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EXPERIMENTAL ANALYSIS OF DIE CLEARANCE DISTRIBUTION IN A PRESSTOOL ASSEMBLY

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Summary

Shearing is one of the most widely used methods for manufacturing sheet metal components. Extensive research studies are currently being carried out in the field of tool making aiming at improving the quality of shearing. This paper analyses yet another issue arising from the production of sheet metal components. The distribution of die clearance in a progressive tool that produces sheet metal products is the focus of this study. The effect of uneven distribution of die clearance on the quality of shear is experimentally analysed. A methodology to control the uneven distribution of die clearance is also worked out.

Key words: *presstool, shearing, die clearance, progressive tool, sheet metal component.*

1. Introduction

Presstools are devices to produce sheet metal components in mass quantities using operations like punching, notching, lancing, bending, shaving, drawing, embossing, coining and trimming. Basically, punching operations consist of the sheet metal cutting by mechanical induction of shearing tensions using a rigid punch and die [1]. One of the most important requirements of the shearing process is the quality of the sheared edge, which is affected not only by the material characteristics but also by the process parameters such as the die clearance and the sharpness of the cutting edges [2-6]. The die clearance is the space between the male and the female cutting edges of a die set. For a blank to part cleanly from the material strip, there must be exactly the correct space between the cutting edges of a punch and a die. If too little clearance exists, secondary shear takes place, which results in poor quality of the blanked product [7]. Excessive clearance dishes the blank and produces long, stringy burrs all around the edge. The application of correct clearances will result in a blank free of burrs, and with the burnished portion of its edge extending to the greatest possible depth. The die clearance is calculated based on the feedstrip material and its thickness. Ideally, the die clearance is evenly distributed around the punch as shown in Fig.1 (a). In order to manufacture a presstool, tolerances are assigned to various dimensions of the presstool parts. Due to the cumulative effect of these tolerances, the condition of even distribution of die clearance can never be achieved in practice. The resulting distribution is shown in Fig. 1(b). The uneven distribution of die clearance affects the shearing action taking place during the descending of the punch. Experiments were conducted in this study to analyse the effect of uneven distribution of die clearance on the quality of the sheet metal product. Further, a methodology has also been worked out to control the uneven distribution of die clearance.

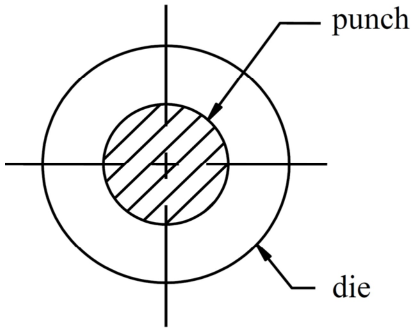


Fig. 1(a) Even distribution of die clearance

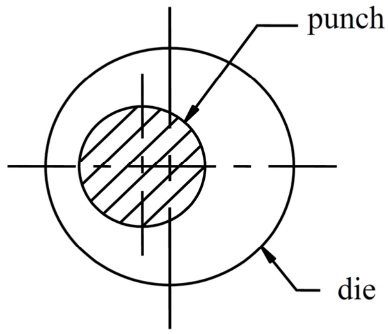


Fig. 1(b) Uneven distribution of die clearance

2. Effect of uneven distribution of die clearance

Due to uneven distribution, clearance becomes insufficient on one side of the punch and it is excessive on the other side as shown in Fig.2. The effect of uneven distribution of die clearance on the sheared edge of a blank is shown in Fig.3. On one side of the blank, burr is left due to excessive clearance while, on the other side, secondary shear takes place due to insufficient clearance. Even though the ideal condition of evenly distributed die clearance is not possible to achieve, the degree of unevenness can be controlled by defining a zone called 'minimum die clearance zone' as shown in Fig.4. This zone limits the offset of the punch with respect to the die so that a minimum die clearance is maintained on any side around the punch.

