FORMING

PUNCHING AND PIERCING STEEL SHEET AND STRIP

TECHNICAL BULLETIN TB-F3

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This issue supersedes all previous issues

1 PUNCHING AND PIERCING OPERATIONS

Most steel sheet destined for fabrication undergoes some form of cutting or severing operation involving a punch and die. This occurs early in the fabrication stage and is invariably performed while the steel is still in flat form.

In punching, a strip of predetermined shape is cut, in a single press stroke, from strip or sheet. The piece punched out is the workpiece, the outside piece is scrap.

Piercing, also termed punching or perforating, is a similar operation to punching, the difference being the punched-out slug is scrap and the metal that surrounds the punch is the workpiece.

Notching is an operation where a punch cuts a piece of metal from the edge of the workpiece.

Each operation involves the use of a punch and die, and as the cutting action and the edge characteristics of punched parts are the same, for simplicity the term punching in this bulletin includes the blanking, piercing and notching operations unless otherwise indicated. Slitting and shearing or guillotining have many similarities to these operations but are discussed separately in Technical Bulletin TB-F2 of this series, Shearing and Slitting of Steel Sheet and Strip.

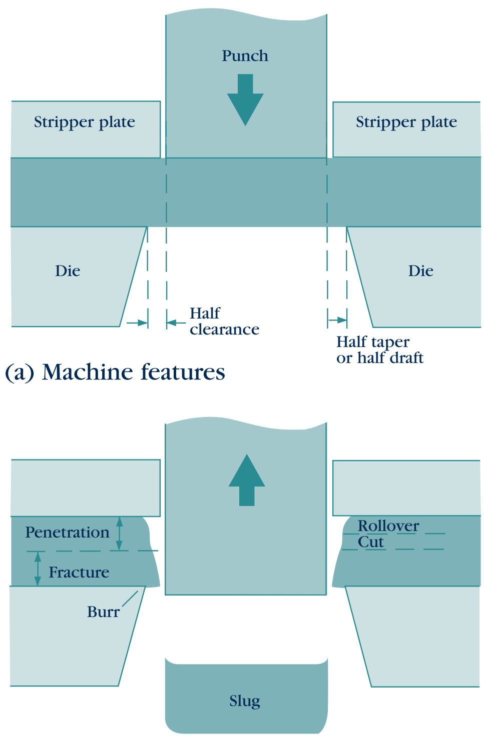
A hole produced by drilling or other machining methods has a straight sidewall for the full thickness of the steel workpiece. A punched hole sidewall is generally straight and smooth for only a portion of the thickness, beginning near the punch end of the hole. The remainder of the side-wall is fractured in an irregular cone beyond the starting portion of the hole, producing what is called fracture, breakout or die break. *(Refer to Figures 1 and 2)*. Punching is a fast and usually economical method for making holes of any shape in steel sheet at medium to high production rates. The degree of achievable accuracy is satisfactory for a wide variety of uses. If the sidewall quality of a punched hole is unsatisfactory it can usually be improved by shaving or reaming.

Figure 1 shows the features of the punching operation and the resultant sheared edge. The tool basically consists of a punch and tapered die. Taper or draft is expressed as mm/mm or as an angle. Clearance is the difference between punch size and die opening size *(compared to actual gap between top and bottom blades in slitting and shearing operations)*. The workpiece is held in position by a stripper plate or stripper.

2 MECHANISM OF PUNCHING

During the punching operation the punch descends *(Figure 1)* and penetrates the sheet until the stresses in the unpenetrated area reach the fracture stress, then fracture occurs. The downstroke continues until the slug or blank is pushed into the die cavity, the sheet surrounding the punch being held firmly in position by the stripper plate until withdrawal of the punch is complete.

Figure 1 – Illustrates four essential features of the punched edge of steel sheet; rollover, cut, fracture, burr.



