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Analysis of Slitting of Aluminum Body Panels in the Aspect of Scrap Reduction

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1. Introduction

Modern manufacturing techniques are rife with problems related to ensuring the quality of manufactured products while minimising the cost of production and increasing process efficiency. In the 21stcentury, the production of new products must be subject to "*eco-design production*," which involves limiting negative impacts on the surrounding natural environment. The dominant components of this activity include the rational use of energy and environmental protection [3, 8, 9, 11]. In this regard, it is important to correctly design and realise technological processes. This paper concerns the improvement of slitting, a widely used technological process, and directly reducing the negative impact of this process on the surrounding environment. Slitting is a sheet metal-, metal alloy- or foil-cutting process that uses circular knives. Industries use slitting to split wide coiled sheets into narrower widths or for the edge trimming of rolled sheets [2, 4]. Modern product design and manufacturing often utilises a wide variety of materials, including aluminium alloys, to reduce vehicle weight [12, 13]. However, aluminium alloys often display differing technological behaviour due to differences in their mechanical and surface properties and mass density when subjected to slitting operations. The mechanism of separation in slitting is often considered a result of fracture initiation from both the upper and lower knife cutting edges. If the technological process parameters are suitable for the material being cut, these fractures will spread towards each other and eventually meet, causing complete separation. This mechanism of separation is often very hard to accomplish in the slitting of automotive panels due to the difficulties encountered in precision process parameter settings [6, 10]. As a result, such defects can appear after processing in aluminium panels e.g., deformation, twisting, bowing, and defects of the sheared edge such as burrs and slivers). The accumulation of burrs and slivers on the knife, die and the work piece's sheared edge can result in an unacceptable surface finish and increases crap (Fig. 1). In addition to the higher cost of aluminium compared to steel, this problem is one of the main obstacles preventing the widespread use of aluminium in auto body panels.

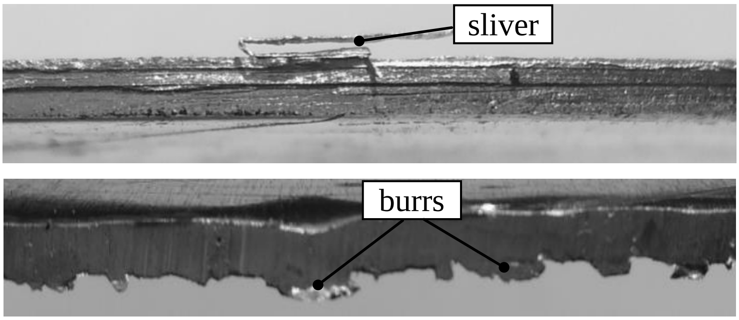

Fig. 1. A typical defects of the workpiece's sheared edge
Rys. 1. Typowe defekty napotykane na powierzchni przecięcia wyrobu

The objectives of this article are to study the influence of two main slitting technological process parameters (clearance and cutting velocity) on the quality of final product. No correlations or relationships currently exist in the literature between these parameters and the features of the sheared edge in the slitting process. This lack of understanding makes it difficult to predict the quality of the final product based on the process conditions. The results obtained from this study can be used by industry to reduce scrap formation in the auto body panel production cycle.

2. Experimental procedure

The experimental research is conducted on the test stand shown in Figure 1 using a KSE 10/10 slitting machine. This machine consists of two rotary knives driven by the engine. The contact between the knives and sheet is considered non-sliding contact that uses a polyurethane roll, which move the sheet in the horizontal direction. The sheet is clamped by a sheet holder, and a cant and rake angle (Fig. 2) are applied to the upper knife. The clearance, defined as the distance between the upper and lower knife cutting edges in the horizontal direction, is set by a clearance regulator. The slitting velocity is set by a knob with a scale.

