

# STAINLESS STEEL INFORMATION SERIES

## DEEP DRAWING OF STAINLESS STEEL

Pressing and drawing are both processes whereby a flat piece of sheet metal (a blank) is formed into a cylindrical or box-shaped component by means of a punch and die or draw ring. The essential difference between pressing and drawing is that pressing involves holding the sheet such that the metal is stretched into the required shape, whereas in drawing, the material is caused to flow into the die with little thinning of the material occurring. An article is considered to be deep drawn when its depth is one and a half times or greater than the diameter of the article.

The essential components of a drawing press and cup are shown in Fig 1 below:

A blank of correct dimensions is placed over the draw ring. Where required, hold-down clamps are lowered onto the blank and the hold-down pressure varied to control the flow of metal into the die. The punch is lowered onto the centre of the blank and pushed into the die. As the punch moves past the die ring, the metal is wrapped around the nose of the punch and the outer portions of the blank move radially inward to form a straight walled cup. As the cup is formed, the portion of the blank in contact with the face of the punch remains virtually unchanged. The walls of the cup, however, become thicker due to the movement of excess metal (providing that hold-down pressures are

such that stretching of sidewalls does not occur). The reason for this can be easily understood if a cylinder were to be formed from a flat piece of cardboard. In order to form the side walls, notches would have to be cut in the blank to remove excess material as illustrated in Fig 2:

Therefore, during the drawing process, this excess metal in the blank is drawn over the draw ring and flows into the sidewalls, where it results in thickening of the metal. This causes high contractional forces at the top of the cylinder which, if metal flow is not controlled, can lead to problems such as wrinkling. >