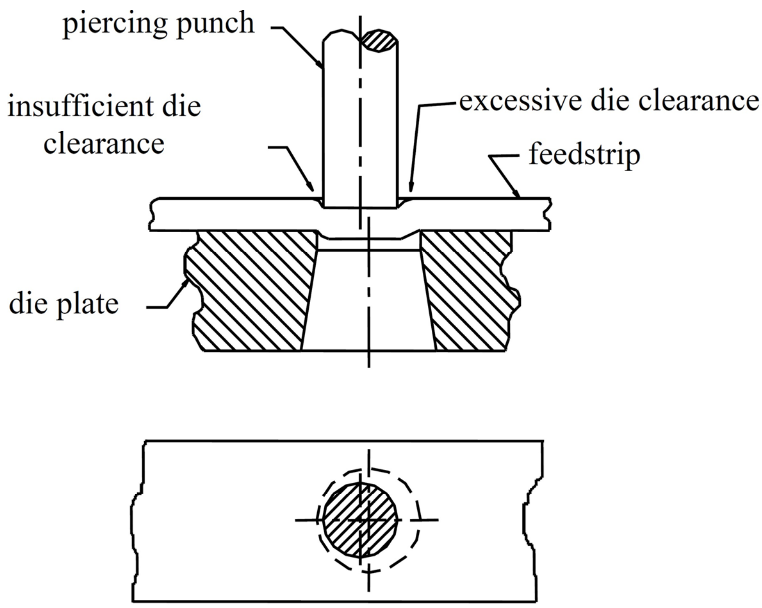


Fig. 2 Piercing in progress

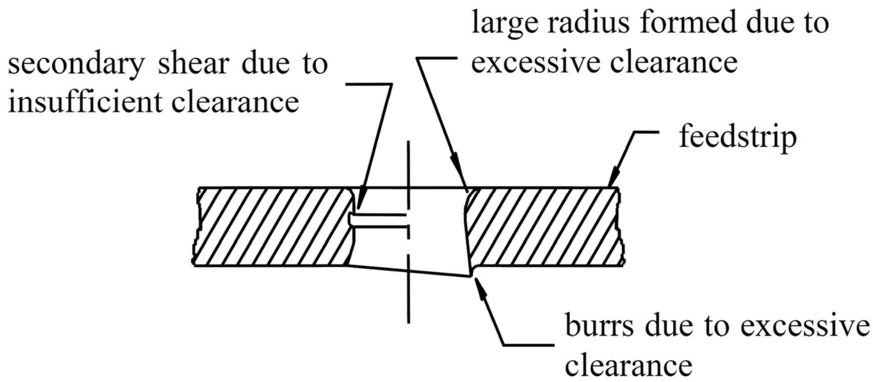


Fig. 3 Effect of uneven die clearance

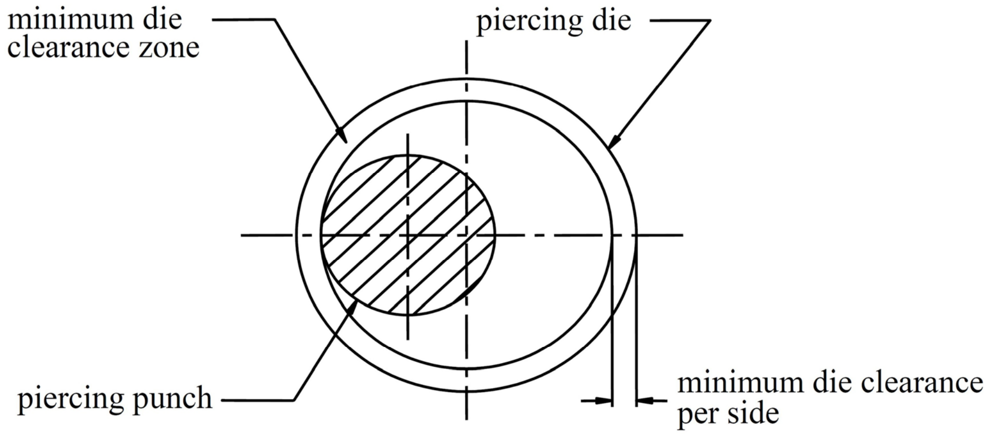


Fig. 4 Minimum die clearance zone

The value of the minimum die clearance is decided based on the service requirement of the component to be blanked using the presstool. If the component to be blanked is, for instance, a washer, the burr left out near the sheared edge, and the secondary shear produced on the other side will not affect the basic function of the washer. Therefore, the minimum die clearance assigned for the presstool that produces the washer can be less. On the other hand, the minimum die clearance should be greater for a critical product. Experiments are conducted to determine the value of the minimum die clearance for the current study.