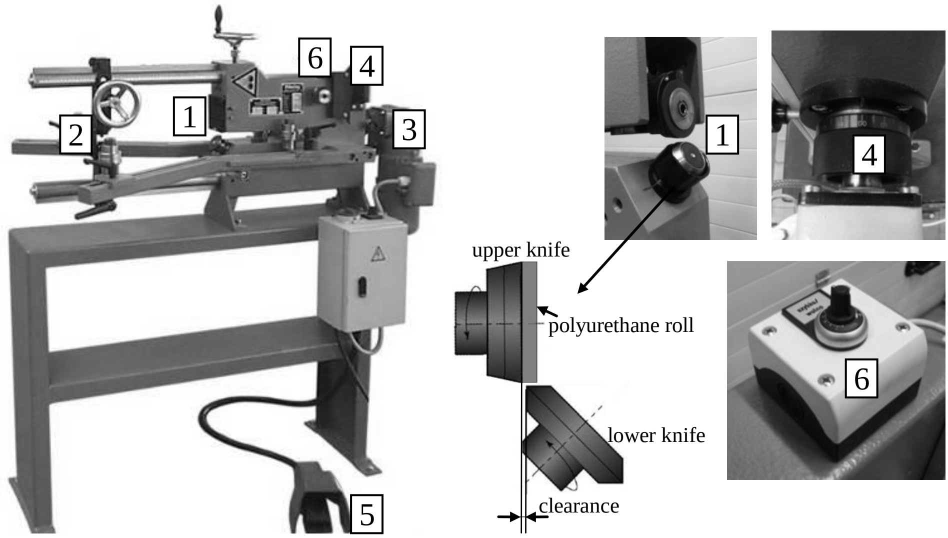

Fig. 2. Schematic view of the slitting equipment: 1 – knives, 2 – sheet holder, 3 – engine, 4 – clearance regulator, 5 – drive pedal, 6 – slitting velocity regulator
Rys. 2. Schemat stanowiska badawczego: 1 – noże, 2 – podtrzymka arkuszy, 3 – silnik, 4 – gwintowane gniazdo ze skalą do regulacji luzu, 5 – pedał napędu, 6 – regulator prędkości cięcia

The clearance between the shearing edges and slitting velocity are varied to simulate the different slitting conditions in our experimental study. The experiments are executed for the slitting velocities v = 3, 7, 17, 27, and 32 m/min and clearances c = 0.03, 0.05, 0.09, 0.13, and 0.15 mm, with no lubrication. The length of the sheet shearing line is l = 300 mm. Aluminum alloy AA6111-T4 measuring 1.5 mm thick, which is often employed for exterior panels in the automotive industry, is used to simulate typical production conditions. The material's tensile properties in the longitudinal direction are listed in Table 1.

Highly localised shear deformation takes place in the sheet during the slitting process due to the sharp knife edges, leading to ductile fracture. Consequently, the cutting of the sheet leads to a typical sheared edge profile in the work piece that can be separated into four zones: roll-over, burnish, fracture and burr (Fig. 3). The quality of the final product is determined based on the size of these zones. A good shear edge quality is correlated with a maximum burnished zone size and minimum rollover and fracture zone sizes and burr height.

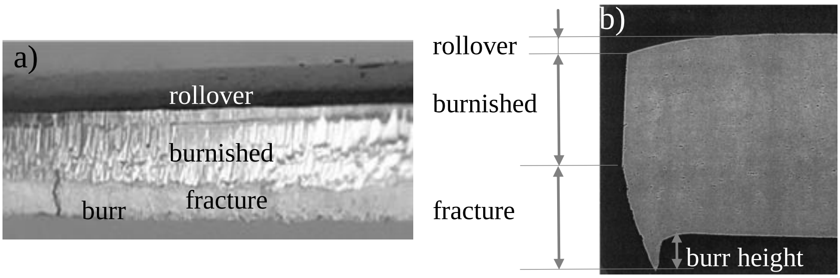

Fig. 3. Typical sheared edge profile with marked zones: a) front view, b) cross-sectional view
Rys. 3. Typowy profil powierzchni przecięcia wyrobu z oznaczonymi strefami: a) widok z przodu, b) przekrój poprzeczny

Table 1. Tensile properties of the investigated material
Tabela 1. Własności badanego materiału wyznaczone w próbie rozciągania

Material	Y.S. (MPa)	U.T.S (MPa)	Total elong. (%)	Uniform elong. (%)	*n*-Value
AA6111-T4	190	310	23	21	0.19

3. Results and discussion

Fig. 4 present characteristic features of the sheared edges of interest viewed by "Vision Engineering" optical microscopy. The values of the zones (Fig. 3) are measured from the specimens at different locations over the cut edge in the *z*-direction, averaged and presented in Fig. 5.