(a) Machine features

(b) Material features

Rollover is a downward curve in the top surface of the held sheet *(or upward curve in the bottom surface of the slug or blank)* caused by deformation of the sheet before the actual cut commences.

Cut or burnish is the burnished, straight portion of the edge caused by direct contact between the walls of the tool and the steel strip. Rollover portion plus cut portion is the depth of penetration before fracture.

Fracture, also called breakout or die break is that portion of the edge where separation has occurred by fracture after the fracture stress point has been reached.

Burr is a heavily worked lip that occurs on parting of the bottom surface of the held sheet and the top surface of the slug or blank. A burr is always present in conventional punching, and increases in height as the tools wear. The maximum permissible burr height often depends on the end application, but in general, continuing to punch after the burr height has reached 0.07-0.10 mm leads to rapid tool wear. The burr present on a punched edge is very heavily cold worked, and can cause initiation of cracks during subsequent working operations.

3 PUNCH AND DIE CLEARANCES

3.1 Edge Characteristics

It is essential that tools be built with the correct clearance between punch and die for the steel type and thickness being used. Clearance determines the edge characteristics on the punched part, has a significant influence on tool wear and, if correctly chosen, minimises operational problems. Clearances expressed in this bulletin refer to the difference between punch and die diameter *(in Technical Bulletin TB-F2 of this series, Shearing and Slitting Steel Sheet and Strip, clearance is the gap between top and bottom blades)*. While the edge features in Figure 1 always exist, the prominence of each feature changes with changing clearances. Figure 2 details the types of edges which can be produced and these are classified as Types 1 to 5. It will be seen that as the clearance is increased the edge profile changes from a square edge with little rollover *(Type 5)* to an angular edge with increased rollover *(Type 1)*. Edge quality deteriorates with increasing clearance.

Higher strength steels with low ductility, high strength steels and high carbon steels generally show less rollover and lower burr height *(a better quality edge)* for a given clearance.

3.2 Operational Problems

Operational problems caused by the size of the slug relative to the die, or punched hole relative to the punch, are influenced by both the clearance and the mechanical properties of the workpiece.

3.2.1 SLUG LIFTING

Slug lifting is the phenomenon of slugs which are not held tightly in the die, being sucked up by the rising punch. This causes marking on the subsequent work and tool damage by miss-hitting. Slug lifting can be a particular problem with high strength, low ductility metals or where small holes are pierced at high speed, especially when the clearances used are designed for more ductile steel materials which give a slightly larger slug.

Making the clearance tight reduces the problem, but increases the rate of tool wear. If slug retention requires clearances below that necessary for optimum tool wear, one of the following mechanical slug retention methods can be used:

a) air holes in punches to avoid reduced pressure above the slug

b) pusher pins in punches to eject slugs mechanically

c) venturis under the die cavity to reduce pressure beneath the slug

d) blunting the edges of sharpened punch and die by stoning, thus increasing slug size.

3.2.2 DIE FIRING

For the same clearance the slugs from ductile steels are sightly larger than those from steels with low ductility. Consequently, if ductile steels are punched with minimum clearance the slugs can be sufficiently tight in the die to cause severe erosion of the die walls, a condition known as die firing. In extreme cases, cracking of the die segments can occur.

The clearance conditions chosen are therefore a compromise between the required edge quality, rate of tool wear, and operational difficulties such as slug lifting and die firing. Satisfactory results are obtained over a range of clearance conditions. It is common practice to construct tools with clearance at the tight end of the satisfactory range, so that as the tool is sharpened, clearance increases to the wide end of the range as a consequence of the die draft. For example, a tool constructed with total clearance of 10% of 0.50 mm thickness work metal *(0.05 mm clearance)* and 0.003 mm/mm draft, would increase in clearance to 22% total clearance for useable die thickness of 20 mm.