3. Experimental determination of minimum die clearance

3.1 Manufacture of Presstool

The component considered for the current analysis is a link plate as shown in Fig. 5. It is made of SAE1055 steel. In order to determine the width of the minimum die clearance zone,

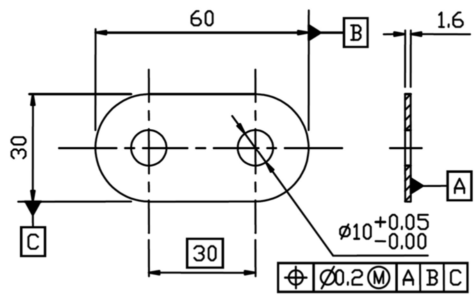


Fig. 5 Link plate

samples are produced by piercing the sheet metal with different die clearances. The samples are pierced by using the presstool shown in Fig.6. Its sectional view is shown in Fig.7. In order to align the axes of the punch plate, the stripper plate and the die plate holes, a locating

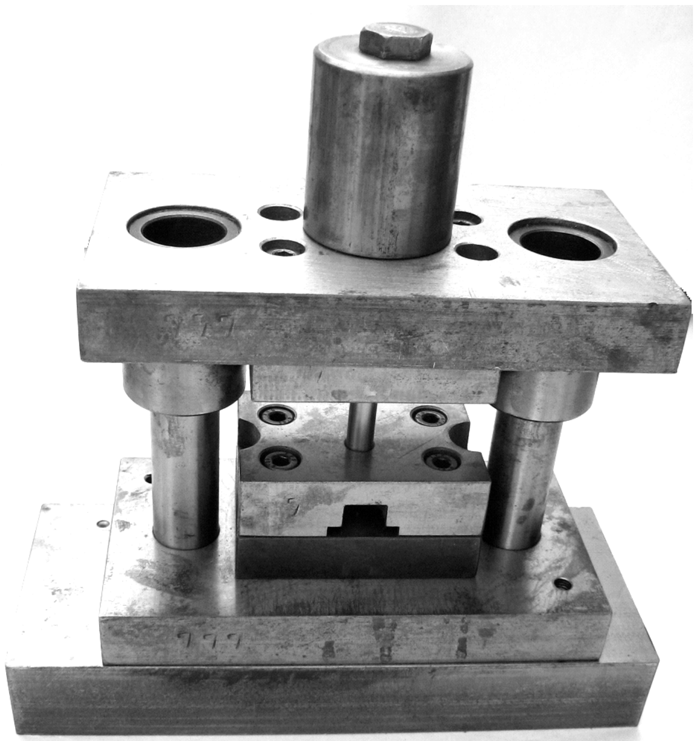


Fig. 6 Experimental setup

pin is used during the assembly. The locating pin shown in Fig.8 is inserted into the punch plate and it penetrates through the stripper and the die plates. The locating pin is inserted

