Making Holes

Dr J Ferreira, Mr A Banach,

TD Coating Centre (Pty) Ltd
www.td.co.za, info@td.co.za

With the TD Coating Centre having developed its own range of punches, extensive research had been made into punching. It was found that the technology behind the simple process of "making holes in things" is quite astounding and that there can be a scientific approach to optimising the punch life. The article details some of the findings and will provide some guidelines to improving the punching process and optimising the life of the punch.

Introduction

The concept behind making a hole in a part is quite simple : find an available punch and a die, keep a rule of thumb 8-10 % clearance, press the punch into the steel, exceed the shear strength of the steel and viola! a hole. The problem is that none of the above process takes into account the mechanical properties of the steel punched, the wear propensity of the steel vs the punch, the mechanism by which the punch eventually fails, the stress induced on the punch and die, and the ability to repeat the punching process over and over with minimum downtime. Especially in the case of stainless steel where the material properties differ between the different grades, and even the wear mechanisms may differ between the grades. By understanding some of the processes involved in the punching process, the operation can be readily improved on to provide a better quality hole, with minimum of maintenance.

Clearance

There tends to be a "rule of thumb" attitude towards clearance. Nothing is further from the truth. Consider that each material punched has its own tensile behaviour (yield, tensile, ductility) and fracture toughness (ability to withstand cracks and defects). The typical punch process proceeds by exerting a force on the steel, forming a shear area until a critical stress level is reached, and after this a crack forms which ruptures the remaining steel (see figure1). The objective of the right clearance should be to slightly stretch the steel into the hole before the pierce, which results in the steel relaxing and providing some clearance between the punch and the steel during piercing. If the steel is not stretched into the hole, the steel will tend to "grab" onto the punch resulting in higher punch loads, and larger stresses during extraction. This can cause head breakage during **extraction**.

The rupturing of the steel should also proceed with minimum effort by creating an easy-as-possible path between the shear region formed by the punch, and that formed by the die. Figure 2 illustrates this process. Figure 2a shows that if the clearance is too tight, the crack path is tortuous, resulting in higher stress, and more wear on the punch and die which will in turn result in premature blunting and burring. If the clearance is too big (fig 2c), a longer crack path is followed, which also means an extrusion effect with higher stress and the optimum condition is not achieved. Correct clearance (fig 2b) minimises the crack path, resulting in the lowest stress condition, longest punch life and lowest burr height over time. Figure 3 also shows the result of correct clearance on the appearance of the slug.

To summarise a quite extensive topic, the correct clearance should achieve a slight stretch, allow piercing of the steel to the correct depth, before rupture of an optimum path length is achieved. Appreciably, each material will have it own set of mechanical properties that matches this ideal condition. Figure 4 shows some clearance data derived from actual testing. It would appear that a material has "sweet spots" whereby a minimum burr height can be achieved - much like the sweet spot on tennis racquet or golf club, except in this case there seems to be two. However, the larger clearance result in lower stress and hence is the preferred clearance. Also note though that the chart is for material thickness' of 1.0 - 1.5 mm. With increasing thickness and for materials with less ductility (e.g. ferritic stainless vs austenitic stainless), the material rupture properties change, and the ideal % clearance can be presumed to increase (for steels).

Punch Design

Punch heads breaking off is normally presumed to occur during extraction. This is also not always correct. The heads may fail during the **piercing stroke**. How so? Metallurgy 101 tells us that steels act in an elastic manner before it plastically deforms. Hence steels operating under the yield point can be considered as a spring with an incredibly high spring constant. Thus, during the piercing stroke, the punch is compressed under high load, and on snap-through rupture this compressed energy is released as shock wave up the punch, causing an extremely high tensile load on the punch. Should the punch head design be inadequate to absorb the stress, the head will break. In fact, commonly used countersunk head punches don't effectively handle this high stress. Punches that should be used are either ones with a. a thicker head (e.g. 8mm vs 5 mm), or, b. with an increased radius under the head, or, c. of different design such as trombone punches or 30° tapered head punches. The latter two can offer up to 90% higher strength compared to conventional punches, and are more fatigue resistant than even heavy load shoulder punches. Figure 5 shows some of the stress concentrations experienced and the effect of changing the head thickness or design.

