Purpose Oriented Clearance Selection in Blanking Process

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Abstract
Blanking is an important process in metal forming and manufacturing industry. It has a wide range of usage but the parameters governing the process are many. Amongst the other parameters clearance has the most dominant effects on both surface quality of the workpieces and the energy consumption of the whole system. So adjustment of the clearance has an utmost importance to serve the purpose of which aspect should to be achieved. However, achieving the desired outcomes by the adjustment of clearance often relies on lengthy trial and error procedures. So, modelling the process by FEM can save from time, money and labor. In this study, investigations were made by using FEM and experimental methods to observe the effect of clearance on punch load, cutting energy and surface zone distributions. AISI 304 stainless steel with 2 mm thickness was blanked by using a 300 kN hydraulic press under five different clearance values (1%, 3%, 5%, 10% and 20% of thickness) for experimental studies. Deform 2D was used for modelling of the process. The results showed that if the purpose is to achieve good surface quality, less than 5% clearance should be used. If punch loads are the main concern, more than 5% clearance should be used. Also the proposal of the cutting energy parameter and an optimal clearance value for AISI 304 was given in the scope of the work.

Keywords: Blanking, Clearance, Punch load, Surface quality.

1. Introduction

Blanking is a major process and has a wide variety of usage in sheet metal processing and forming applications. The process can be described as the perforation of the workpiece which was placed between an upper die (punch) and a lower die. The general aspects of the process seem simple but there are many varieties that determine the energy efficiency and production quality of the process.

The main parameters can be stated as the punch-die clearance, cutting velocity, material and thickness of the workpiece, kinematics of the press, tool material and geometry.

These parameters, single or combined, have drastic effects on the energy consumption of the process and on the quality of the workpieces (blanks).

For many years, researchers have tried to determine the effects of some of these parameters and related outcomes in the blanking process by experimental and numerical (Finite Element) methods. The experimental methods have been mainly about punch-die clearance [1, 2, 3], tooling and wearing of the components [4, 5, 6, 7], and cutting velocity [8, 9, 10, 11, 12, 13]. The researches that follow numerical methods have been mainly focused on the simulation of the whole process, investigating the parameters and try to foresee the outcomes [14, 15]. Prediction of the optimum clearance value for a given sheet material and thickness [16, 17, 18, 19], prediction of sheared edge quality [20, 21, 22] and prediction of burr formation [23, 24, 25, 26] have been the main topics in numerical methods for blanking process.

The results of these studies pointed out that amongst the other parameters; punch-die clearance has the most influence on the whole process. The change in clearance alters many major outcome parameters that vary from punch load and tool wear to the overall surface quality and distribution of the zones on the blanks surfaces.

However, there is a big uncertainty about the punch-die clearance. The main problem is the values that were given in different studies. The prediction of ideal clearance or the effects of clearance on other outcomes that were given in the studies are only for specific conditions. Also, taking one aspect and try to optimize the clearance specifically to achieve that aspect is not a right way because of the intricate nature of the process. From the combined results of the researches, it can be understood that clearance can be chosen in the range of 1%-20% of the workpiece thickness. In a process where the tooling has to be precise, tolerance limits center around ±0.01 mm and only a minor flaw or change in the value of one parameter can alter many outcomes, this enormous gap of clearance selection values are highly irrational.

To clarify the effect of clearance on various parameters, 5 different clearance values (1%, 3%, 5%, 10% and 20%) were used to blank round parts from AISI 304 stainless steel with 2 mm thickness. Investigations were made by using FEM and experimental methods to observe the effect of clearance on punch load, cutting energy, zone distributions and surface quality.

2. Finite Element Model

Deform-2D package was used to make the FEM models. The program uses a FEM code based on an implicit Lagrangian computational routine and defines the process as axisymmetric on a 2D plane so modeling only one half of the tooling is enough for executing the runs [19].

The half of the setup can be seen in Figure 1. The model consists of four parts; the punch, workpiece, a blank holder to hold the workpiece for unwanted bending during process and a lower die. The blank diameter of the lower die was 10 mm. Punch diameters were changed according to the clearance values.

The workpiece was considered as a plastic object whereas the punch, blank holder and the lower die as non-deformable rigid bodies. 10000 isoparametric quadratic elements with 0.03 mm element size were used as the element meshes of the workpiece. Also by using equally spaced mesh density windows, mesh elements were tried to be equally concentrated around the deformation zone which was given in Figure 2.

