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FAST CUTTING CLEARANCE EVALUATION IN PIERCING PROCESSES BY MEANS OF VISION SYSTEM

CEZARY JASIŃSKI*, ŁUKASZ MORAWIŃSKI

Department of Production Engineering, Warsaw University of Technology, Narbutta 85, 02-524 Warsaw, Poland
**Corresponding author: cjasins1@wip.pw.edu.pl*

Abstract

Cutting is one of the most commonly used processes in sheet metal forming. One of the most important parameters of this process is the clearance. Clearance value is defined as the distance between the cutting edge of the punch and the cutting edge of the die. It is relative to the sheet thickness and has a significant effect on the quality of the cutting hole surface, the size of the hole and the possibility of a burr occurring or the rollover area on the edge of the product. In the cutting process clearance value increase during tools wear. Its correct evaluation allows to determine moment when the tools should be replaced. In the presented paper authors have proposed fast clearance evaluation method base on the geometry measurement of the finished product. Measurements was carried out by means of vision system equipped with specially designed illumination, which allows to extract the rollover area at the edge of the hole. Then measured rollover area diameter was compared to clearance values.

Key words: Shear Cutting; Cutting Clearance; Vision System

1. INTRODUCTION

Cutting is one of the most frequently curried out sheet metal forming processes. It allows to obtain a flat product of any shape or product with holes of different shapes, dimensions and locations. Cutting is usually curried out by means of press, in which tools in the form of punch and die with sharp cutting edge are used.

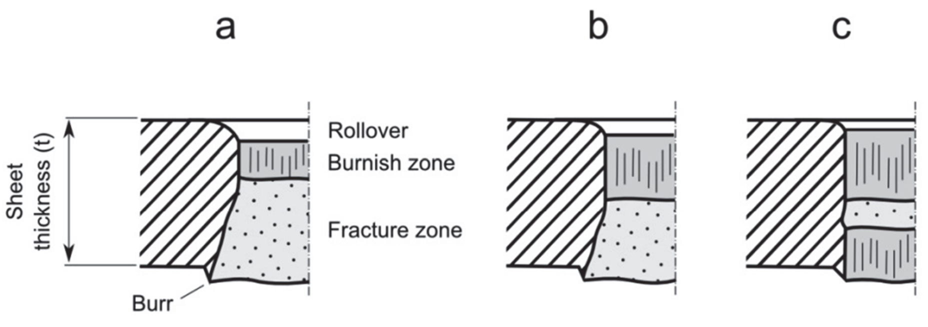

Fig. 1. Influence of the clearance on the cutting hole surface quality: (a) too large clearance;(b) optimum clearance; (c) very small clearance.

One of the basic parameters of cutting process is the clearance, which is the difference between the radius of the hole in the cutting plate (die) and the radius of the punch reference to the sheet thickness. The applied clearance determines the course of the punching process and affects the quality of the cutting hole surface and sheet geometry in the cutting area (Erbel et al., 2003; Nothhaft et al., 2012; Pater & Samołyk, 2013) (figure 1). The clearance between die and punch increase with the wear of tools during cutting operations (Arslan & Özdemir, 2016; Mucha & Jaworski, 2017). As the clearance increases, the slope of the cutting surface in the slug and the hole increases. At the same time, the burnish zone is reduced and fracture zone

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increased. Furthermore rollover area width increases at the edge of the hole. Incorrect clearance value also contributes to burrs occurrence, which often must be removed in the next technological operations. Depending on the purpose of the product, the above mentioned defects may not be allowed. For this reason, it is important to evaluate the actual clearance value in the cutting process.

2. CLEARANCE ESTIMATION METHOD

As previously mentioned, clearance value influence on the specimen geometry and the zones of the cut out hole surface. Therefore, the correlation between the selected parameter (for example rollover area diameter or angle of the cut out hole surface slop) and clearance between tools can be determined. Most of these parameters can be determined by means of microscopic measurements of the cut out hole surface. Unfortunately, microscopic examinations are time consuming, which are practically impossible to curry out fast evaluation of the clearance and hinders their use in production conditions.