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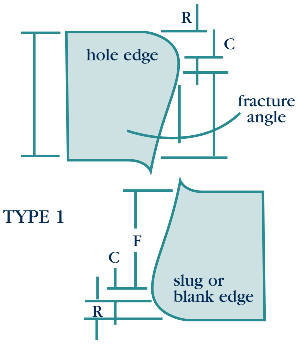
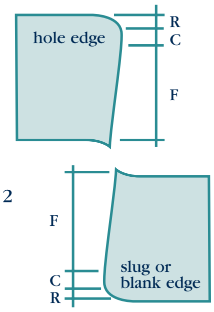
Figure 2 – Edge characteristics – effect of punch-to-die clearance on edge characteristics of holes and slugs or blanks, produced by punching low carbon steel sheet , maximum hardness HRB75.

TYPE 1



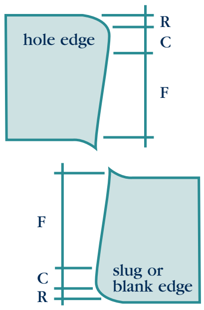
KEY
TOTAL CLEARANCE 35-40% OF STEEL THICKNESS
Large rollover (10%-20% of thickness) and a large burr plus bending or deformation at the edge. Cut depth (10-20% of thickness) on the edge of a slug or blank may be small and irregular or even absent. Fracture depth is about 75% of steel thickness and the fractured surface has a large angle (14-16°).
Satisfactory only for non-critical applications where edge quality and workpiece flatness are not important.
R = Rollover C = Cut F = Fracture

TYPE 2



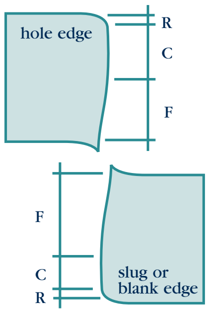
KEY
TOTAL CLEARANCE 20-25% OF STEEL THICKNESS
Moderate rollover (8-10% of thickness) and a small burr. Cut depth 15-25% of thickness. Fracture depth is 60-75% of thickness and fracture angle is small (8-11°).
Provide maximum die life and a hole or blank suitable for general work on which a large cut depth is not required.

TYPE 3



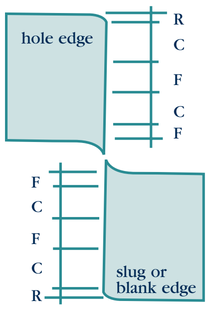
KEY
TOTAL CLEARANCE 15-20% OF STEEL THICKNESS
Small rollover (6-8% of thickness) and a small burr. Cut depth 25-40% of thickness. Fracture depth is about 50% of the steel thickness and fracture angle is small (7-11°).
Radial stress is low, making the edge particularly suitable for use in parts made from work-hardenable material that will undergo severe forming. The clean, stress-free edge reduces the possibility of edge cracking during forming.

TYPE 4



KEY
TOTAL CLEARANCE 10-15% OF STEEL THICKNESS
Small rollover (4-7% of thickness) and a medium height burr. Cut depth is about 50% of the steel thickness. Fracture depth is 35-50% of thickness. The fractured surface is rough and has a small angle (6-11°).
Suitable edge for subsequent edge finishing such as shaving or machining.

TYPE 5



KEY
TOTAL CLEARANCE 2-5% OF STEEL THICKNESS
Minimum rollover (2-5% of thickness) and a large burr. Cut depth is 50-70% of thickness in two portions, alternating with fracture. Fracture depth is 25-45% of thickness in two portions.
Useful where edges must have a maximum straight-wall depth without secondary operations. Die life is extremely short.

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3.2.3 WARPING OF FEED MATERIAL

When a job specifies the need for a large number of holes to be punched a problem can occur in keeping the feed material flat. This phenomenon can be caused by the accumulation effect of punching. Each time a hole is punched, the steel around the hole is stretched downward leaving the top of the sheet in tension with the downward movement of metal causing a corresponding compression in the bottom surface. For a few holes this stress difference is insignificant but with many holes the total difference can reach the point when the feed material deforms.