During the course of the process, mesh density windows follow the path of the punch and discretize the element number of meshes in a specified limit inside the boundaries of the windows.

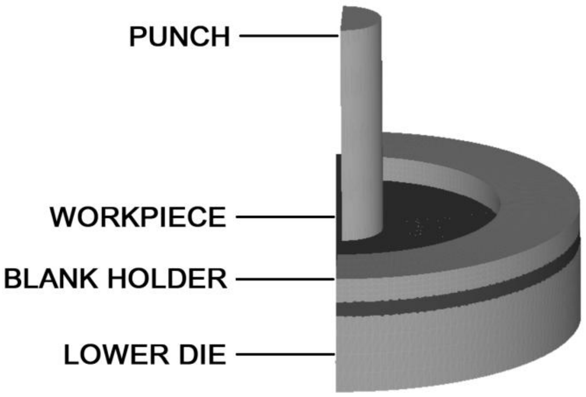

Figure 1. The blanking set up for simulations

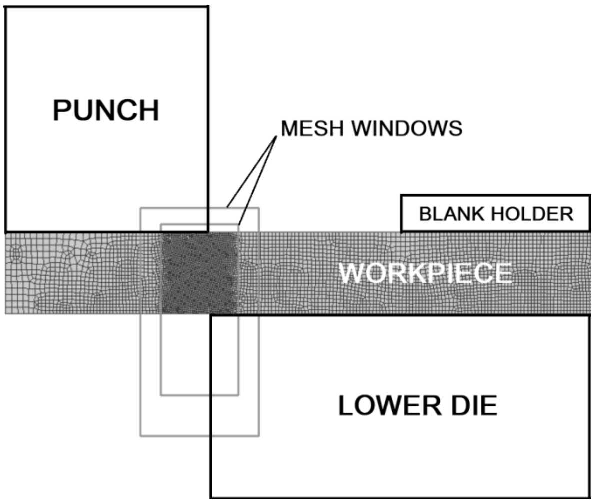

Figure 2. Mesh distribution on the workpiece

Friction between the workpiece and tools were assumed to follow constant shear friction expressed in Equation 1 as;

$$f_s = mk \ , \qquad (1)$$

Where f_s is the frictional stress, k is the shear yield stress and m is the friction factor. This states that the friction is a function of the yield stress of the deforming body.

In a blanking process, large plastic strain generation happens in the narrow shear zone. It was assumed that the material was isotropic and yielding occurred according to the Von Mises yield criterion expressed in Equation 2 as;

$$\bar{\sigma} = K\bar{\varepsilon}^n \ , \qquad (2)$$

where $\bar{\sigma}$ is the effective stress, $\bar{\varepsilon}$ is the effective strain, K is the material constant, and n is the strain-hardening exponent [27].

The fracture criterion was chosen as Normalized Cockroft and Latham which states that the fracture occurs when the effective strain reaches the critical value expressed in Equation 3 as;

$$\int_{0}^{\varepsilon^{-f}} \left(\frac{\sigma^*}{\bar{\sigma}}\right) d\bar{\varepsilon} = C \ , \qquad (3)$$

where σ^* is the maximum principal tensile stress, ε^{-f} the fracture strain and C is the critical value. The effective stress and effective strain are defined as $\bar{\sigma}$ and $\bar{\varepsilon}$. The critical value C for AISI 304 is free from the effects of working operation and found by executing a tensile test.

As mentioned before; during the blanking, large plastic strain generation occurs that leads to the shearing of the workpiece in the vicinity of the punch and lower die. This zone is called the shear band. The stress ratio $\left(\frac{\sigma^*}{\bar{\sigma}}\right)$ is assumed to be constant throughout that band where the deformation is highly concentrated. Therefore this assumption may be implemented into Cockroft and Latham criterion and approximated by $\varepsilon^{-f} = C$ at the shear band. This approach postulates that a crack initiation occurs at the point of the sheet whose effective strain first reaches the fracture strain of the work material [18].

Element deletion method was chosen to simulate the crack propagation on the workpiece. The adjustments were made that in each step, element deformation is taken into account and element deletion occurs when the critical values are reached.

3. Experimental Setup and Material Properties

The designed die set and its components were given in Figure 3. The die set consists of six components; upper die block (1), punch (2), punch holder (3), blank holder (4), lower die (5) and lower die block (6).

Heat treated AISI 4140 were used in the manufacturing of the guide rods on the upper block, punches and the lower die. The blocks and holders were made of St 37 steel.

