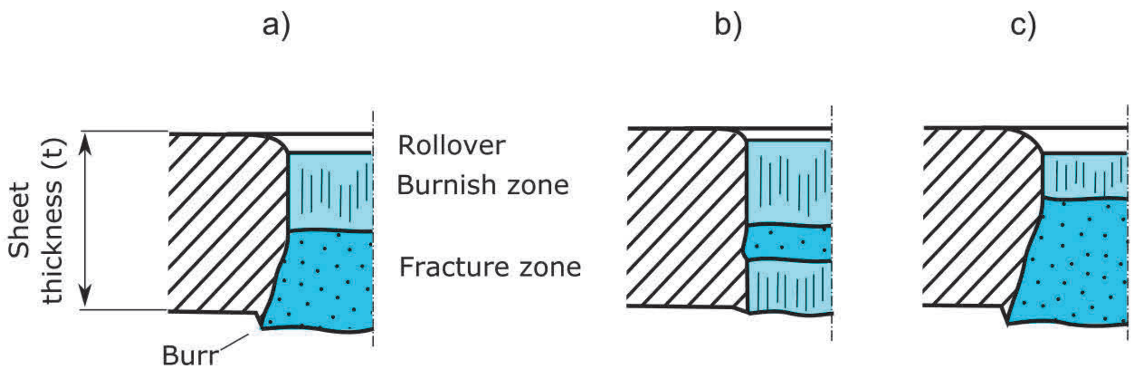

Figure 1 Areas in the cutting surface a), cutting surface for small clearance b) and for large clearance c)

As previously mentioned, the correlation between the cutting surface parameters and the clearance can be determined. These parameters can be obtained by means of microscopic measurements of the cut out hole. Unfortunately, microscopic examinations are time consuming. The authors have proposed a method, which allows to evaluate clearance based on the rollover width. Rollover area increase with the clearance [5,6] therefore, it is possible to estimate the clearance based on the rollover width W_r measurements, which is the half of the difference between the external rollover area diameter d_r and the inner diameter of the hole d_i (**Figure 2**). These dimensions are measured in the sheet plane, and there's no need to perform cross-sections through the hole, so it can be conducted on finished products. High speed measurements were obtained using the vision system described in the next chapter.

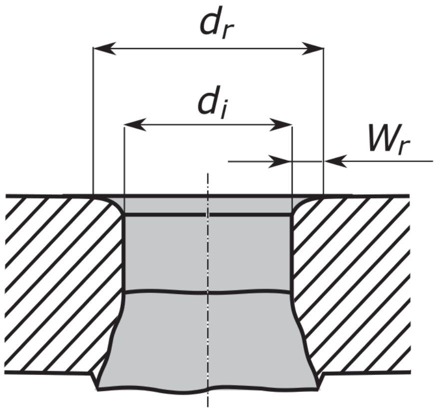

Figure 2 Rollover width measurement

2. EXPERIMENTAL SETUP

Specially prepared vision system [7] was used for rollover width measurements (**Figure 3a**). It is composed of camera with telecentric lens (1), an axial collimated illumination (2), backlight illumination (3) and PC (4) for analyzing the images of the sample (5). Backlight allows to highlight shape of the hole and thus measure its internal diameter. Additional collimated axial lighting was used to illuminate the object from the rollover side. This type of light highlights any irregularities in the surface of a flat sheet, which allows to extract the rollover area. Simultaneous use of both types of illuminations resulted in images of black rings corresponding to the rollover area (**Figure 3b**).