One solution is to punch every second hole in one direction and then the remaining holes in the reverse direction. This reduces the tension/compression build up cycle with distortion effects working against each other.

3.3 Die Clearance for Various Materials

Commonly used initial total clearances and draft for some BlueScope Steel Limited products are shown in Table 1. However, optimum initial clearance varies with the type of tool used. Specific recommendations can be obtained if full particulars are supplied to a BlueScope Steel State Sales Office.

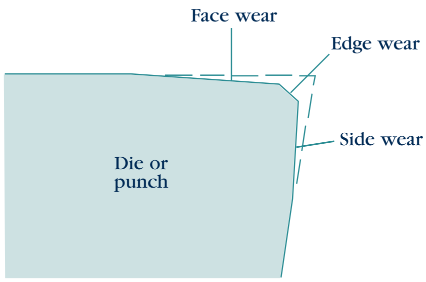
Table 1 – A general guide to initial clearance and draft for punching

Steel sheet product	Initial total clearance (% of sheet thickness)	Total draft mm/mm
UNCOATED		
Ductile products	10-15	0.003-0.006
Low ductility products CA85T-G	8-12	0.003-0.006
METALLIC COATED		
Ductile products	10-15	0.01
Low ductility products ZINC-HI-TEN® G450 ZINC-HI-TEN® G500 ZINC-HI-TEN® G550 ZINCALUME® G550	8-12	0.01
ORGANIC FINISHED (COLORBOND®)		
Ductile base products	10-15	0.01
Low ductility products ZINC-HI-TEN® G550 ZINCALUME® G550	8-12	0.01
ELECTRICAL		
Electrical steel products	10-15	0.003-0.006

4 TOOL WEAR

Tool wear usually takes place on the face, edge and side of the tool. Figure 3 indicates these areas.

Figure 3 – Tool wear areas



4.1 Face Wear

Face wear is primarily related to the surface condition and ductility of the workpiece, and lubrication. These factors are more important than clearance in determining the amount of wear on the tool face.

4.2 Edge Wear

Edge wear is primarily related to clearance which controls the proportion of the workpiece thickness cut before fracture. As shown in Figure 2 the proportion of the thickness cut decreases with increasing clearance. The rate of wear of tool edges therefore decreases with increasing clearance.

4.3 Side Wear

The rate of tool side wear decreases with increasing clearance. The size of the punched hole relative to the punch, *(or slug relative to the die)*, is related to clearance. Increasing clearance decreases the tightness with which the punched hole grips the punch side *(or the slug grips the die side)*.

It is generally found that the overall rate of tool wear increases with decreasing clearance.

5 TOOL SIZE

In general, for blanking operations where a slug is the finished product, the die opening is made to the required part size. Conversely, in piercing, the punch is made to the required hole size. This general rule is modified to some extent by material properties, clearance and tool sharpness.

6 STRIPPING

The stripper *(Figure 1)* is used to hold the workpiece firmly in position during both the downstroke and upstroke of the punch. Strippers are of two main types; fixed *(or box)* type and spring type. The type used can influence the quality of the cut edge and side wear on the punch during penetration and particularly, withdrawal. The spring type usually gives better results than the simpler box type.

7 SHEARING FORCE

Assuming a sharp tool with punch and die surface flat and perpendicular to the motion of the punch, the force required to punch a steel of known shear strength can be calculated from:

Equation 1

$$F = L\,t\,R_S$$

where F = shearing force, N

L = length of cutting edge or perimeter of cut, mm

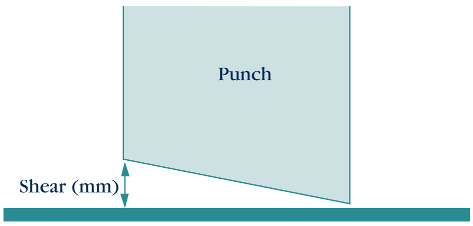
t = material thickness, mm

R_S = shear strength, MPa

The force needed to shear a given material varies with the type of cutting operation and the condition of the tool edge. The apparent shear strength of metals cut in dies is slightly lower than the shear strength of the same metal cut in a straight shear, and is lower when using a sharp tool rather than a blunt tool[5]. However, a general value for shear strength can be taken as 80% of the tensile strength.