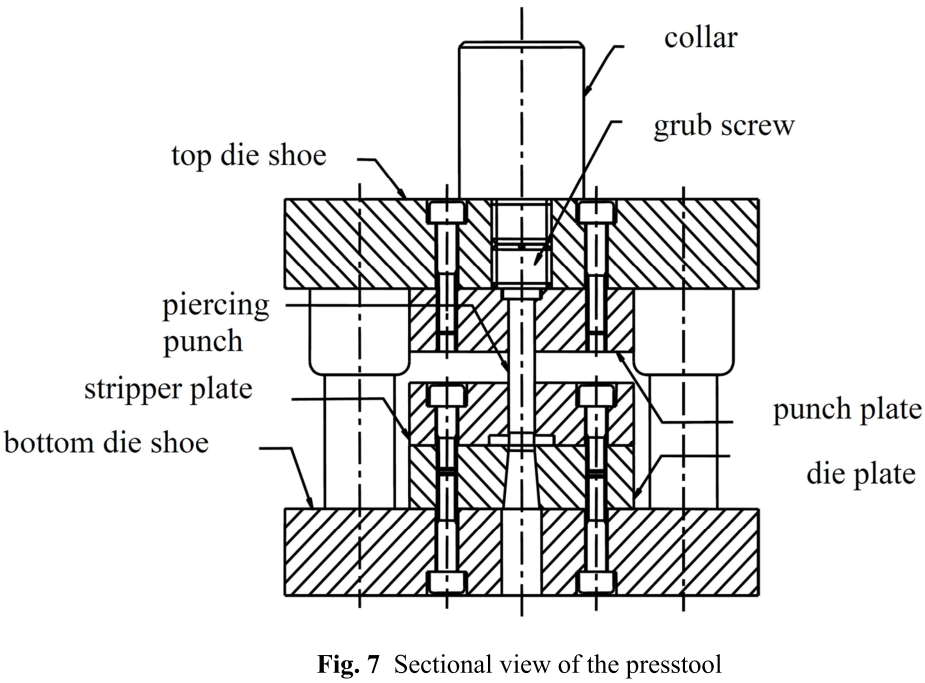


Fig. 7 Sectional view of the presstool

through the holes that are machined on these plates to fit the piercing punch. The fasteners of these plates are tightened in this condition thus ensuring proper alignment of the holes' axes. The locating pin is removed from the top of the upper die shoe without dismantling the three plates. The required punch is inserted from the top and it is held in place by a grub screw and a collar as shown in Fig.7.

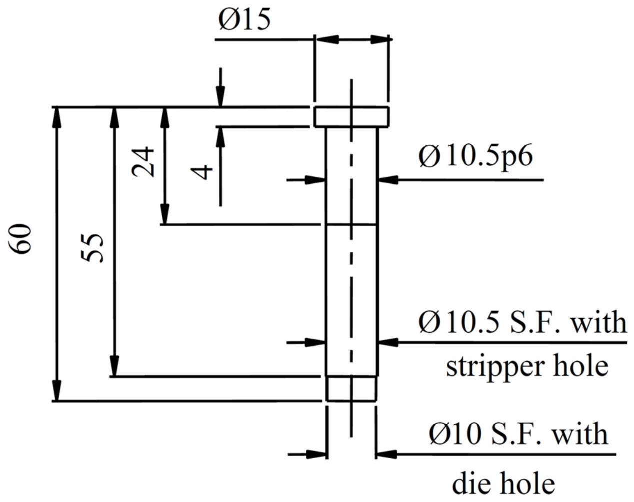


Fig. 8 Locating Pin

There are totally eight punches used in the experiment. The die clearance is varied from 1% to 6% of the feedstrip thickness using these punches. The value of the minimum die clearance is then determined from this range based on the outcome of the experiment. The sizes of the punches are listed in Table 1.

Table 1 Punch sizes for different die clearances

Die Clearance /%	Clearance per side /mm	Punch size ØP /mm
1	0.016	9.968
1.5	0.024	9.952
2	0.032	9.936
2.5	0.040	9.920
3	0.048	9.904
4	0.064	9.872
5	0.080	9.840
6	0.096	9.808

3.2 Preparation of Samples

Strips of 40 mm in length and 20mm in width are cut out of the rolling stock 1.6 mm thick. The material of the strip is SAE 1055, whose chemical composition is given in Table 2.