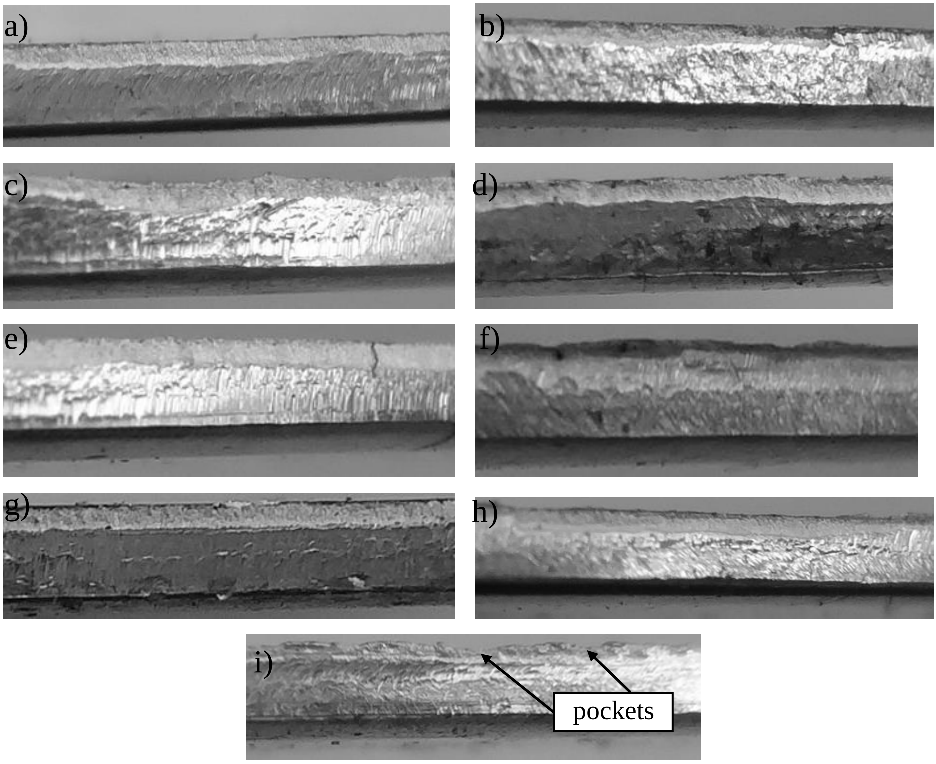

Fig. 4. Characteristic features of the sheared edges under study: a) v = 7 m/min, c = 0.05 mm, b) v = 27 m/min, c = 0.05 mm, c) v = 7 m/min, c = 0.13 mm, d) v = 27 m/min, c = 0.13 mm, e) v = 3 m/min, c = 0.09 mm, f) v = 32 m/min, c = 0.09 mm, g) v = 17 m/min, c = 0.03 mm, h) v = 17 m/min, c = 0.15 mm, i) v = 17 m/min, c = 0.09 mm

Rys. 4. Charakterystyczne cechy wybranych powierzchni przecięcia: a) v = 7 m/min, c = 0,05 mm, b) v = 27 m/min, c = 0,05 mm, c) v = 7 m/min, c = 0,13 mm, d) v = 27 m/min, c = 0,13 mm, e) v = 3 m/min, c = 0,09 mm, f) v = 32 m/min, c = 0,09 mm, g) v = 17 m/min, c = 0,03 mm, h) v = 17 m/min, c = 0,15 mm, i) v = 17 m/min, c = 0,09 mm

Fig. 5a shows the effect of the clearance and slitting velocity on burr height. The general trend seen in the light alloys during the shearing process is for the burr height of the work piece to increase with increasing cutting clearance [6, 10]. There are differences, though, in the relative rate of burr height increase with clearance. Increasing the clearance from c = 0.03 mm (2% of the sheet thickness) to c = 0.09 mm (6%t) increases the burr height for the analysed slitting velocities.