Another reason for head breakage is that punches always undergo some sort of bending during operation. Should a punch with a flat top be used (countersunk or cylindrical), the high rigidity will cause bending fractures under the head. Punches with heads that are slightly tapered on the top (such as cheeseheads, or heavy load shoulder punches), or allow movement (such as trombone, tapered head, etc.) should be used as shown in figure 6.

Punch Steels

The stalwart of punches has always been high speed steels (HSS) such as DIN 1.3343. However, with new steel developments, the shortcomings of HSS have been showing up. In brief, when a punch "goes blunt", the reason can be either a. pure wear (abrasion), b. microcracking, or c. chipping. The actual the cause of the problem should be determined.

To combat abrasion resistance, hard steels with abrasion resistant structures are required. HSS has good adhesion wear resistance, hence under abrasive conditions, HSS is not the best choice.

Microcracking is basically localised overloading. Consider that the punch rubs against the steel being pierced under high load conditions which causes localised microwelding (adhesive wear). The only way to continue punch movement is by breaking the microweld which will cause local high stress points and if the steel cannot tolerate further stress, micro-size cracking will occur. This may lead to chipping of the punch, and hence "blunting". Thus two problems have to be overcome here viz. 1. Adhesive wear must be prevent/delayed by using coatings or steels that have a combination of adhesive and abrasive wear resistance, and 2. Steels must be used that have better fatigue strength. The new steels that fall into this category are the powder metallurgy (PM) steels and lower alloy cold work steels.

Lastly, chipping here is defined as a crack that appears purely due to loading conditions - i.e. due to fatigue. A punch is a part that experiences repetitive loads, and at some point, the inherent fatigue resistance of the base steel will start playing a major role in the failures, and hence blunting. Once again, the PM steels and low alloy cold work steels have better fatigue resistance. It has been shown that a major limiting factor in the endurance and strength capability of a tool steel is its microstructure. During conventional casting and processing, banded structures will form and these act as stress raisers and fracture initiation sites. Powder metallurgy steels are constructed from micro-fine powders and do not suffer from this problem. Hence strength and endurance is improved, and PM steels are tailor made to combine abrasion and adhesive wear properties at higher than usual hardness (64 - 68 HRc).

Punch Tips

Normally punches are supplied with flat tips. However, to pierce with this type of tip requires 100% overload of the punched steel to exceed the shear strength. If defects can be induced in the steels to take advantage of the fracture toughness effect, then one can reduce the energy to break material. Simply it means the following : 1. Keep punches and dies sharp. The sharp edge is a stress concentration point on the punched steel and fracture will occur more readily. 2. Use bevelled edges. A single bevel as shown in figure 7 cuts into the punched steel and provides a sharp pre-cracked site from with fracture can occur. However single bevel edges should used with rigid setup to avoid punch flexing. A double bevel tip (fig 7r) provides a sharp corner from with fractures may easily originate, the punch stays straight and stresses are severely reduced. Audibly stresses are also reduced. When stresses are reduced, the punch experiences less wear and micro-failures, it will stay sharper for longer and produce less burring for longer.

The Optimum Punch?

From a purely mechanical point of view : it is a powdered metal base, coated punch (with an appropriate tip). Table 1 shows performance comparisons of various punches. In brief, the synergistic effect of a better base steel and a good wear resistant coating sees a radical jump in performance (>16 times!). However, it is more important to look at the lifespan-vs-cost figures (table 1) as at the end of the day **this** relates to the actual production cost - the cost of the punch doesn't. Still, table 1 shows it makes far more sense to consider the PM steel, coated punches. The next best cost effective solution is conventional steel base with appropriate coating.

As thin film coatings such as PVD and TD prevent abrasive wear due to its high hardness, prevent adhesive wear due to it being a ceramic, friction is radically reduced on the pierce and extraction stroke and sharpness is maintained for longer. To select the correct coating and make it effectively work is unfortunately beyond the scope of this article. There are some important factors though that is proprietary information.