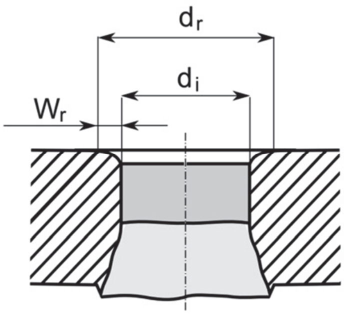

***Fig. 2.** Rollover and hole diameter measurement.*

The authors have proposed a method, which allows to evaluate clearance base on the rollover area at the edge of the hole. Increases in the clearance values causes increase of the rollover area (Faura et al., 2001; Greban et al., 2007) Therefore, it is possible to estimate the amount of clearance based on the measurements of the hole and data from specimens measurements for known clearance values. The proposed method is based on the measurement of the rollover area W_r like in figure 2, which is the half of the difference between the external rollover area diameter d_r and the inner diameter of the hole d_i. Because measurements are carried out in the sheet plane, there's no need to perform cross-sections through the hole and they can be conducted on finished products. High speed measurements were obtained using the vision system described in the following section.

3. EXPERIMENTAL SET-UP

The clearance measurement concept was implemented by means of a specially prepared vision system. Figure 3a shows the scheme of the experimental measurement set-up. Basic components of the vision system are camera with telecentric lens (1), an axial collimated illuminator (2), a backlight illuminator (3) and PC (4) for analyzing the images of the sample (5). The backlight used in the measurements allows to highlight shape of the hole (figure 3b) and thus measure its internal diameter. In order to measure the rollover area width, additional collimated axial lighting was used to illuminate the

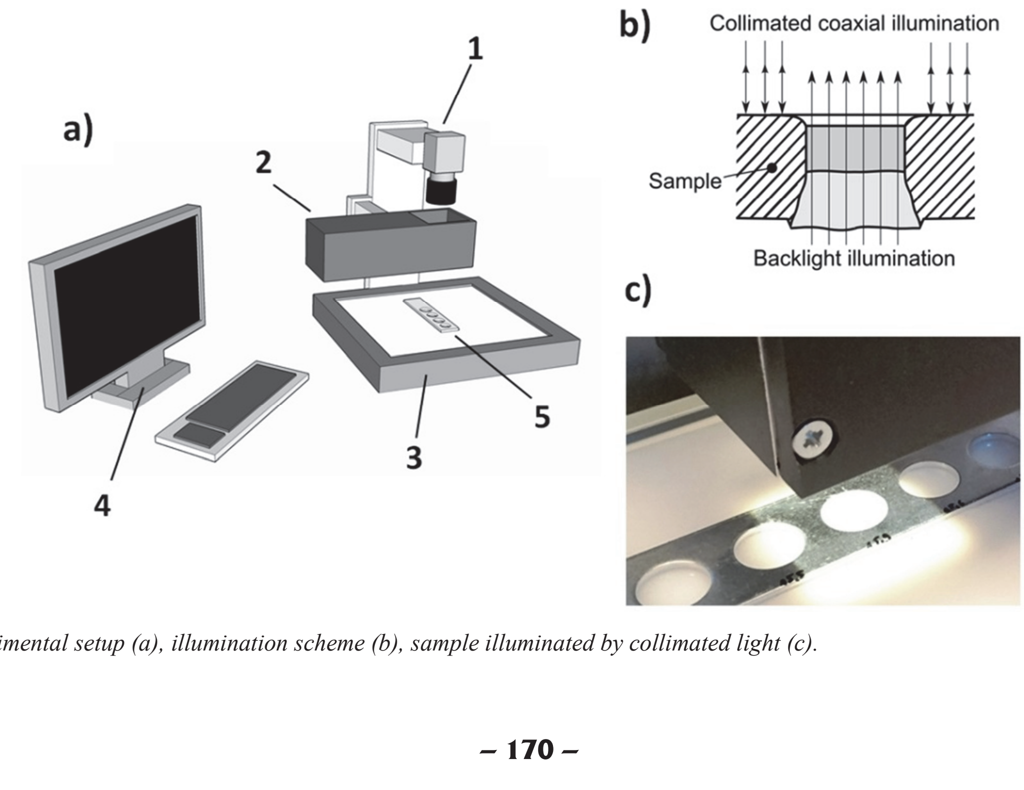

***Fig. 3.** Experimental setup (a), illumination scheme (b), sample illuminated by collimated light (c).*

object from the rollover side. The basic feature of this light is to highlight any irregularities in the surface of a flat sheet, which allows to extract the rollover area on the edge of the hole.