Angular shear *(Figure 4)* on either the punch for piercing or die for blanking reduces the peak load by shearing a little of the workpiece at a time instead of making the whole cut instantaneously as is the case of a flat punch and die. The total energy required is not reduced, but a lower force is exerted for a longer period.

Figure 4 – Angular shear



In general, angular shear equal to 33% of stock thickness reduces shearing force by approximately 25% and shear equal to stock thickness, or full shear, reduces shearing force by 50%[2]. Shear is not usually used with slender punches as they lack column strength. In this case, a similar reduction in maximum load can be achieved by staggering the punch length in compound tools.

Press capacity, C, is often determined from the shearing force, F, by the empirical relationship:

Equation 2

$$C = \frac{F}{f_S}$$

where C = press capacity

f_S = shear factor and is given values ranging 0.5 - 0.75 [2,3]

A higher shear factor is used for precision work where equipment is operated below its nominal capacity to reduce wear and machine flexing and when carbide tools are used.

8 POWER REQUIREMENTS

Power requirements or flywheel capacities require a knowledge of energy absorbed in shearing. This is approximated by Equation 3.

Equation 3

$$E = F\,p$$

where E = energy, J

F = force, N *(as per Equation 1)*

p = penetration, mm *(refer Section 2 and Figure 1)*

A factor of 1.15 is often included to allow for machine friction[2]. This factor is a general figure as machine condition varies widely.

9 TOOL CONSTRUCTION

The standard of tool construction varies with the end requirements, but in general, tools need to be of robust design, with accurate alignment of punch and die. Lateral movement of the punch relative to the die causes tool blunting by collision of the edges of punch and die *(called edging)*. A wide range of tool materials is available. Each type has its own area of application depending on the life required, the type and thickness of sheet to be cut, and the design of the tools.

9.1 Short Run Tooling

Many low cost tool types for short runs *(up to 100,000 parts)* are available. These include template die and steel rule die tooling[4].

9.2 Medium and Long Run Tooling

For medium and long run tooling, hardened tool steels are used. Recommendations for tool steel selection are detailed in the “Metals Handbook”, and are also available from tool steel suppliers.

9.3 Extra Long Run Tooling

Tungsten carbide is the tool material for long runs, high productivity and where close tolerances and minimum burr are important.

Although carbide tools are more expensive, the number of parts produced between tool sharpening is increased by a factor of eight to twelve compared to steel tools.

A range of carbide grades containing varying proportions of tungsten carbide to cobalt binder is available. Wear resistance increases with increasing quantities of tungsten carbide, however, toughness decreases. It is essential to choose a grade of carbide with sufficient toughness or impact strength to avoid chipping of the edges of the punch and die. Carbide tools have less resistance to edging than other tool steels, necessitating control of lateral movement by tool design and the use of a high precision press. For this reason the shearing force should not exceed two-thirds of the rated press capacity when using carbide tools *(refer Section 7)*. Carbide tools are also very susceptible to thermal spalling and overheating, and is not recommended for piercing very thick material.

10 LUBRICATION

The use of suitable punching lubricant decreases the rate of tool wear and increases stripping efficiency. However, the choice of lubricants is often limited by the requirements of further operations and end uses. For blanking and piercing with no post cleaning operations, low viscosity mineral oils with small concentrations of extreme pressure additives and rust inhibitors in a volatile carrier are commonly used.