This data presented in table 1 is extremely powerful. Consider an actual case study where a customer was using not-so-cheap TD coated PM steel punches. The customer perforates 409 and 304 stainless steel. Upon him visiting a European counterpart and presenting some production figures, the Europeans - who run normal HSS punches - were astounded to see that the cost of punches of the South African company was virtually insignificant considering the price of the final part made, so much so that they asked to local company to double check their figures. In the European plant, it is a significant cost as the punches have to be often re-sharpened and replaced. It is an illustration of the correct concept when choosing a punch, namely **life-vs-cost** of the punch, not just the price of the punch. It is far more important to have the correct life-vs-cost ratio punch, than to have cheap punches. In many cases it has been observed that punch purchase costs have dropped more than 90% once the proper punch is used and correct setup has been achieved.

Summary

In this article, some major points were briefly touched on to provide some guidelines to improving the punch process. However, it is a brief overview and in some cases further trials should be performed to achieve ideal settings. Once this has been done though, significant cost savings are realised, better quality holes are pierced - all with minimum downtime. There are other points which also have a significant effect on punch life, although these cannot be discussed here. Our research did show though that some old ideas needs to be canned, some new ideas need to be implemented and more sound engineering practise should be applied to the almost arbitrary concept of making holes. Especially as we need to be highly cost effective in our local manufacturing operations.

TD Coating Centre (Pty) Ltd
Tel : 027-(0)11-9085396, Fax : 027-(0)11-9085305
info@td.co.za, www.td.co.za

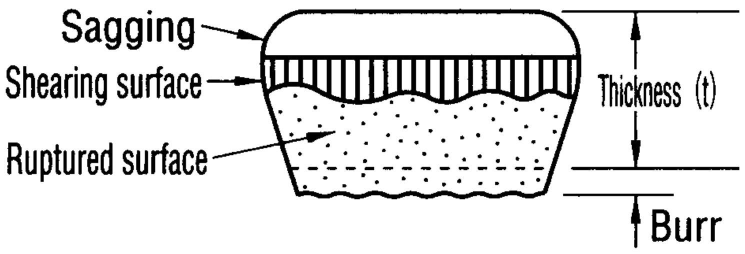


Figure 1 : Basic fracture areas of a punched part[1]

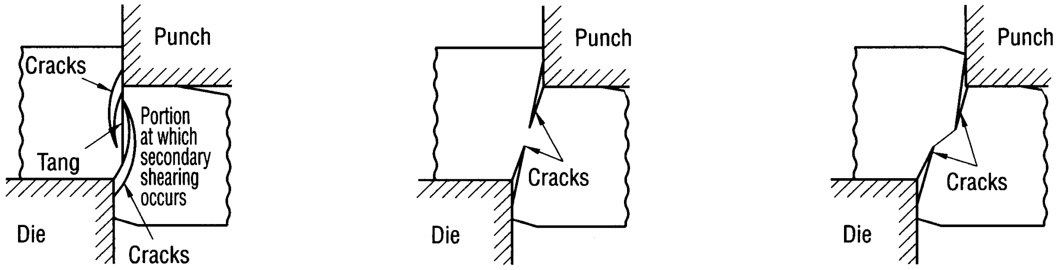
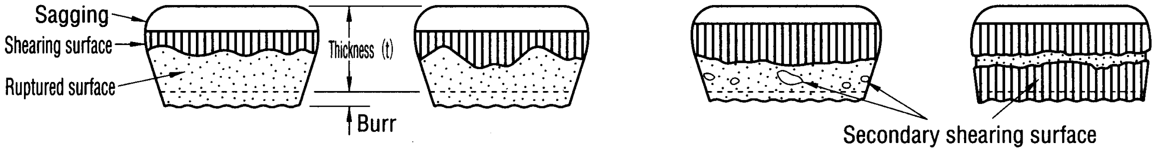


Figure 2 : Effect of clearance on fracture path (l) clearance too small, (m) clearance correct, (r) clearance too big[1]



(a) Clearance is large. (b) Clearance is medium. (c) Clearance is small. (d) Clearance is very small.