As a result of the simultaneous use of both types of illuminations, images with black ring of the rollover area was obtained as it could be seen on figure 4. The rollover area analysis was based on measuring the width W_r of the rings by means of the software developed in the LabView environment.

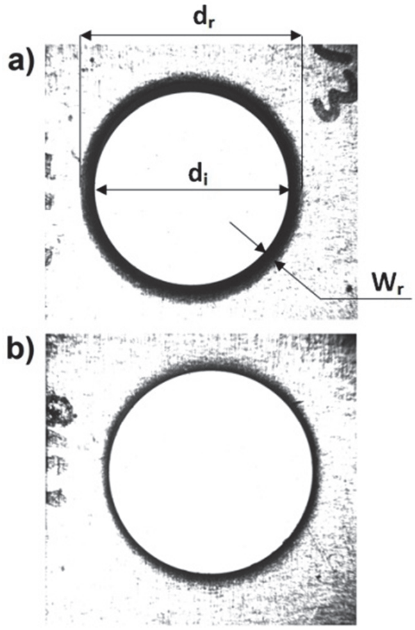

Fig. 4. *Hole images recorded by the vision system for rollover width W_r of 1,1 mm (a) and 0,6 mm (b).*

The rollover area measurement in LabView begins with detecting the center of the hole visible in the image as a white area limited by a black ring. Next, along the straight lines spreading out radially from the center of the hole, edge searching was performed (figure 5). The angle between these lines was 0,2°. Two types of edges were detected along each line. The first one with the descending slope which is the edge of the hole in the sheet and the second with a ascending slope representing the outer edge of the rollover area. Points coordinates lying on the same straight line, spreading out radially from the center of the hole are paired together. For each of the pair of coordinates corresponding to the inner and outer edges of the rollover area, the distance was calculated. A median has been determined from calculated distances, which is at the same time the width of the ring W_r.

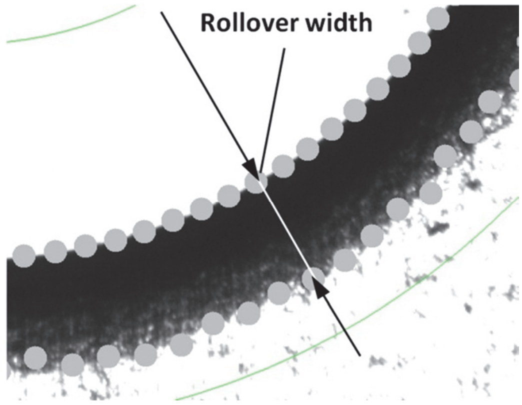

Fig. 5. *Rollover width measurement.*

The described method of the rollover measurement works very well for perfectly flat sheets. Unfortunately, when the illuminated surface is not perfectly flat, or a small non-perpendicularity of the sheet surface to the optical axis of the vision system occurs, the angle of the collimated light reflection change. This change reduces the contrast between the rollover area and the flat surface of the sample. This leads to wrong edge detection at the border of these two areas, which is shown in figure 6.

In order to eliminate the negative influence of uneven light distribution on the sample surface, the recorded holes images were pre-processed (figure 7). In the first stage, the contrast was locally increased. This operation based on dividing the image into small blocks and increasing the block contrast based on the local histogram. This operation preceded the local threshold. Local threshold also works with small image blocks. Based on the pixels brightness distribution in analyzed block a value of 0 or 1 is assigned to the analyzed pixel. After this step, the sample image contained only black (0) and white (1) pixels. In the next step, an erosion operation was performed to remove small texture elements from the flat surface of the sample. The last operation was dilatation, which restored the original width of the rollover area - this width was reduced after the erosion operation. The pre-processed image was subjected to the edge detection algorithm.

Figure 8 shows the operation of the algorithm based on local threshold and the edge detection of the rollover area for a perfect flat and slightly curved sample. The obtained rollover edge detection resolution was 0.02 mm.