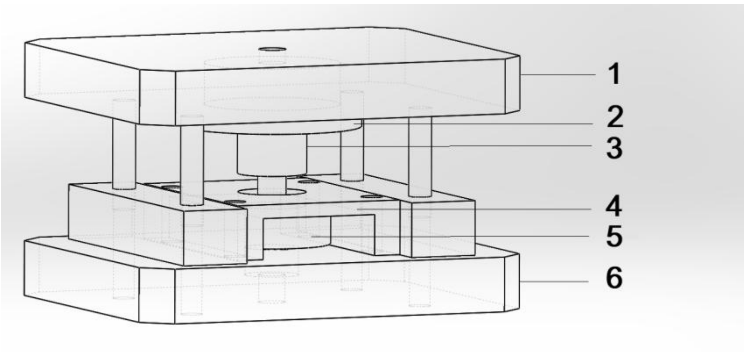

Figure 3. The die set for experimental studies

All experiments were made under a constant punch speed of 0.01 m/s. A hydraulic press that has 300 kN capacity was employed to execute the blanking processes.

AISI 304 stainless steel was used for both simulation and experimental studies. AISI 304 is a well-known and generic stainless steel that has wide range of usage from daily use tools like hypodermic needles to heavy industry areas like nuclear applications [28].

The flow curve of AISI 304 were directly taken from Deform 2D’s database to assure the consistency of experimental and simulation studies. The flow curve of AISI 304 can be seen in Figure 4.

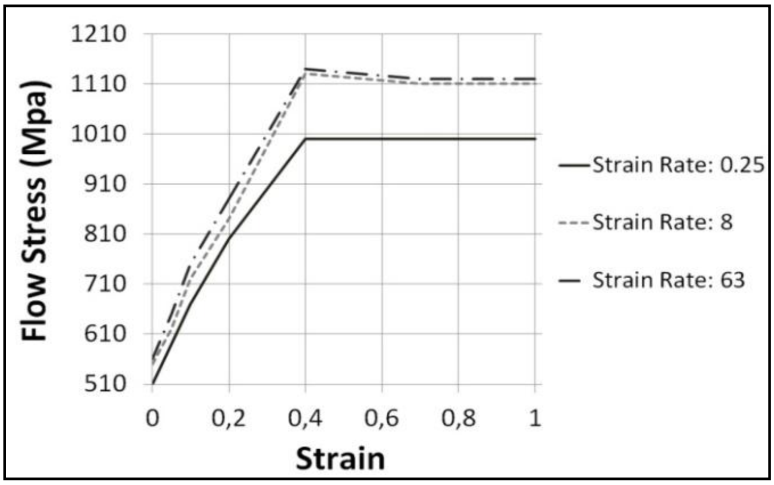

Figure 4. The flow curve of AISI 304 according to strain rate

The lower die was manufactured having a 10 mm blank diameter. Five different clearance values (1%, 3%, 5%, 10% and 20% of thickness) were used and punch diameters were calculated according to the clearance formula expressed in Equation 4 as;

$$C = 100\frac{D_m - D_p}{2t}(\%), \qquad (4)$$

Where D_m is the lower die diameter, D_p is the punch diameter and t is the workpiece thickness.

The calculated diameters for punches were given in Table 1. The clearance between the punch and die has to be precise so punches are manufactured within the tolerance limit of ±0.01 mm without any radiuses at the edges.

Table 1. Manufactured punch diameters according to clearances

Clearance	Punch Diameter
1 %	9.96
3 %	9.88
5 %	9.80
10 %	9.60
20 %	9.20

4. Results and Discussion

4.1 Zone Distributions and Punch Load

When a material is blanked, the sheared part gets some distinct zones on its edge. These zones feature different characteristics and the distribution percentages of them are the measure of surface quality for that part. This zones are; rollover zone; which is the bending depth of the workpiece before punch edge cut through the workpiece surface, shear zone; which is the burnished part with low roughness created when the material is locked between the punch and lower die until the crack occurs, crack zone; the zone started at the end of shear zone which is the result of crack propagation leading to full rupture. Crack zone has a rougher surface than shear zone and the desired situation is where rollover and crack zone depths are minimum and sheared zone depth is maximum, possible. Burr formations should also be mentioned. Burr formations may occur at the end of the crack zone if the adjustments of parameters could not be adjusted properly and they are especially the main reasons for extra cleaning operations. Figure 5 shows the zone distribution on the microscopic image of a blank.