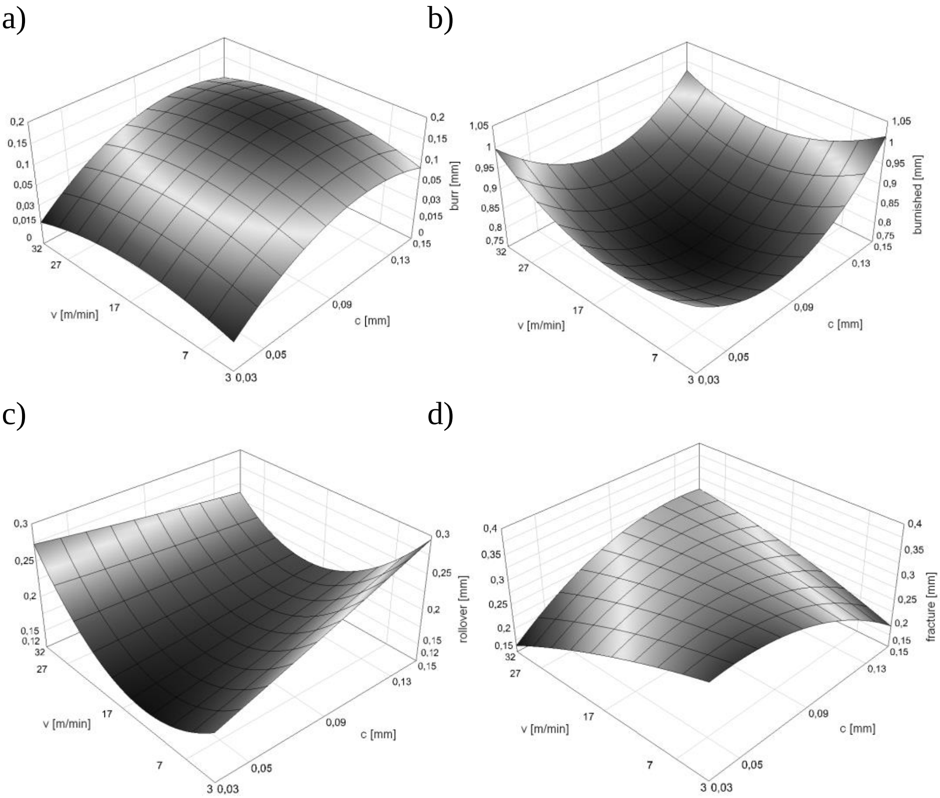

Fig. 5. Influence of the slitting velocity and clearance on the size of each zone: a) burr, b) burnish, c) rollover, and d) fracture
Rys. 5. Wpływ prędkości cięcia i luzu na wartości stref: a) zadzioru, b) gładkiej, c) zaokrąglenia, d) chropowatej (pękania)

When the clearance is set at c > 6%t, the burr height decreases. The highest burrs are obtained when the middle range of velocities is used (v = 17 m/min) and when c = 6%t. The height of the burrs in this case is non-uniform along the line of cutting, with some deep pockets that can serve as stress concentrators if stretching is applied parallel to this surface (Fig. 4i). Burrs can become separated from the cut part if there is a significant gradient of clearance along the shearing line. These local burrs are subjected to additional forces and torn off from the side of the sheared surface. When the clearance is set at c = 6%t, the burnished zone is reduced (Fig. 5b) and the velocity effect is reinforced. A high zone value (approximately 66% of the sheet thickness) is obtained when clearances of c = 2%t and c = 10%t are used. In these cases, the effect of velocity on the burnished zone is reduced. Interestingly, increasing the velocity results in a geometrical burnished area structure (Fig. 6). A high cutting velocity results in a plastic flow phase during slitting. This phase is less steady over a high range of velocities (v = 27–32 m/min) and causes the formation of unequal characteristics in the burnished zone (Fig. 6b).

a) b)

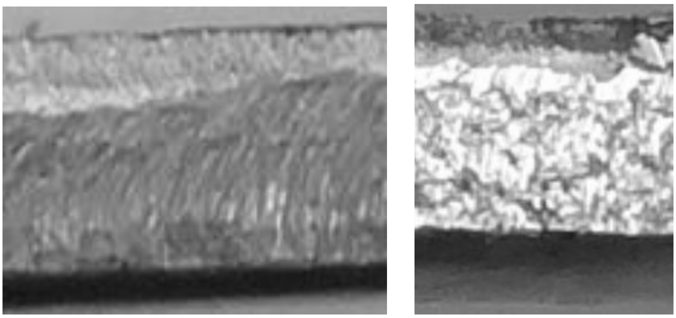

Fig. 6. Influence of the slitting velocity on the burnished zone's geometrical structure: a) v = 7 m/min and b) v = 27 m/min
Rys. 6. Wpływ prędkości cięcia na strukturę geometryczną strefy gładkiej: a) v = 7 m/min, b) v = 27 m/min