Table 2 Chemical composition of feedstrip material (in %)

C	Mn	P	S	Si
0.53	0.72	0.014	0.002	0.25

For analysing the quality of shear, the pierced samples are cut into two halves along the axis of the hole as shown in Fig.9 using the wire cutting operation. In order to expose the cut surface for microscopic examination, the samples are held in a cylindrical plastic holder using fillers as shown in Fig. 10. The cut surfaces are polished and etched to expose the cracks formed during the shearing operation. Intermediate and final polishing are done by using emery papers and rotating disc. Alumina powder and then a diamond paste of 0.5 micrometer in size are used on the rotating disc for final polishing. The etchant used on the polished surface is Nital, having a composition of 2-4 % nitric acid and 98-96% alcohol. A microscope with a magnification factor of 200 was used for observing the cracks. A camera attached to the microscope captures the cracks and the material flow during shearing. The intensity and the length of the cracks formed reveal the quality of the shear.

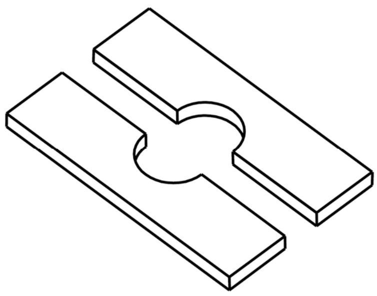
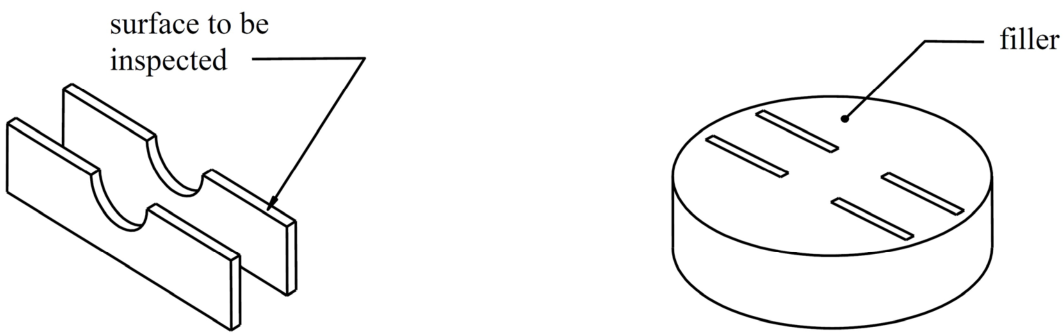


Fig. 9 Pierced sample cut for inspection



(a) Orienting the cut surface **(b)** Holding the halves in a holder

Fig. 10 Preparation of cut surface for microscopic inspection

3.3 Experimental Analysis of Pierced Samples

During the metal cutting process in the presstool, cracks are initiated from the punch and die cutting edges. If correct clearance is applied, the cracks ‘A’, originating from both ends, meet as shown in Fig.11 (a). Slug is separated from the feedstrip as the cracks meet. If the clearance is insufficient, the cracks originating from the cutting edges do not meet as shown in Fig.11(b). Consequently, a third crack ‘B’ develops between the previously formed cracks. Slug is fully separated from the feedstrip once the third crack completely joins the previously formed cracks. Since the third crack is formed halfway along the length of the previously formed cracks, a portion of the latter is left behind on the feedstrip. These residues are exposed by cutting the pierced samples across the hole and observed through the microscope after polishing and etching. The unwanted cracks weaken the sheet metal product during its working life.

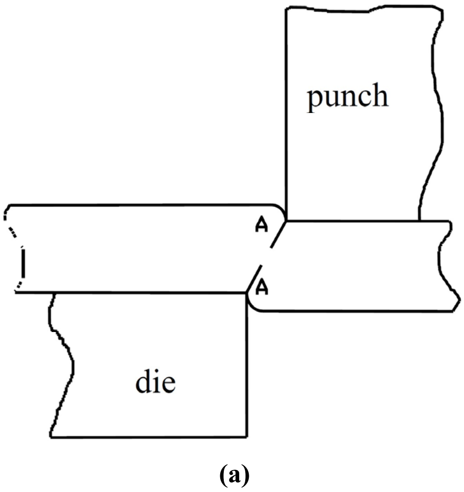


Fig. 11 Initiation of cracks during metal cutting with the application of (a) correct clearance and (b) insufficient clearance

The cut surface containing the cracks produced during the shearing process is schematically shown in Fig.12. The die clearance maintained per side is 1% of the feedstrip thickness. The cracks shown in the drawing are drawn not to scale. The cracks are photographed with a magnification factor of 200. The photographs of the cracks are shown in Fig.13. The arrow indicates the location of the crack. Similar analyses were done on the samples pierced with die clearances of 1.5, 2, 2.5, 3, 4, 5 and 6% per side.