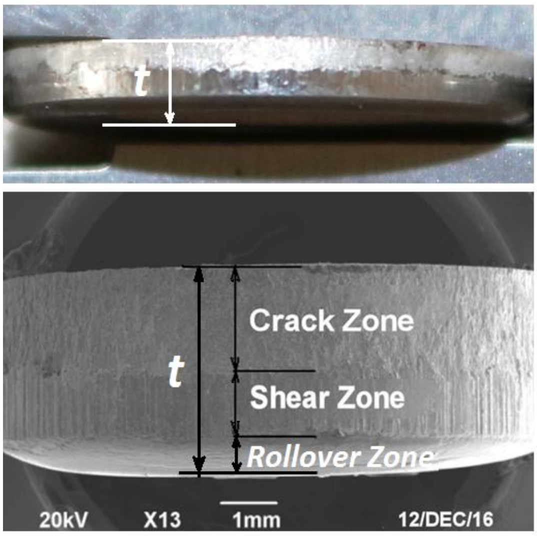

Figure 5. Zones shown on a blank (t=2 mm, clearance= 5%)

Comparison of the FEM image and the microscopic image of the cut blank were given in Figure 6.

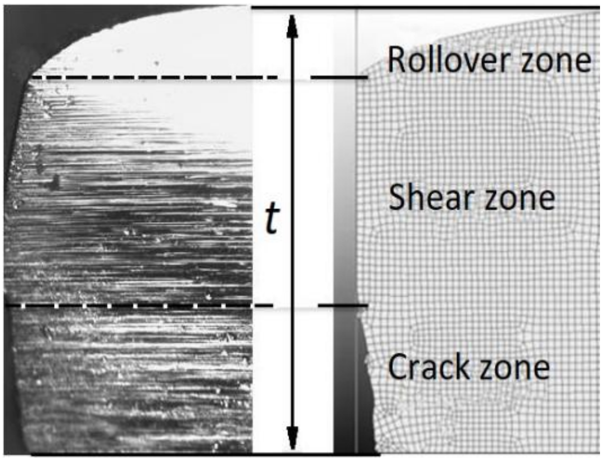

Figure 6. Comparison of FEM and cut blank images (t=2 mm)

Clearance is the most important parameter which can change the distribution depths of the zones along with other parameters like punch load, cutting energy and tool wear. The FEM images of the blanks under five clearances were given in Figure 7.

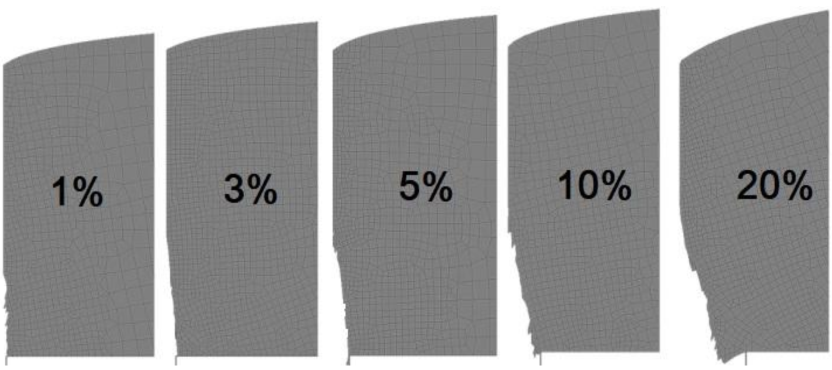

Figure 7. FEM images of the blanks under different clearances.

Too tight clearance can increase the shear zone and give good surface quality or too loose clearance has the advantage of lower punch load but lacks the surface quality. The main problem here is the selection of clearance and its effects on a parameter while sacrificing another parameter. So the selection has to be done for the desired outcome or to find an optimal point which can ensure many outcomes but to do that, the process should be evaluated as a whole.

The percentages of zone distributions were given in Table 2.

Table 2. Zone distributions under different clearances

Zones (%)	Clearance				
	1%	**3%**	**5%**	**10%**	**20%**
Rollover	6.92	7.69	10.76	12.30	15.38
Shear	61.55	57.69	46.15	39.23	26.92
Crack	27.69	32.30	36.92	40.76	46.15
Burr	3.84	2.30	6.15	7.69	11.53

The distributions changed with changing clearance but to interpret the whole situation, punch load had to be investigated.