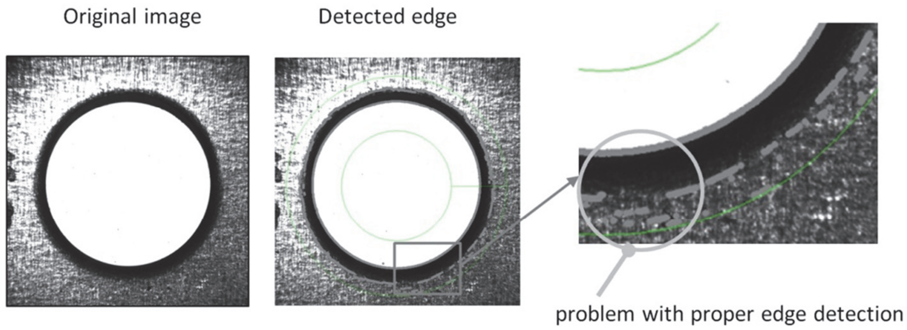

Fig. 6. Measurement problem for imperfect flat surfaces.

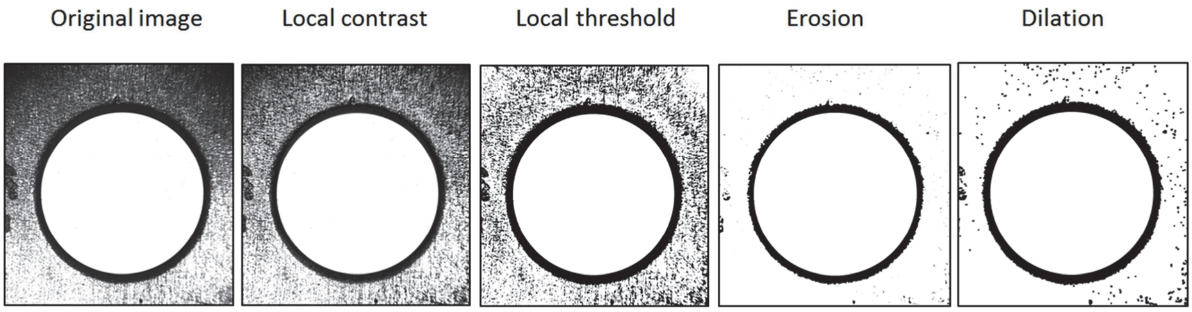

Fig. 7. Pre-processing of the sample image.