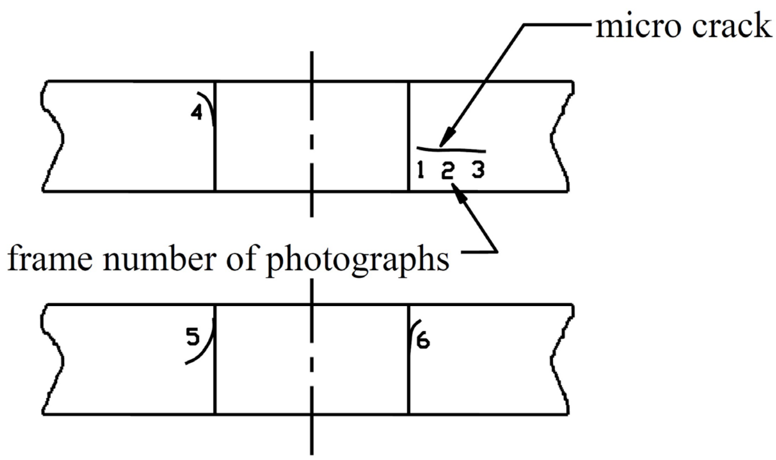
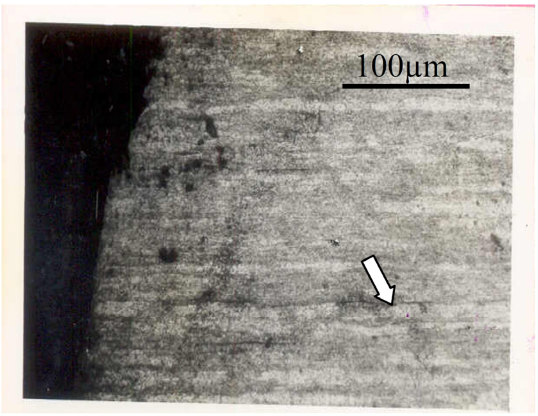
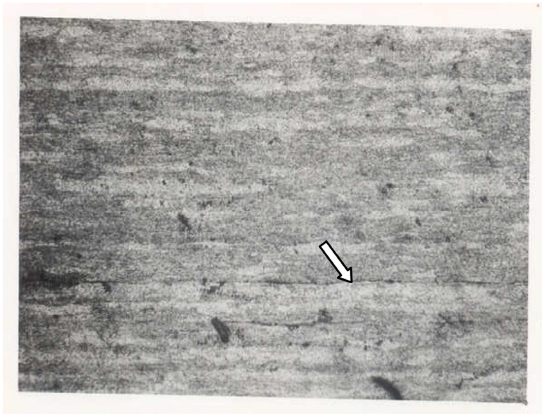


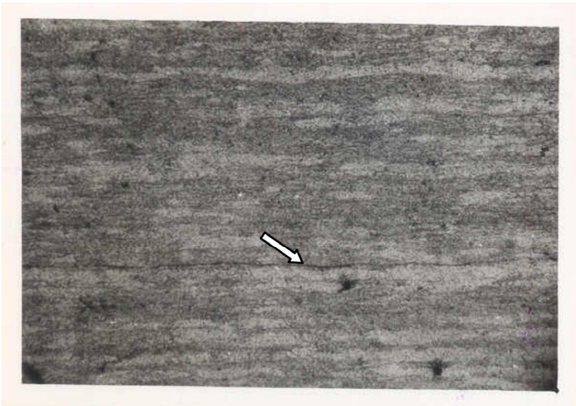
Fig. 12 Schematic representation of cracks formed on the sample pierced with 1% die clearance