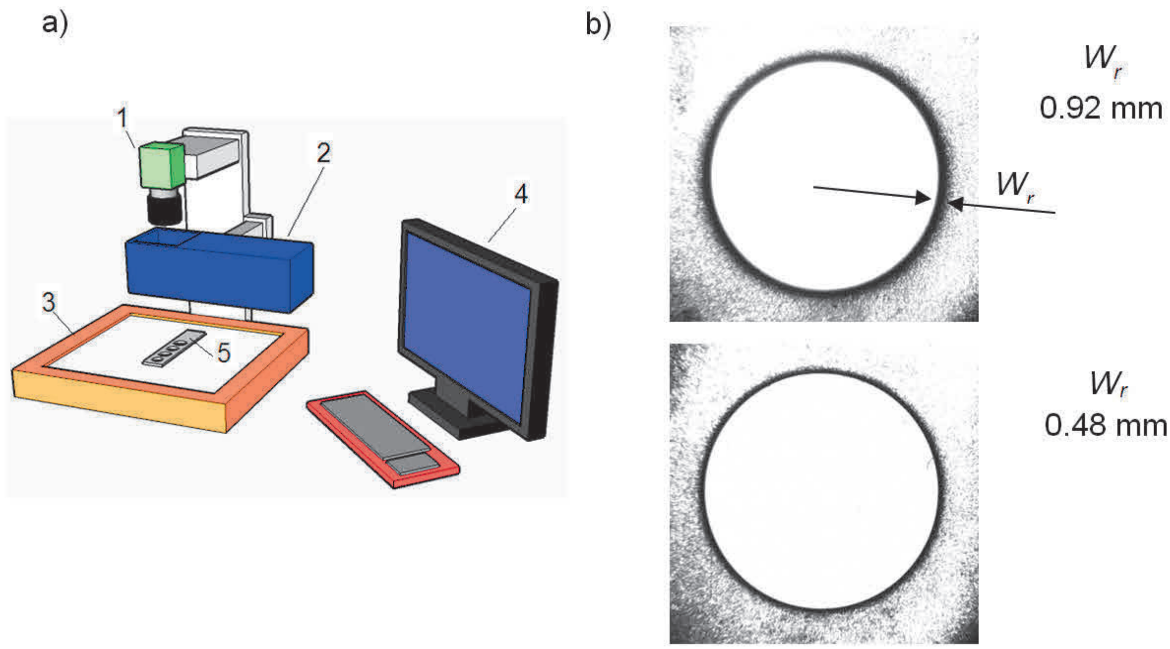

Figure 3 Experimental setup a) and holes with different rollover widths registered by the vision system b)

The rollover width W_r measurement was based on the black rings analysis by means of the software developed in the LabView environment. The analysis begins with detecting the center of the hole visible as a white area limited by a black ring. In the next step, edge searching was performed radially from the center of the hole. Two types of edges were detected, the first one which is the edge of the hole and the second representing the outer edge of the rollover area. The width of the ring W_r was calculated as a distance between these two edges. This method works very well for perfectly flat sheets. When the illuminated surface is not perfectly flat, or non-perpendicular to the optical axis of the vision system, the contrast between the rollover area and the flat surface of the sample is reduced. This may be the reason of wrong edge detection. In order to increase the local contrast of the rollover area, the recorded images were pre-processed (**Figure 4**). The pre-processed image was subjected to the edge detection algorithm. Obtained rollover edge detection resolution was 0.02 mm.