Figure 3 : Effect of clearance on appearance of slug[1]

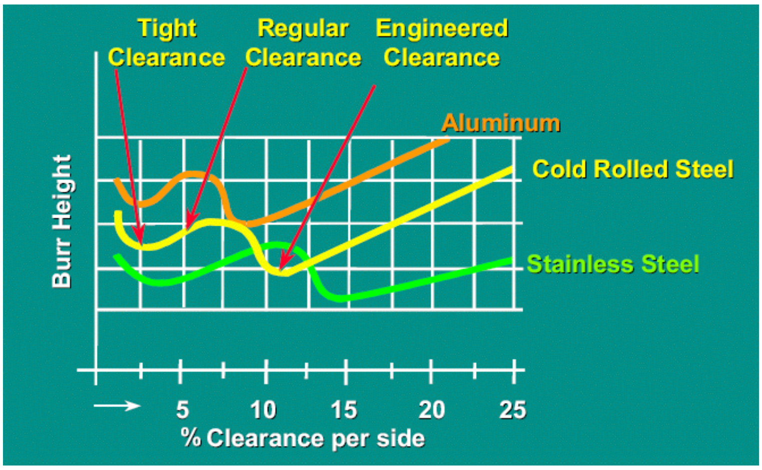


Figure 4 : Correctly engineered clearance will minimise burr height[2]

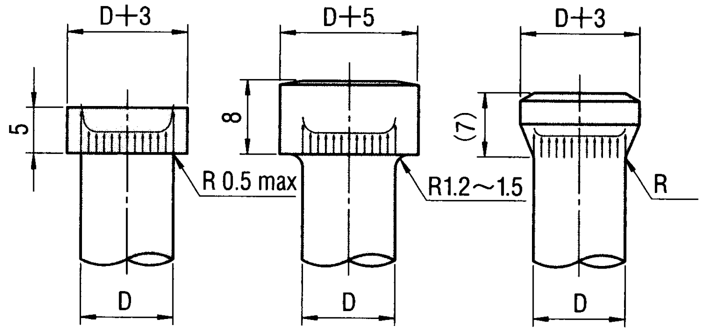


Figure 5: Effect of head design on stress level. (l) shoulder punch, (m) heavy load shoulder punch, (r) tapered head punch. Height of arrows indicate stress level.[1]

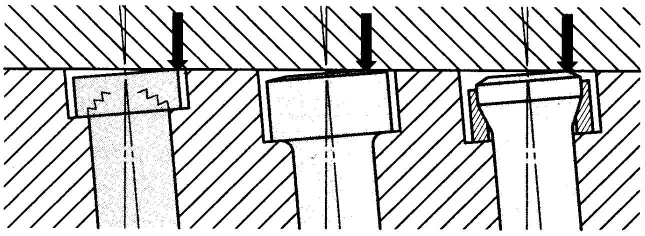


Figure 6 : (l) flat head may cause bending fatigue, (m & r) taper on heavy load shoulder punches and tapered head punches reduce the problem[1]

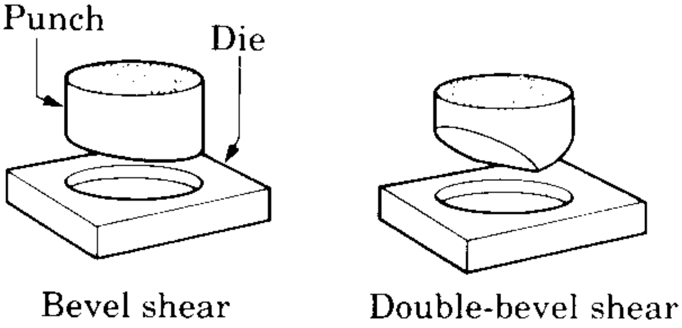


Figure 7 : (l) Single bevel shear, (r) double bevel shear[3]

Table 1: Comparison of performance, cost and life-vs-cost of punches[1,4]

	Performance/ Life Increase	**Cost**	***Life-vs-Cost***
High Cr Steel	1	1.0	*1.0*
HSS Punch	2	1.4	*1.4*
TD coated medium Cr steel	7.5	1.5	*5.1*
PM Steel	8	1.6	*5.0*
TD coated PM Steel Punch	16	2.3	*6.8*

References

1. Misumi punch catalogue
2. Dayton Progress test results
3. "Manufacturing Engineering and Technology", Kalpakjian, Addison-Wesley Publishing Company.
4. TD Coating Centre data and cost of competitive imported punches