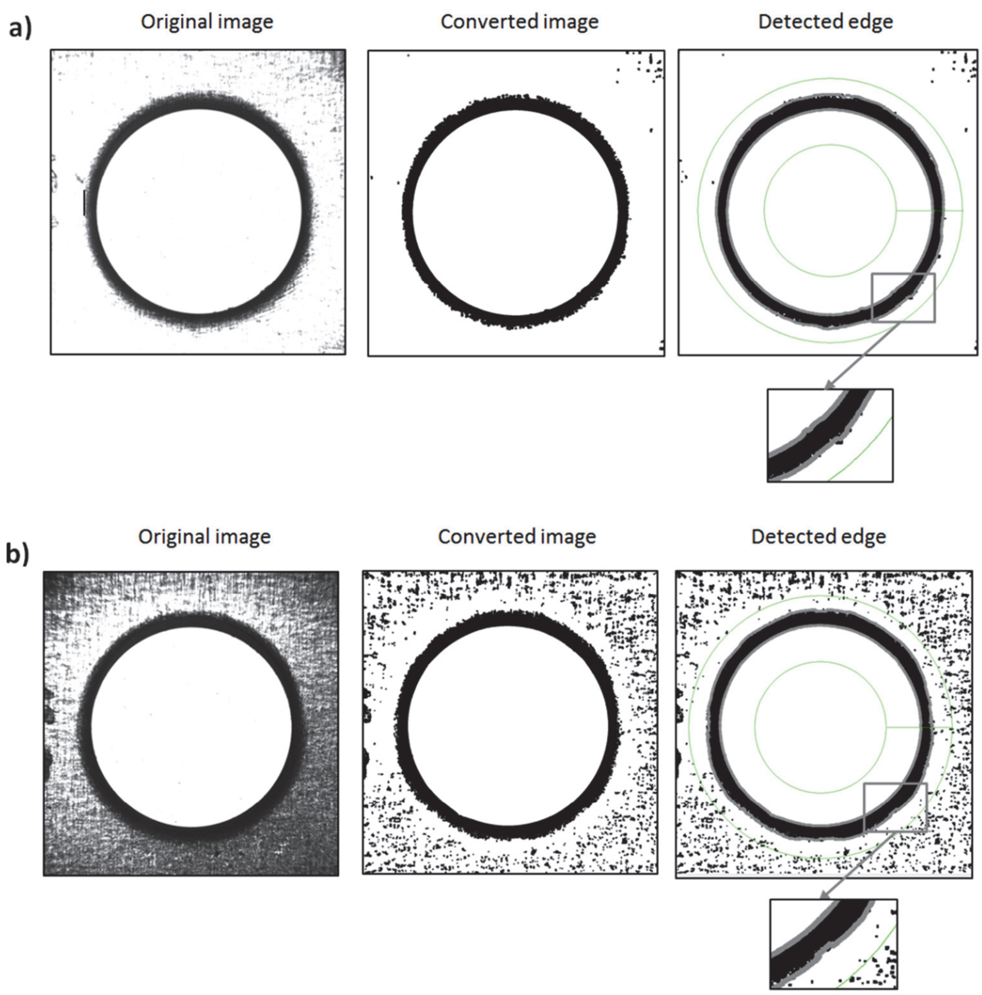

Fig. 8. Rollover area detection on pre-processed image for perfect flat (a) and slightly curved sample (b).

4. RESULTS

Clearance influence evaluation on the rollover width was carried out for aluminum sheet 1050 with a thickness of 1 mm and 2 mm. A die with a cutting edge diameter of 16 mm and a set of punches with the different diameters of the working parts (shown in table 1), were used for cutting holes. Tools and sample specimens are shown in figure 9. In order to verify the proposed method, some of the specimens were made of slightly curved sheet.

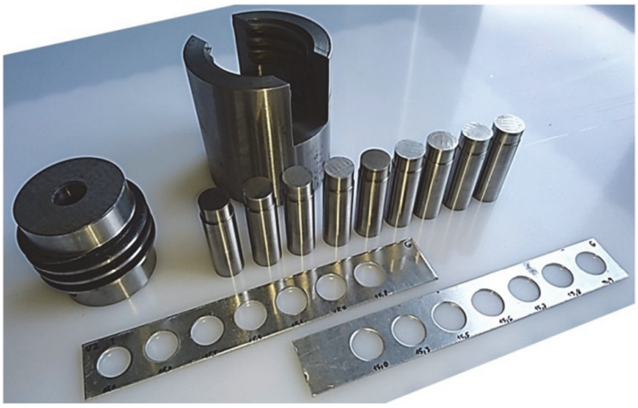

Fig. 9. *Cutting tools and selected specimens.*

Based on the punches and the die geometry, the clearance per side in mm and clearance in relation to the sheet thickness in % were determined. For each tool set, three cutting operations were made on a every sheet. Figure 11 presents the rollover area width in the function of clearance related to the sheet thickness of 1 mm. The graph shows that there is a non-linear dependence between the mentioned parameters. It should be noted that for the same tool sets, only small differences were found between the widths of the rollover area. It means that the width of the rollover area is strongly related to the clearance.

Figure 12 shows the rollover area width in the function of clearance related to the sheet thickness, this time of 2 mm. Also in this case the results repeatability obtained by the same tools geometry is high. The single deviating measuring points are connected with a part of the specimens that were made of slight curved sheet. It was found that the sheet unflatness causes measurement errors during the analysis of the rollover area by means of proposed method.

Table 1. *Tools dimensions*

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

Selected specimens were measured on a digital microscope (Morawiński et al., 2013) to determine the accurate rollover profile (figure 10b). These measurements were used to verify the widths of the rollovers obtained by the vision system. A comparison for different clearance values of 2 mm sheet obtained by the microscope and vision system is shown in figure 10a. The differences visible on the figure 10a result from two reasons. The first is the number of measurements. Microscopic measurements were made in 4 places and video measurements averaged the result from the whole perimeter of the hole. The second is the unevenness of the rollover width at the various points around the hole's perimeter. They mainly result from curved sheets and defects occurring in the place of piercing. Obtained results confirmed the measurements correctness carried out by proposed method.

Figure 13 shows the dependence of the rollover width on the clearance per side given in mm. Clearance used in millimeters allowed for a direct comparison of the rollovers widths obtained for aluminum sheet 1050 with a thickness of 1 mm and 2 mm. Small differences in the width of the rollover area for the same tool parameters indicate that the thickness of the sheet has weak influence on the rollover width.