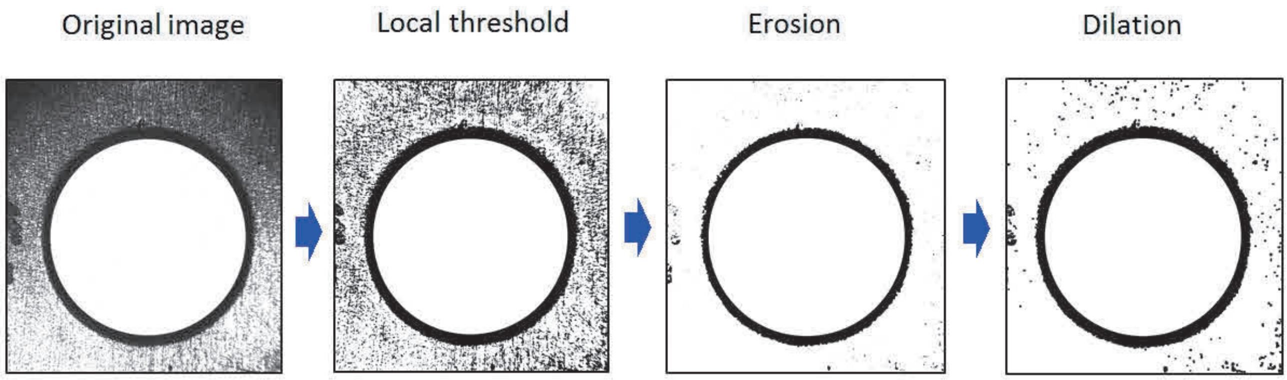

Figure 4 Image preprocessing

3. RESULTS

The measurements were carried out on a deep drawing sheet DC04 with a thickness of 1 mm and 2 mm. Three specimens of DC04 sheet were prepared for each thickness. In order to determine the clearance influence on the size of the rollover area, 7 punches of different diameters and one die were prepared. In this way, 7 different clearance values were obtained, which were used for blanking process. In **Table 1** the tools dimensions and clearance used during the research are presented.

Table 1 Tools dimensions and clearance used during the research

Punch number	1	2	3	4	5	6	7
Punch diameter (mm)	15.00	15.28	15.45	15.56	15.65	15.76	15.89
Die diameter (mm)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Clearance (mm)	0.5	0.36	0.28	0.22	0.18	0.12	0.06
Clearance for 1 mm (%)	50.00	36.00	27.50	22.00	17.50	12.00	5.50
Clearance for 2 mm (%)	25.00	18.00	13.75	11.00	8.75	6.00	2.75

Three specimens were made for each sheet thickness. For each of 6 specimens 7 holes were performed with a different clearance value. The specimens obtained in this way were measured on an experimental setup. Three piercing processes carried out using each of the punches allowed to verify the repeatability of the rollover area width W_r. In addition, each of the holes was measured three times. Based on these measurements, it was possible to check the measurement repeatability of the experimental vision system. **Figure 5a** shows the results obtained for 1 mm thickness DC04 steel. The graph shows the relationship between the width of the rollover area and the clearance in relation to the sheet thickness in %, at which the hole was obtained during piercing. The graph shows good repeatability of the rollover area size for each clearance value. **Figure 5b** shows the relationship between rollover width and clearance for 2 mm thickness DC04 sheet. Also for this sheet, three piercing processes were made for each of the punches. The repeatability of the rollover area width for a given clearance value is comparable to a 1 mm thickness sheet. Differences are noticeable in the width of the rollover W_r.

