Blanking and piercing theory, applications and recent experimental results

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Abstract. Blanking and piercing are manufacturing processes by which certain geometrical shapes are sheared off a sheet metal. If the sheared off part is the one required, the processes referred to as blanking and if the remaining part in the sheet is the one required, the process is referred to as piercing. In this paper, the theory and practice of these processes are reviewed and discussed. The main parameters affecting these processes are presented and discussed. These include: the radial clearance percentage, punch and die geometrical parameters, for example punch and die profile radii. The abovementioned parameters on the force and energy required to effect blanking together with their effect on the quality of the products are also presented and discussed. Recent experimental results together with photomacrographs and photomicrographs are also included and discussed. Finally, the effect of punch and die wear on the quality of the blanks is also given and discussed.

1. Introduction
Blanking and piercing are manufacturing processes by which engineering or industrial parts of certain geometrical shapes are sheared off sheet materials such that the produced parts do not need further or subsequent machining unless very high quality is required. If the sheared off part is the object the process is referred to as blanking and if the remaining part is the required part the process is referred to as piercing. The literature on these processes is voluminous and goes back to the forties. Most of the work has been directed towards improving the quality of the product and the effect of punch speed on the quality of the produced blanks. They found that blanks produced at punch speed of 3m/s were of better quality than those produced at conventional speeds [1,2]. They carried out experiments on cast iron, mild steel, brass, copper, zinc, aluminum and lead to investigate the effect of clearance, tool shear and the ratio of punch diameter, d, to thickness, t, in blanking circular discs. They found that as the ratio d/t increases the maximum blanking force per unit sheared area decreases and that the maximum blanking force is greatest at no clearance. They also concluded that similar influence of the d/t ratio on the energy required to effect blanking existed. The d/t ratio has been specifically studied by Maeda and Temura, [3], for mild steel, soft copper and soft aluminum. They found that for values of d/t >5 the maximum blanking force per unit sheared area is almost independent of the ratio whereas for d/t ≤5 theblanking force is highly dependent on the d/t ratio. Following Zener and Hollomen findings, interest in the dynamic blanking and piercing has been stimulated in late sixties. An extensive amount of information on the comparison between dynamic and quasi-static blanking of ferrous and non-ferrous materials, regarding the quality of the produced blanks, the maximum blanking force and energy required to effect blanking, both in the cold and hot conditions, together with the effect of
percentage radial clearance had been published in refs. [3-13]. In general it is concluded that improvement in the quality of the blank has been achieved in high speed blanking particularly for ferrous materials, and they are always higher than those of slow speed. However, the energy requirement was less for non-ferrous ones. As the quality of the produced parts is of prime importance, examination of the available literature reveals that most of the published work was directed towards studying the effect of the percentage radial clearance, strain rate and temperature on the blanking force and energy required to effect blanking aiming to improve the blank quality and tool (punch and die) lives. Little work is published on the effect of geometrical parameters of punch and die on the blank quality and tool life. Koura and Zaid [14] investigated the effect of out of roundness of the punch and die in determining the quality of blanks. Kazzutake Komori [15] investigated the blanking operation using the node operation method, giving attention to the effect of various kinds of ductile fraction criterion on crack initiation and propagation during the blanking process. He reported that the methods gave good agreement with the autographic record (punch force-punch displacement curve) as calculated by the suggested work method agrees fairly with the one obtained experimentally [15]. Thipprakmas reported that fine blanking method for improving the wear resistance method of sprocket parts. The sprocket is a profile wheel with teeth. Its periphery is widely used in the drive system which makes it subjected to wear. This requires that the sprocket should posses high strength and good wear resistance. The traditional method in manufacturing the sprocket is the hobbing process followed by heat treatment to increase its strength, hardness and wear resistance. Recently, the fine blanking process has seen increase in use for manufacturing the sprocket with the advantages of improving strength and better surface quality which in twin will improve the wear resistance, furthermore, the reduction of the process operations leading to saving of the production time and cost; as compared to its traditional manufacturing process by hobbing [16]. He has also investigated the fine blanking process for manufacturing the sprocket regarding the improvements in its strength and wear resistance using the metallurgical examination of the fine blanked sprocket and found that the improvement in its hardness and wear resistance is attributed to the grain elongation in the plastically deformed zone as supported by the photomicrographs in this region. It is therefore, anticipated that using fine blanking fore producing the sprocket may select low carbon steel instead of the medium carbon in its production cost [16].