Verification measurements were made on the basis of the conducted tests. The verification measurement was based on the rollover areas analysis for 6 holes and previously obtained dependences determining the clearance. Table 2 presents real clearance obtained based on tool measurement and the calculated clearance determined based on obtained curved (figure 12) and the rollover width measurement by means of vision system. The maximum clearance error per side reached 0.08 mm.

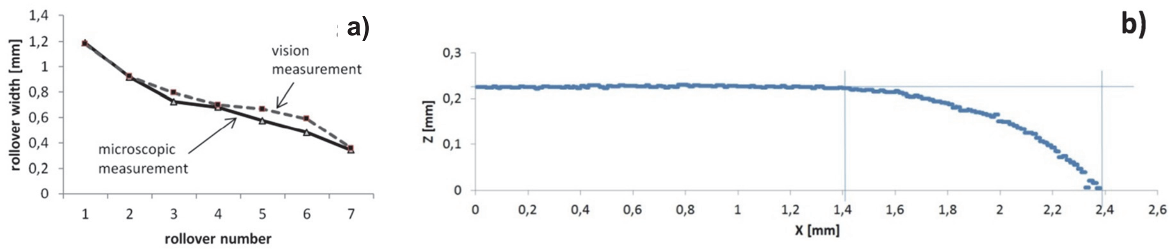

Fig. 10. A comparison for different clearance values of 2 mm sheet obtained by the microscope and vision system (a), specimen exemplary profile obtained by means of digital microscope (b)

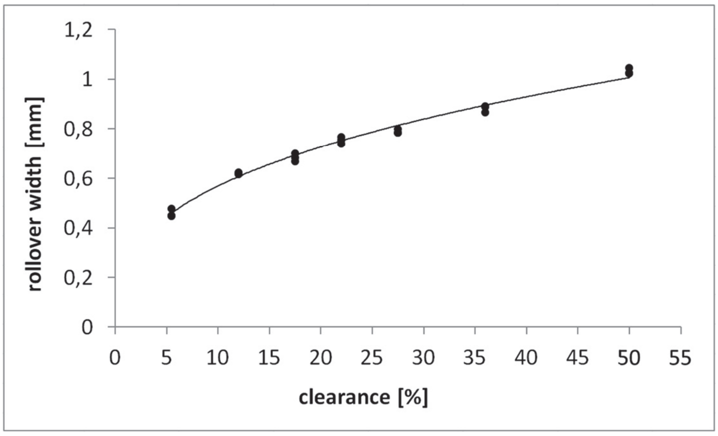

Fig. 11. Clearance-rollover width curve for A1050 with 1 mm thickness.

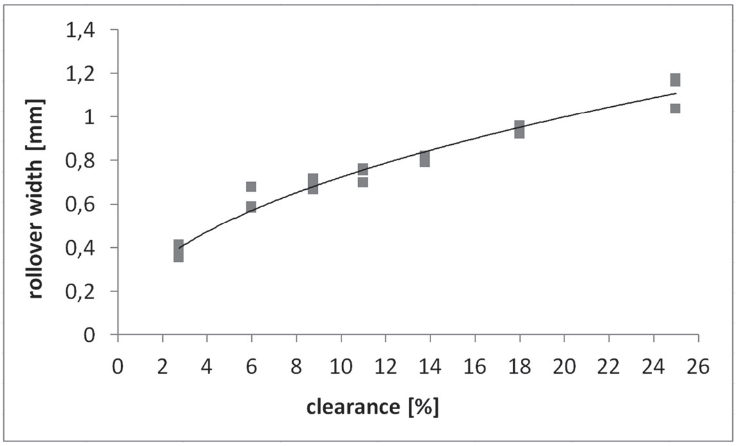

Fig. 12. Clearance-rollover width curve for A1050 with 2 mm thickness.

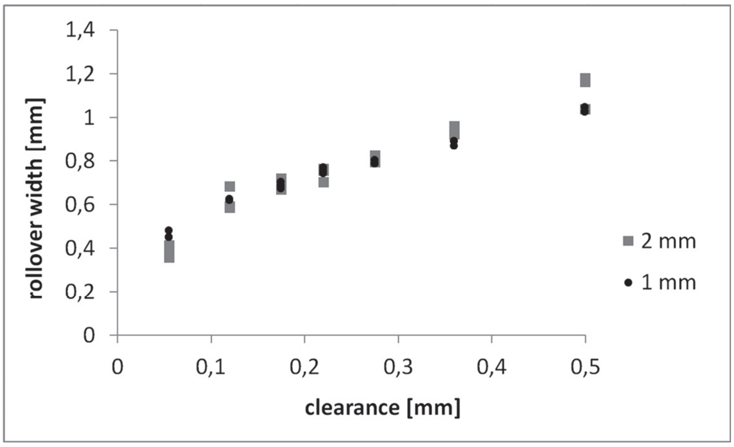

Fig. 13. Clearance-rollover width relationship for 1 mm and 2 mm thickness A1050 sheets.