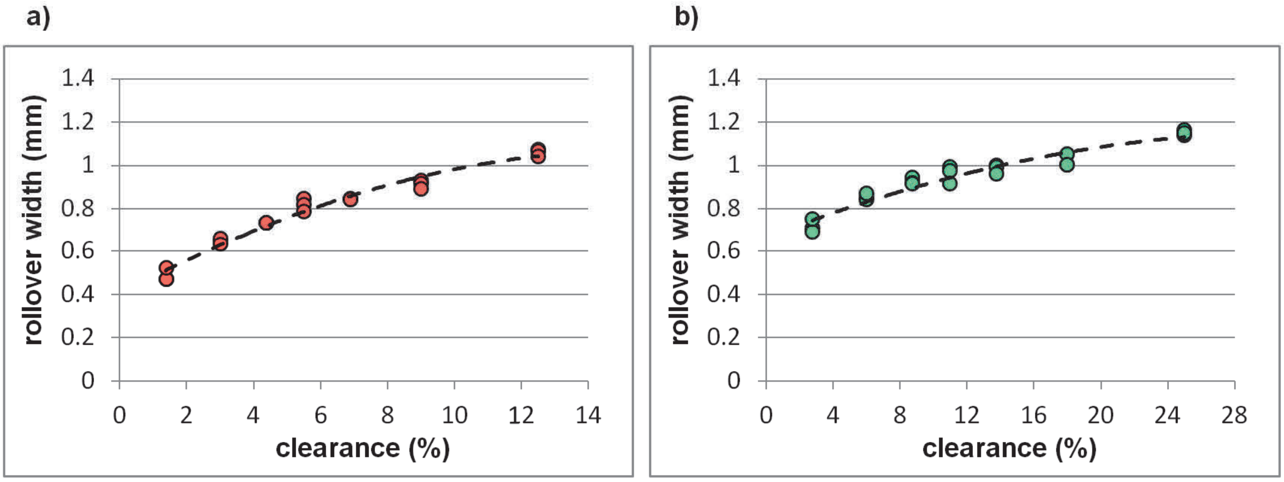

Figure 5 Relationship between rollover width and clearance for DC04 1 mm a) and 2 mm b) sheet thickness

In **Table 2** the clearance value is presented together with three measurements results (M1, M2, M3) of rollover width W_r for each of the 7 holes obtained on one of the specimens. At the end of the table there is the value of the measurement spread for each hole.

Table 2 Clearance value and three rollover width measurements for 1 mm thickness sheet

Punch no.	clearance (mm)	clearance (%)	M1 (mm)	M2 (mm)	M3 (mm)	spread (mm)
1	0.50	12.50	1.06	1.06	1.07	0.02
2	0.36	9.00	0.91	0.92	0.93	0.02
3	0.28	6.88	0.86	0.83	0.84	0.03
4	0.22	5.50	0.85	0.81	0.85	0.04
5	0.18	4.38	0.75	0.74	0.74	0.02
6	0.12	3.00	0.65	0.65	0.65	0.00
7	0.06	1.38	0.51	0.45	0.47	0.06

The results indicate that the measurement repeatability is high. The spread of the measurement values reaches a maximum of 0.06 mm. This spread is due to many reasons. The first is the resolution of the measurement system. The size of one pixel in the image is 0.02 mm. The edges of the rollover area are detected with this pixel accuracy. The rollover width W_r is measured between the inner and the outer edge of the ring shown in **Figure 3b**. For this reason, the maximum error due to the system resolution can reach 0.04 mm. This error can be significantly reduced by changing the camera and the optical system mounted on the experimental set-up. Verifications of measurement repeatability were also made for 2 mm DC04 sheet. In **Table 3** the values of clearance and 3 W_r measurement results are presented together with spread values for one of the specimens. In the case of these measurements, the maximum spread was 0.03 mm, which indicates very good repeatability of the presented vision system.

Table 3 Clearance value and three rollover width measurements for 2 mm thickness sheet

Punch no.	clearance (mm)	clearance (%)	M1 (mm)	M2 (mm)	M3 (mm)	spread (mm)
1	0.50	12.50	1.14	1.12	1.14	0.02
2	0.36	9.00	1.06	1.03	1.05	0.03
3	0.28	6.88	1.00	1.00	1.00	0.01
4	0.22	5.50	1.00	0.99	0.99	0.01
5	0.18	4,38	0.95	0.93	0.94	0.02
6	0.12	3.00	0.83	0.84	0.85	0.02
7	0.06	1.38	0.73	0.71	0.71	0.02

Figure 6 shows a summary of the measurements for both sheet thicknesses. It presents the relationship between the rollover width and the real clearance. Replacing the clearance in relation to the sheet thickness in % with clearance per side in mm allowed direct comparison of the results for both sheet thicknesses.