1.1 Accuracy of blanks

Although the blanking and piercing produces products which do not require subsequent machining, however in predict the products suffer small parentages of geometrical errors e.g., dishing, doming and edge taper as indicated and magnified for clarity purposes in Figure1. Also indicated on the figure1 the ideal blank without errors by the dotted line.

1.2 Main Parameters Affecting Blanking and Piercing

The main parameters affecting the blanking and piercing processes are summarized under four main elements namely;

1.2.1 Parameters related to the workpiece material
1.2.2 Parameters to the punch and die
1.2.3 Parameters related to the process.
1.2.4 Parameters related to the machines used for providing the force required to effect the process these are summarized in table 1.

| Parameters Affecting Blanking and Piercing |
|-------------------------------------------|
| Parameters related to workpiece dimensions, geometrical shape, physical properties, mechanical properties |
| Parameters related to the punch and die radial clearance %, c/to, punch and die profile radius, rp and rd, punch and die diameters, dp, dd, surface roughness, out of roundness |
| Parameters related to the process strain rate, working temperature (cold, warm or hot) |
| Parameters related to the machine presses (hydraulic, mechanical, electrical), hammers (falling using hydraulic, high energy rate petroforge, dynamic) |

2. Materials and experimental procedures

2.1 Materials
The specimens used for the blanking process were strips of sheet 50 mm wide and 2 mm thick, made of 0.84% carbon steel, Y8A, of the chemical composition shown in table 2. The punches and dies were all made of die steel X12M of the chemical composition shown in table 3. The die diameter was 25.001 mm and the group of punches were calculated and manufactured to provide radial clearance percentages defined as, the radial clearance between the punch and die, (c) over sheet thickness, (to) i.e. (c/to) % to cover a range from 0.12% to 17.6%.. All punches and dies were heat treated by quenching in oil from 1040 C and tempered at 300 C to attain a Rockwell hardness RC54. All punches and dies diameters were measured using the universal measuring microscope to accuracy of 0.5 micron.

| Table 2. Chemical Composition of Workpiece Material Y8A |
|--------------------------------|
| Element | C% | Cr% | Mn% | Si% |
| Weight percentage | 0.75-0.84 | < 0.15 | 0.15-0.30 | 0.15-0.3 |

| Table 3. Chemical Composition of Punches and Dies, Steel X12M |
|--------------------------------|
| Element | C% | Mo% | Cr% | V% | Si% |
| Weight percentage | 1.45-1.65 | 0.4-0.6 | 11.0-12.5 | 0.15-0.30 | 0.15-0.35 |

2.2 Experimental procedures
All the blanking tests were carried out using the designed and manufactured apparatus shown in Figure 2.
The tests were carried out on a universal testing machine of 500KN capacity at a cross head speed of 5mm/min in two steps: the first step involved the variation of the punch profile radius, keeping the die profile sharp until blanking is completed and the second step involved the variation of the die profile radius keeping the punch profile sharp. The punch and die profile radii were measured using the profile measuring machine at a magnification of 30. the maximum blanking force was determined directly from the autographic record and the energy required to effect blanking is determined from the area under the autographic record, punch load-punch displacement curve, Figure 3a using a planimeter. The accuracy of the blanks was determined by measuring the amount of dishing, doming and edge taper on the sectioned and mounted blanks using a profile projector type PT300 at a magnification of X10. Finally, to study the mechanism of deformation and the metallurgical aspects of the process, the blanking tests were interrupted before, at and after the maximum blanking force was reached, at points a, b and c of Figure 3b. The partially and completely blanked specimens are then sectioned along their diameters, mounted in Bakelite, ground, polished with 1 micron diamond past and etched in 1% natal solution for 5 seconds, metallurgically examined for crack formation and photographed. Hardness and microhardness Vickers survey were carried out at the shear zone. The total number of performed tests were hundred and sixty.