Punch load is another main outcome parameter in a blanking process. Punch load to shear a blank is not adjustable and it is a result of the process. But, minimum required punch load to cut the blank is simply calculated in Equation 5 as [29];

$$F = L * t * \tau , \qquad (5)$$

Where F is the blanking force (N), L is the forming circumference (mm), t is the strip thickness (mm) and τ is the shear strength (MPa).

Maximum punch load difference between FEM and experimental results for five clearances were given in Figure 8.

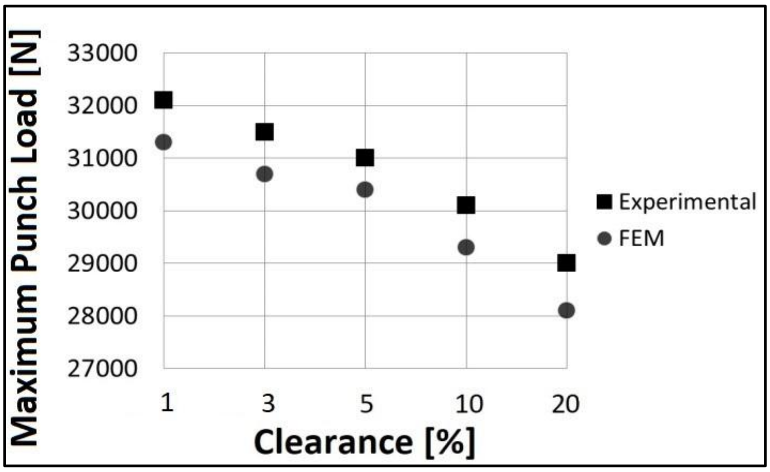

Figure 8. Maximum punch load difference between FEM and experimental results according to clearances.

Punch loads decrease with increasing clearances according to Figure 8 because of the increased touch length from the cutting corners that causes more bending moment under the same press load. This practically can be interpreted into usage of high clearances all times to save energy but the situation needs a combined look including the zone distributions to assess the situation correctly.

Tight clearance causes less material to be pulled in the die cavity and gets stuck between the punch and die. This situation increases the friction which also contributes to the increase in punch load aside from the effect of moment. Also, too much friction and metal to metal contact cause the edge and flanks of the punch get worn much more quickly but in terms of surface quality, a blank having a long shear zone and minimal burr at the edges can be manufactured. Also a warning has to be made that in case of too tight clearance, crack zone may have a more protruded surface than a tight clearance because of the formation of secondary cracks during the course of full rupture.

In the situation of too loose clearance, punch load decreases substantially and also the increased gap can save premature tool wearing due to much lower friction forces. But on the other hand, the surface quality degrades enormously because of the excess material pulled into the die cavity causing more rollover, lengthier crack zone and burr formation.

As it is evident from Table 2, when the clearance increases, shear zone percentage drops whereas rollover zone, crack zone and burr formation percentages increase. But for AISI 304 there was a slight difference in the generation of burr formation which also justified the too tight clearance theory. The burr formation percentage is much more for 1% clearance than 3% clearance. The main reason is the secondary cracks created during the full rupture.

4.2 Zone Distributions and Punch Load

Cutting energy refers to the ratio between punch load and stroke depth. Many studies take punch load [2, 8, 10, 11] as the sole energy saving parameter and try to make the adjustments to lower the punch load at its lowest level. However, during the blanking process, stroke depth has to be considered and the depth of this parameter is directly related to the clearance value. In this context, taking cutting energy as the main energy saving parameter is a much more valid approach. Also, cutting energy invalidates the wrong interpretation of "higher the clearance, lowest the punch load" perception because the ratio between punch load and stroke depth changes also with clearance. And, cutting energy doesn't follow a linear path as the blanking load that can be seen in Figure 8.

The change of blanking load and stroke depth for minimum (1%) and maximum (20%) clearances were given in Figure 9.