When analysing the mechanics of the slitting process, it becomes clear that the bending of the sheet during this process changes the overall symmetry of the shearing, creating additional tension near the upper-knife's shearing edge and additional compression near the lower knife edge. With increased clearance and slitting velocity, the bending of the sheet plays a more important role in the deformation mechanism. Analysing the trimming, guillotining and blanking processes [5, 7, 14] makes it evident that bending occurs for any gap, even at a clearance of zero. Assuming that the forces from the shearing edges are locally applied at the sharp edges, the bending moment should be equal to zero. However, the contact stresses are distributed along a certain area of the shearing edges and the work piece. Therefore, a bending moment exists even for zero clearance and has a strong influence on rollover formation. It is evident from the analyses that changing the velocity significantly influences the rollover (Fig. 5c). The highest values of this zone are obtained when (v = 3–7 m/min) or high velocities (v = 32 m/min) are used. At small velocities, increasing the clearance increases the rollover, while at high velocities, increasing the clearance decreases the rollover.

During the cracking phase, the initiated crack propagates through the rest of the material thickness by (initial) stable growth or by becoming unstable when it reaches a critical crack length before reaching the other side of the material [1]. Both stable and unstable crack propagation produce rough fractured surfaces in this aluminium alloy material family. It is notable that, within the fracture zone, there is a possibility of the crack taking multiple paths. Certain broken pieces constrained within the cutting clearance may fall in the way of the tool motion and become further sheared, resulting in a secondary burnish zone. Our experimental studies show that this zone does not occur for the analysed process parameters. The material's cracks proceed steadily and without multiple cracking paths. This research shows that the fractured area depends on both the clearance and slitting velocity (Fig. 5d), and the smallest fractured zone values are obtained using high cutting velocities and small clearances. For small cutting velocities, is possible to reduce the fractured zone when the clearance measures c = 10%t.

4. Conclusions

Slitting process experimental researches are conducted for aluminum alloy in this study by combining different process conditions. The objective of this work is to understand the effect of main process parameters on the quality of final product in an attempt to reduce scrap formation in the auto body panels production cycle. It has been experimentally observed that the cutting velocity and clearance have a significant influence on the quality of cut surface. The high quality of the product can be obtained not only for the one process configuration but more. The results obtained can be a great significance to the control of the properties of materials sheared and offer a possibility of an effective interference with the designing of the technological process and an adaptation of the technological quality to the adequate functional requirements and operating conditions. This will reduce energy consumption and negative impact of this process on the natural environment.

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Analiza procesu cięcia na nożycach krążkowych aluminiowych paneli karoseryjnych w aspekcie redukcji odpadu

Abstrakt

Współczesne techniki wytwarzania nie są pozbawione problemów związanych z zapewnieniem odpowiedniej jakości wytwarzanych elementów przy jednoczesnej minimalizacji kosztów ich produkcji jak i wzroście wydajności procesu. Mimo wielu publikacji na temat cięcia na liniach przemysłowych nadal występują problemy jeśli chodzi o dobór warunków procesu ze względu na wymaganą jakość wyrobu finalnego. Szczególnie dotyczy to obróbki stopów aluminium z których wykonuje się wiele elementów w przemyśle motoryzacyjnym, lotniczym i elektrotechnicznym. W pracy eksperymentalnie zbadano wpływ warunków procesu cięcia na jakość technologiczną aluminiowych paneli karoseryjnych, które najczęściej wytwarzane są ze stopów aluminium AA6111-T4. Określono wpływ luzu między krawędziami tnącymi narzędzi i prędkości cięcia na jakość powierzchni przecięcia tego materiału. Wykazano, że parametry te w bardzo dużym stopniu wpływają na jakość wyrobu finalnego, a ich nieprecyzyjny dobór może spowodować powstawanie defektów na powierzchni przecięcia (zadziorów, odchyłek kształtu, zaokrągleń) i wzrost odpadów po cięciu. Wyniki analiz mogą być wykorzystane do projektowania procesu cięcia stopów aluminium na nożycach krążkowych, a także być podstawą doboru parametrów procesu w aspekcie jakości technologicznej wyrobu. Pozwoli to na podniesienie ich jakości i zmniejszenie odpadów materiałowych. Spowoduje to bezpośrednio zmniejszenie zużycia energii i przyczyni się do ograniczenia negatywnego wpływu tego procesu na otaczające środowisko.

Słowa kluczowe: proces cięcia, stop aluminium AA6111-T4, odpady
Key words: slitting process, aluminum alloy AA6111-T4, waste