Figure 2. Blanking apparatus

Figure 3. Punch displacement
3. Results and Discussions

3.1 Effect of radial clearance percentage

3.1.1 Effect on force

In all tests, the maximum blanking force is approximately constant at all values of radial clearance percentages, when the punch and die profile radii are kept sharp, Figure 4. The slight variations are due to small variations in the sheet thickness from the rolling process. This is due to the fact that the blanking force = the shear stress, T, x sheared periphery x sheared thickness. As it is obvious, all these parameters are not affected by the radial clearance percentages.

3.1.2 Effect on blanking energy

The blanking energy consumed to affect mechanical separation of the blank consists of four portions: one the energy dissipated in friction between the punch and the penetrated part of the sheet plus energy dissipated in friction between the bottom part of the blank and the die and the main consumed in shearing off the blank from the sheet and finally the energy consumed in forming the dishing and doming. Examination of Figure 5, indicates an increase in energy due to the high friction between the punch and die within the clearance region being high at the beginning of the process forming the dishing. As the punch penetrates certain distance in the sheet during the punch travel this consumed energy is reduced in the clearance zone reaching its minimum value at the bottom of the curves shown in Fig.4, then after that the total blanking energy starts to increase because the amount of dishing and doming increase to their maximum at the end of the mechanical separation of the blank. The other portions of energy, namely the energy consumed in shearing off the blank from the sheet is constant. This is similar in all the curves. This agrees with the previous findings of other researchers, [4-8]. This is expected as the periphery and the thickness and the shear stress and the punch and die profile radii are all constants in the group of tests. This is of vital importance as it was found that the produced blanks at the optimum value of the radial clearance percentage has the best blanks quality i.e least dishing, doming and edge taper in addition it saves energy.

Figure 4. Variation of maximum blanking force with the radial clearance percentage at sharp punch and die. Also shown the theoretical value of force, in dotted line.

Figure 5. Variation of the blanking energy with radial clearance percentages at different values of punch profile radius, and square ended die.

3.2 Metallurgical examination

Microstructural examination of the partially blanked specimens (a total of 160 specimens) either with radiused punch or radiused die at different values of percentage radial clearance, first below the point of maximum force, at and beyond the maximum force revealed that the crack formation is dependent on all the aforementioned parameters in the following manner: The photomicrograph of Figs.6(a)
and (b) indicate that at zero punch and die profile radii, the shear lines start to form in the clearance zone before the maximum blanking force is reached. After it is reached, cracks started at the square ends of the punch and die and propagate until they meet and the blank is mechanically separated i.e. there is no shear stresses holding the blank to the parent sheet. Later, the blank is pushed through the die opening against the friction between punch and sheet, blank and sheet and blank and die opening.

As the radial clearance percentages is increased keeping a square ended punch and die results in widening the shear zone and reducing the work hardening in the regions contiguous to the punch and die corners as observed from the microhardness measurements taken in this zone. This is clearly shown in Tables 4 and 5 at and beyond the maximum force. It can be seen from these tables that The hardness at the tip of the crack is found to be 328 HV and 303 HV near the corner of the die. No such cracks occurred at the point of maximum force (at 60% penetration of the sheet thickness), the metallurgical examination revealed that, for all values of percentage radial clearance two cracks occurred: one near the corner of the punch and the second near the corner of the die. However the crack near the corner of the punch is longer. This suggests that crack has first occurred near the corner of the punch following the points of maximum hardness until the hardness falls to the value below that near the corner of the die. The crack then stops and second crack develops near the corner of the die and propagates towards the first one. Pera report, [17] shows that in the punching operation cracks occur in the region of maximum hardness gradient close to the corner of the punch and the die. In these tests it was found that the hardness of the material is less at the die edge than at the punch edge for all values of radial clearance percentages.