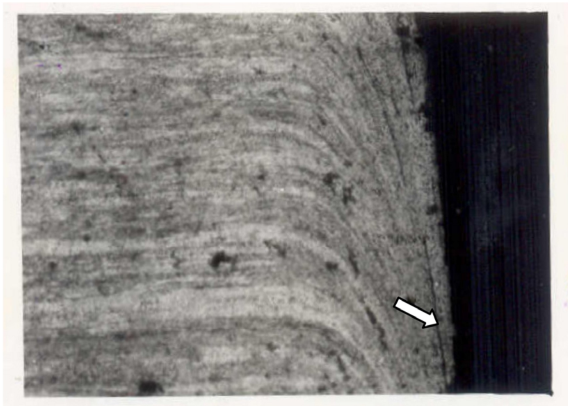
(a) Frame 1



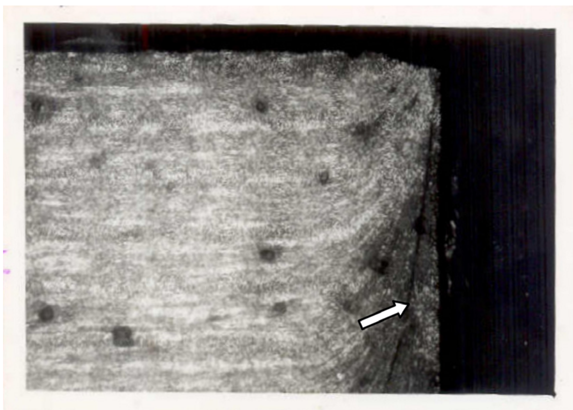
(b) Frame 2



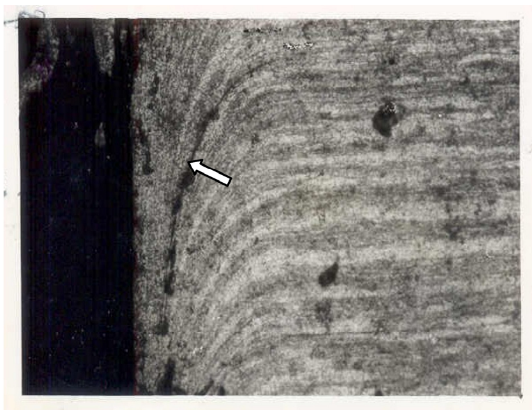
(c) Frame 3



(d) Frame 4



(e) Frame 5



(f) Frame 6

Fig. 13 Photographs of the cracks

Table 3 summarises the results of the microscopic examination of the pierced samples. It is observed from the experiments that the severity of the cracks is greater for smaller die clearances. The severity attains its worst condition at 2% die clearance. As the die clearance is increased from the threshold level of 2%, the cracks are reduced and they are at minimum on the sample pierced with 6% die clearance.

Table 3 Summary of microscopic analysis of pierced samples

Die clearance /%	Results of the analysis
1	Severe cracks are noticed. The cracks are lengthy.
1.5	Many cracks are exposed. They are scattered.
2	Too many cracks are noticed and they are scattered.
2.5	Many cracks which are shorter in length are noticed.
3	Few cracks are noticed.
4	Very few short cracks are noticed.
5	Short cracks fewer than that of 4% die clearance are noticed.
6	Very few, short and minute cracks are noticed.