Table 2. *Real and calculated clearance for 2 mm sheet obtained from the relationship for 2 mm sheet*

No.	1	2	3	4	5	6
Real clearance on side [mm]	0,47	0,33	0,33	0,22	0,12	0,12
Calculated clearance on side [mm]	0,39	0,29	0,30	0,21	0,16	0,16
Real clearance [%]	23,50	16,50	16,50	11,00	6,00	6,00
Calculated clearance [%]	19,61	14,55	15,16	10,61	8,21	8,22

Table 3. *Real and calculated clearance for 2 mm sheet obtained from the relationship for 1 mm flat sheet*

No.	1	2	3	4	5	6
Real clearance on side [mm]	0,47	0,33	0,33	0,22	0,12	0,12
Calculated clearance on side [mm]	0,49	0,33	0,35	0,21	0,15	0,15
Real clearance [%]	23,50	16,50	16,50	11,00	6,00	6,00
Calculated clearance [%]	24,53	16,41	17,35	10,73	7,59	7,60

As shown in figure 13, the width of the rollover area for sheets with a thickness of 1 mm and 2 mm is similar. For this reason, the dependencies obtained from the analysis of 1 mm flat sheet metal were used to determine the clearance for sheet with thickness of 2 mm. The comparison of the real clearance and clearance calculated using the proposed method is presented in table 3. The maximum error in determined clearance was only 0.03 mm in this case. This is close to the obtained measurement resolution. It shows that to determine the clearance for sheets of similar thickness, only one of them could be used for clearance-rollover width curve determination. An additional increase in measuring accuracy can be obtained by increasing the number of measurements for different clearance quantities.

5. CONCLUSIONS

Based on the carried out research, the following conclusions were made:

- There is a relationship between the measured width of the rollover W_r and the clearance,
- The vision measurement of the hole by means of axial and backlight illuminations enables fast and accurate evaluation of its diameter and rollover width,
- Proposed method give the best results for perfectly flat sheet. In case of slightly curved sheet the obtained results are less accurate,
- Information about rollover width allows to determine the clearance value in the cutting process, based on which the quality of the cutting hole surface can be estimated,
- The rollover width after the cutting operation is similar for 1 mm and 2 mm thickness sheets,
- Evaluation of the clearance for sheets of similar thickness can be made, with good approximation, based on dependencies determined only for one of them,
- To confirm the obtained results more tests should be carried out for various materials and sheet thicknesses.

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SZYBKA OCENA LUZU W PROCESACH WYKRAWANIA OTWORÓW Z WYKORZYSTANIEM TECHNIKI WIZYJNEJ

Streszczenie

Procesy wykrawania są jednymi z najczęściej stosowanych w obróbce plastycznej. Parametrem istotnym z punktu widzenia przebiegu tego procesu jest luz. Wartość luzu rozumianego jako różnica pomiędzy średnicą otworu matrycy i stempla odniesiona do grubości blachy ma znaczący wpływ na jakość powierzchni rozdzielenia, wymiary otworu, możliwość wystąpienia zadzioru czy też wielkość zaokrąglenia na krawędzi powstającego wyrobu. Luz powiększa się wraz ze zużyciem narzędzi wykorzystywanych w procesie wykrawania, jego prawidłowa ocena umożliwia określenie momentu, w którym narzędzia te powinny zostać wymienione. W prezentowanej pracy proponowana jest metoda szybkiej oceny luzu bazująca na pomiarze geometrii gotowego wyrobu. Pomiary wykonywane są z wykorzystaniem systemu wizyjnego wyposażonego w specjalnie przygotowane oświetlenie pozwalające wyodrębnić obszar zaokrąglenia na krawędzi otworu. Wielkość zaokrąglenia jest następnie powiązana w wartością luzu.

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