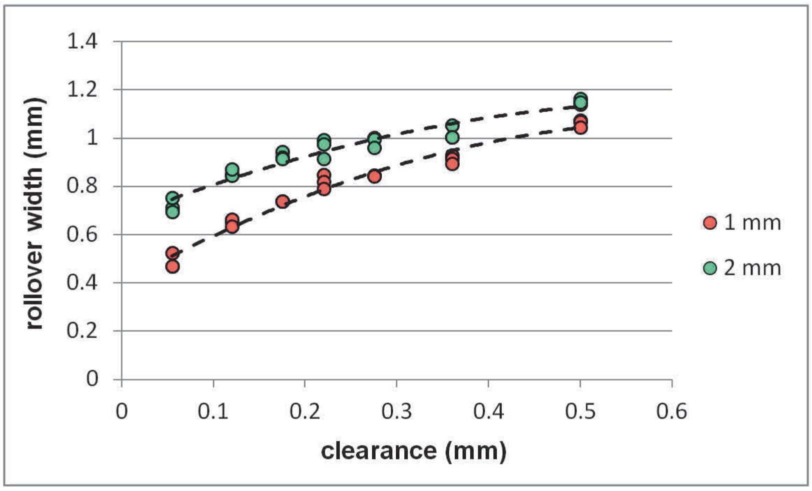

Figure 6 Relationship between the rollover width and the real clearance for both sheet thicknesses

The differences in the rollover width between 1 mm and 2 mm thickness sheets change from 0.1 mm for the largest clearance to 0.2 mm for the smallest clearance. The graph shows a clear relationship between the rollover width and clearance. To confirm the presented dependences, additional tests should be performed in the future for different materials and sheet thicknesses.

4. CONCLUSIONS

In this paper, the authors presented an experimental method of clearance determination. It allows fast clearance determine based on the size of the rollover, without destroying the examined object. The obtained results indicate a high potential of the presented method. The following conclusions were made based on the measurements:

- the vision measurement of the hole by means of axial and backlight illuminations enables fast and accurate evaluation of its diameter and rollover width without destroying the measured object,

- proposed method give the best results for perfectly flat sheet,
- the resolution of the measuring system can be improved by changing the optical elements and the camera,
- there is a relationship between the measured rollover width W_r and the clearance for DC04 sheet,
- information about rollover width allows to determine the clearance value in the cutting process,
- to confirm the obtained results more tests should be carried out for various materials and sheet thicknesses.

REFERENCES

[1] ERBEL, S., KUCZYŃSKI, K. and OLEJNIK, L., *Technologia obróbki plastycznej - Laboratorium*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej, 2003.

[2] PATER, Z. and SAMOŁYK, G. *Podstawy technologii obróbki plastycznej metali*. Lublin: Politechnika Lubelska, 2013.

[3] ARSLAN, Y. and ÖZDEMIR, A. Punch structure, punch wear and cut profiles of AISI 304 stainless steel sheet blanks manufactured using cryogenically treated AISI D3 tool steel punches. *The International Journal of Advanced Manufacturing Technology*. 2016. vol. 87, no. 1, pp. 587-599.

[4] MUCHA, J. and JAWORSKI, J. The Quality Issue of the Parts Blanked from Thin Silicon Sheets. *Journal of Materials Engineering and Performance*. 2017. vol. 26, no. 4, pp.1865-1877.

[5] FAURA, F., SEBASTIÁN, M. and ZAMORA, R. A decision support system for sheet metal blanking process parameters selection. *Journal of Materials Processing Technology*. 2001. vol. 118, no. 1-3, pp. 371-376.

[6] GREBAN, F., MONTEIL, G. and ROIZARD, X. Influence of the structure of blanked materials upon the blanking quality of copper alloys. *Journal of Materials Processing Technology*. 2007. vol. 186, pp. 27-32.

[7] JASIŃSKI, Cezary and MORAWIŃSKI, Łukasz. Szybka ocena luzu w procesie wykrawania z wykorzystaniem techniki wizyjnej. *Przegląd Mechaniczny*. 2018. vol. 77, no. 3, pp. 37-39.