3.4 Determination of Minimum Die Clearance

It has already been discussed that a minimum die clearance has to be maintained around the punches of the progressive tool in order to produce sheet metal products with the required quality. The minimum die clearance is chosen as one among different values of die clearances summarized in Table 3. The experimental results indicate that the minimum die clearance should be greater to get a better quality of shear. But the offset between the piercing punch and the die should be reduced to increase the value of the minimum die clearance as shown in Fig.14. Reducing the offset calls for tightening the tolerances of the presstool parts, which will result in an increase in the manufacturing cost of the presstool assembly. To strike a

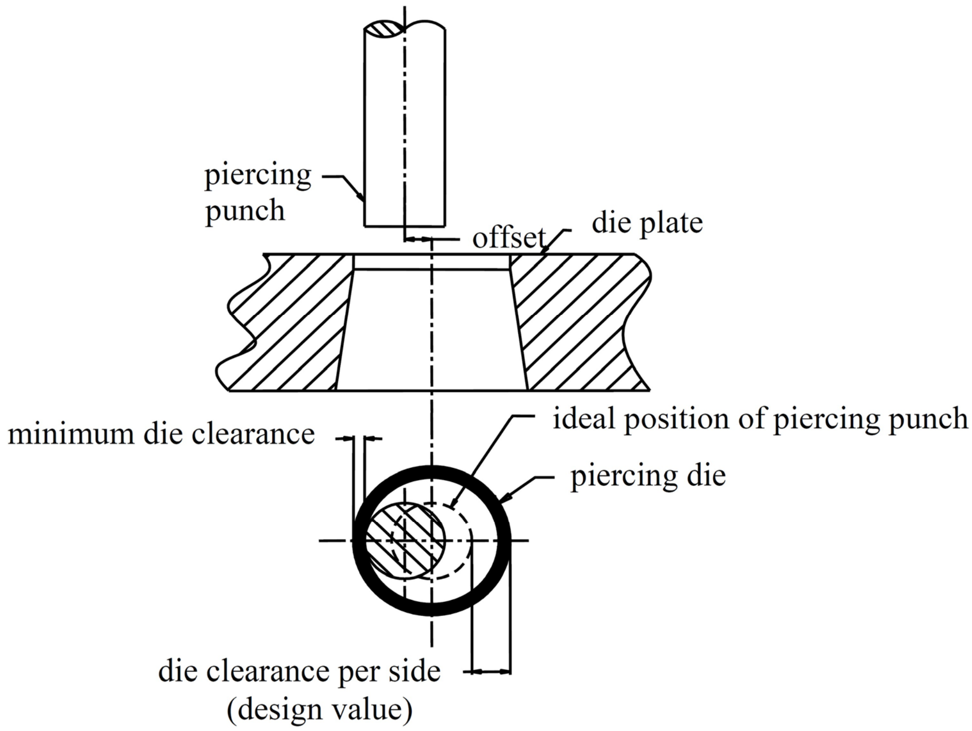


Fig. 14 Interdependence of minimum die clearance and offset

balance between the two conflicting parameters, the functional requirement of the sheet metal product should be analysed. As the minimum die clearance decreases, the residual cracks on the sheet metal product increase. These cracks, formed during the piercing operation, tend to grow during the working cycle of the sheet metal product if the product is subjected to tensile or compressive stresses. The minimum die clearance should be greater for highly critical products and it should be less for less critical sheet metal products. The product under consideration is a link plate and it is a part of a transmission chain assembly. The link plate is subjected to cyclic tensile stresses during its working cycle. Considering the criticality of the product, the minimum die clearance per side is chosen as 5% of the feedstrip thickness. Thus, the experimental analysis conducted in this study has been helpful in the determination of the width of the minimum die clearance zone taking into account the cost and quality of the sheet metal product. The tool design engineers can fix tolerances of a progressive tool assembly based on the methodology adopted in this study, if their primary concern is to produce sheet metal products with the required quality of shear.

4. Conclusions

Die clearance is one of the critical process parameters of sheet metal manufacturing. Extensive research studies are currently being carried out to determine the optimum value of die clearance for various sheet materials. A new approach has been discussed in this study to optimize the clearance evenly around the punches of a presstool. A zone called ‘minimum die clearance zone’ is defined in the space between the punch and the die members of the tool. Experiments were conducted in this study to determine the width of the ‘minimum die clearance zone’. An adequate selection of the width ensures that there exists an optimum range of die clearance all around the punches. This study also correlates the quantity and severity of microcracks that are developed in the vicinity of pierced holes with the distribution of die clearance.

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