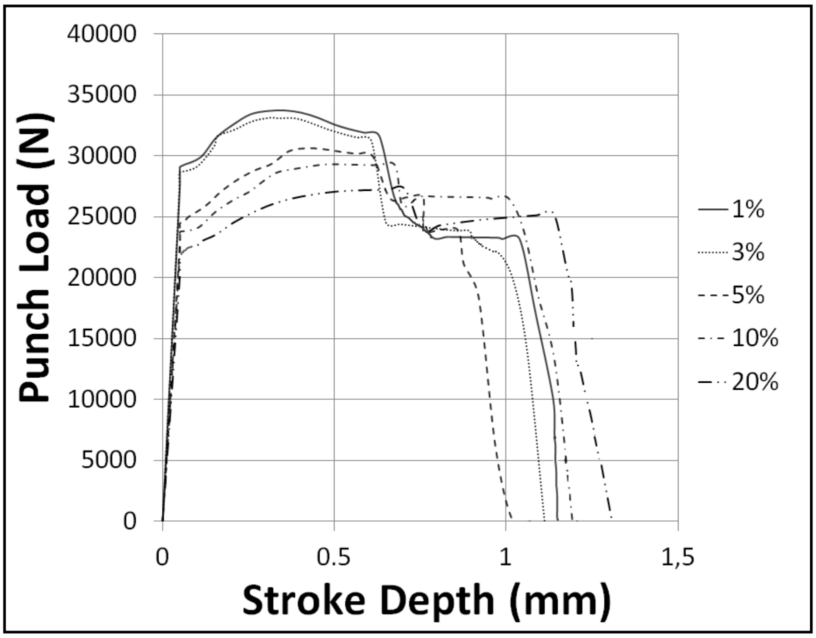

Figure 9. Punch load-stroke depth difference between two clearances

It is evident from Figure 9 that stroke depth changes along with punch load under different clearances and this situation alters the cutting energy values. The maximum cutting energy values for different clearances gathered from FEM analysis were given in Figure 10.

It can be seen that, the minimum energy for blanking 2 mm thick AISI 304 stainless steel was achieved when the clearance is 3% of the workpiece thickness. Through a combined interpretation, it can be assumed that 3% clearance is the optimal clearance where the energy conservation and good surface quality can be achieved at the same time.

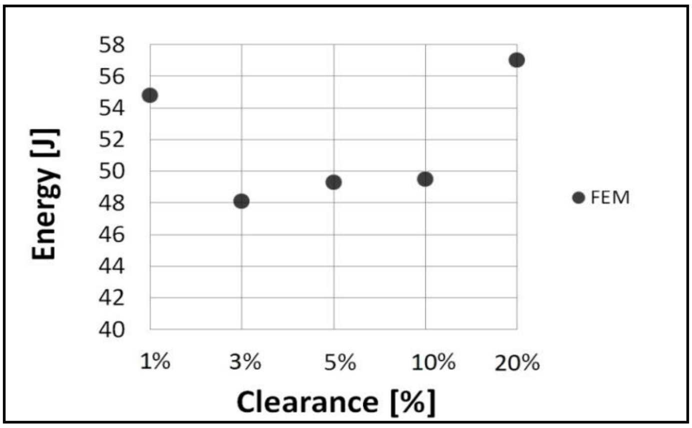

Figure 10. Cutting energy difference between clearances

5. Conclusions

In this study the blanking of AISI 304 stainless steel metal with 2 mm thickness was executed. Five clearance values (1%, 3%, 5%, 10% and 20%) were used to blank round parts. Investigations were made by using FEM and experimental methods to observe the effect of clearance on punch load, cutting energy and zone distributions. Findings were summarized below.

- Clearance has a dominant effect on many parameters. Punch load, stroke depth, cutting energy and zone distributions are directly related with clearance.
- Clearance selection should be based on the purpose of the outcome and should be assessed with the positive and negative relationship of other parameters.
- If surface quality is not a concern, then usage of higher clearances (more than 5%) can be suitable for the job in terms of lower punch loads and prevention of early tool wear. But it should not be forgotten that too much stroke depth increases cutting energy leading to more energy consumption and must be considered.
- If surface quality is a concern, usage of lower clearances (lower than 5%) have the advantages of increasing the shear zone and lowering the other undesired zones like rollover zone, crack zone and burr formations. But the friction and punch load rise due to the metal to metal contact in a narrow zone. This situation may cause early tool wear at the edges and flanks. Also in case of too tight clearance, the potential of secondary crack generation is high that causes protruded surfaces and must be considered carefully.
- Every workpiece material should have an optimal clearance value where both good surface quality and energy saving can be achieved. But to do that, cutting energy which is the ratio of punch load and stroke depth should be used instead of taking only punch load into consideration.
- The behaviors of different workpiece materials to the effects of clearance may show many similarities, but it should be mentioned that the results gathered from this study is restricted to only AISI 304 stainless steel. Specific studies should be made to reach to an exact conclusion if the workpiece material is different.

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