Radiusising either the punch or the die profile resulted in a decrease in both the level of hardness near the modified tool and depth of hardening; it also caused an increase in the width of the shear zone near the edge of the modified tool. The microhardness measurements indicated that hardness is less near the edge of the modified tool and that the hardness decreases as the profile radius increase. No appreciable change in the microhardness of the material at the corner of the square ended tool was noticed beyond the maximum force, table 3 on the other hand change in the order of the microhardness was noticed in the specimen material adjacent to both ends of the modified and non-modified tool at the maximum force. An example is given in Table 2. An interesting results is that the crack always initiated at the corner of the square ended tool, Figs. 6(a) and 6(b), and propagated towards the modified tool until the material is no longer able to carry the applied load, then shearing of the blank occurs. This can be explained using the plain strain deformation model for blanking suggested by Noble and Oxley [18] in which they used a simple stress analysis model to show that the crack formation can be related to the change of the shear flow stress across the shear zone. The greater the shear stress gradient the will be the chance of forming a crack. Thus cracking would be most expected in the regions where the workhardening is high, i.e. in the region adjacent to the square.
ended tool, and least expected in the regions where the workhardening is low, i.e. in the region adjacent to the modified tool. This agrees with the experimental results obtained in this work.

Table 4. Microhardness Vickers survey at the Maximum Blanking Force

| Blanking conditions | Microhardness (HV160) (kp/mm²) |
|---------------------|---------------------------------|
|                     | Punch end | Die end |
| r_p (mm)            | r_d (mm)  | c/t_o % | |
| 0                   | 0         | 18.2    | 295 | 247 |
| 0                   | 0.93      | 18.2    | 280 | 238 |
| 0                   | 1.5       | 18.2    | 272 | 220 |
| 0                   | 2         | 18.2    | 260 | 215 |

Figure 7. Effect of punch profile radius on blanking force, amount of dishing and amount of doming:a), c), and e) respectively.

Figure 8. Effect of die profile radius on blanking energy, amount of dishing, doming and taper, b), d), and e) respectively.
### Table 5. Microhardness Vickers survey beyond the point of maximum blanking force

| Blanking conditions | Microhardness (HV160) (kp/mm²) |
|---------------------|--------------------------------|
|                     | Punch end | Die end |
| r_p (mm)            | r_d (mm)  | c/t_o % |
| 0                   | 0         | 18.2    | 295   | 295 |
| 0                   | 0.93      | 18.2    | 295   | 265 |
| 0                   | 1.5       | 18.2    | 290   | 240 |
| 0                   | 2         | 18.2    | 288   | 228 |

Figures 7 show the effect of punch profile radius on blanking force and the accuracy of the produced blanks, from which it can be seen that increasing the punch profile radius results in deteriorating of the blanks quality. Similarly, Figure 8 indicates that increase of die profile radius radius also resulted in deterioration of blanks quality i.e. increase of the amounts of dishing, doming, and edge taper.

### 3.3 Effect of the wear and surface roughness on blanking and piercing

As it was found that the radial clearance percentage between punch and die is the most important parameters in blanking and piercing in determining the accuracy of the blank, therefore, wear of blanking and piercing tools will cause the optimum radial clearance percentage to change, therefore, wear should be considered in the repair and maintenance of their tools. Similarly, the wear causes the surface roughness of the punches and dies which will have to a lesser degree, the same effect as the change in the radial clearance percentage. Little work on the effect of the wear of tools in these processes is published therefore, this area is still open for research.[19]. This lack of research may be attributed to the complexity of the process which still not fully understood despite the amount of theoretical and experimental research which was work carried out on these processes since mid forties till now. Analytical modeling, and finite element analysis have received much attention in recent years, [19,20]. Review of these current analyses and models are reviewed and discussed in reference [21]. A more detailed study concerning the mechanism of deformation and crack propagation is given by Noble and Oxley showed that the cracks occur in the region of maximum hardness i.e. where the metal has been subjected to the greatest amount of strain hardening, namely at the punch and die edges [17]. PERA report using a plain strain deformation model for blanking showed that crack formation can be related to the change of the shear flow stress across the shear zone, the greater the shear stress gradient the greater the chance for crack formation [18].

### 4. Conclusions

The following points are concluded:

- Although square ended punch and die produce blanks of better quality, it is essential to provide profile radiusing of punch and die to improve their lives. Increasing punch and die profile radii caused increase in both blanking force and energy particularly at small radial clearance percentage.
- In general, providing the profile radii tends to increase the energy and reduces the blanking force and reduces the quality of the blanks. Furthermore, they caused enlargement of the shear zone, being more affected by the die profile radius.
Radiusing the punch and die profiles caused delay in crack formation at small values and non-occurrence at large values and resulted in lower levels of microhardness in the vicinity of the radiused end.

5. References

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