Where carbide tools are used, highly alkaline or sulphur-containing lubricants should be avoided as they reduce the wear resistance of the carbide by attacking the cobalt binder. The rate of tool wear is decreased by the presence of surface coatings which are less abrasive than steel. Zinc-coated steel products, eg GALVABOND® steel, give better tool lives than equivalent uncoated steels. With COLORBOND® prepainted steel, the organic coating acts as a solid lubricant, generally decreasing the rate of tool wear and in many cases obviating the need for any additional liquid lubrication.

The different lubricant types are outlined in more detail in Technical Bulletin TB-F1, Lubrication of Steel Sheet and Strip for Forming.

11 COLORBOND® STEEL PRODUCTS

As indicated in Table 1, no extra clearance needs to be added for the thickness of the coating when punching prepainted or prelaminated steel, and the same tools are used as for the particular metal substrate thickness.

Where practical, the workpiece should always be processed with top or main surface uppermost to prevent scratching of the prime surface during feeding into the press. However, when the piece punched out is the workpiece the shear burr will be on the prime side so subsequent operations will need to be examined to see if this should be changed. Transport of punched blanks with the prime surfaces face to face, to prevent surface marking, is impossible with the shear burr on the prime side. The use of a lubricant is not usually necessary, but when used, it is essential that the lubricant chosen does not damage the organic surface film. SHELLSOL T *(or material with equivalent specification)* is the recommended lubricant.

12 ELECTRICAL STEELS

Electrical steels are punched into motor and transformer laminations, often using high speed progressive tooling. The punchability of these steels is therefore a critical property and the LY-CORE® range of steels is processed to optimise punching performance. The punchability is influenced by the surface treatments - Bright or with an insulating coating *(COREPLATE®, CP3A or CP3B)*.

CP3A and CP3B coatings act as efficient lubricants and reduce tool wear significantly. Extensive testing has shown that, depending on the severity of the punching operation, the number of parts obtained between sharpening is increased by a factor of 2 to 4 when using CP3 coated steel compared to Bright steel[6]. For all but the most difficult punched hole configurations, CP3 coated material requires no additional lubricant in the form of punching oil. Where sharp corners cause inefficient stripping and consequent side wear on the punch, the use of punching oil is beneficial.

Bright material should always be lubricated to achieve maximum tool life.

13 FINE BLANKING

The sheared edge produced by conventional punching is suitable for most end uses, but some applications require subsequent operations such as shaving, milling, broaching or grinding to meet higher standards of dimensional tolerance or edge surface quality. Fine blanking is an alternative method for producing a square-cut edge, cleanly sheared over the entire material thickness in one operation. Fine blanking requires an expensive triple-action press and special tooling, but the initial capital outlay can often be offset by the elimination of costly post-blanking operations.

Further information on fine blanking methods and equipment is available from equipment manufacturers, and special steel sheet requirements should be discussed with BlueScope Steel State Sales Offices.

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ACKNOWLEDGMENT

Some of the text in this bulletin is based on information contained in the "Metals Handbook", Volume 4, by kind permission of the American Society for Metals.

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BlueScope Steel

BlueScope Steel Limited ABN 16 000 011 058
BlueScope Steel (AIS) Pty Ltd ABN 19 000 019 625

9 320075 034887

AUSTRALIA

SYDNEY	Telephone: (02) 9795 6700
MELBOURNE	Telephone: (03) 9586 2222
BRISBANE	Telephone: (07) 3845 9300
ADELAIDE	Telephone: (08) 8243 7333
PERTH	Telephone: (08) 9330 0666

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BlueScope Steel (Malaysia) Sdn Bhd	Telephone: (603) 3250 8333
BlueScope Steel (Thailand) Limited	Telephone: (66 38) 685 710
PT BlueScope Steel Indonesia	Telephone: (62 21) 570 7564
BlueScope Steel Southern Africa (Pty) Limited	Telephone: (27 21) 555 4265

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