## FORMING SHEET METAL INTO CYLINDRICAL OR BOX- SHAPED COMPONENTS

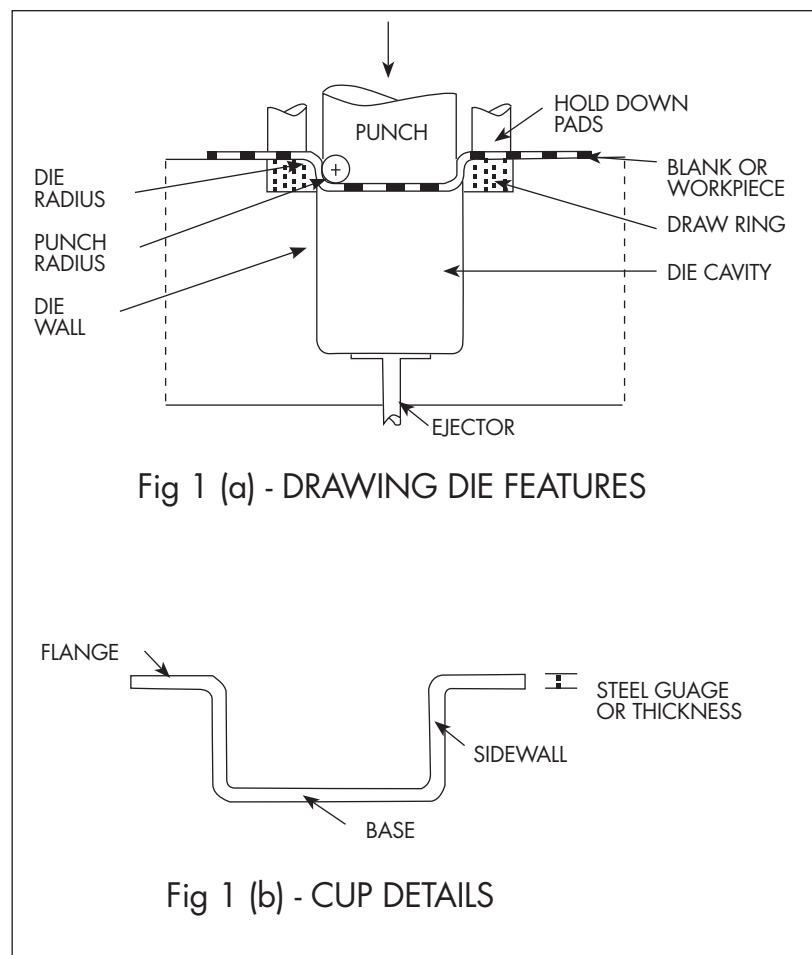


Figure 1

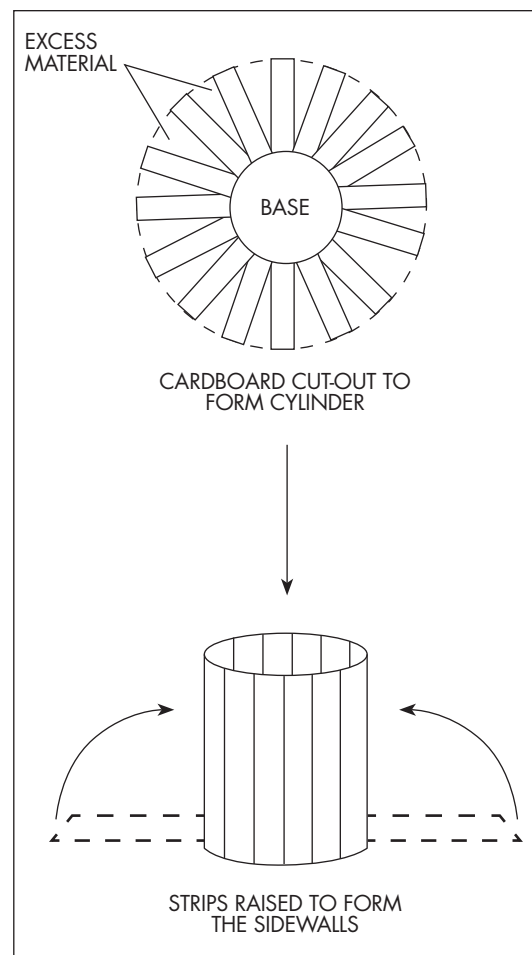


Figure 2

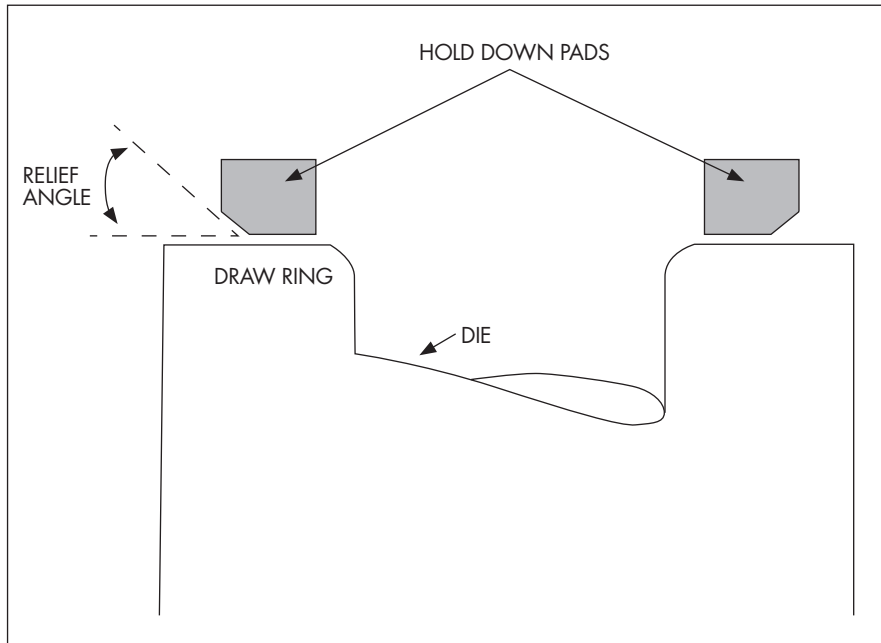


Figure 3

## METAL FLOW INTO THE DIE CAN BE FURTHER RETARDED BY INSERTING A "DRAW BEAD" IN THE RING

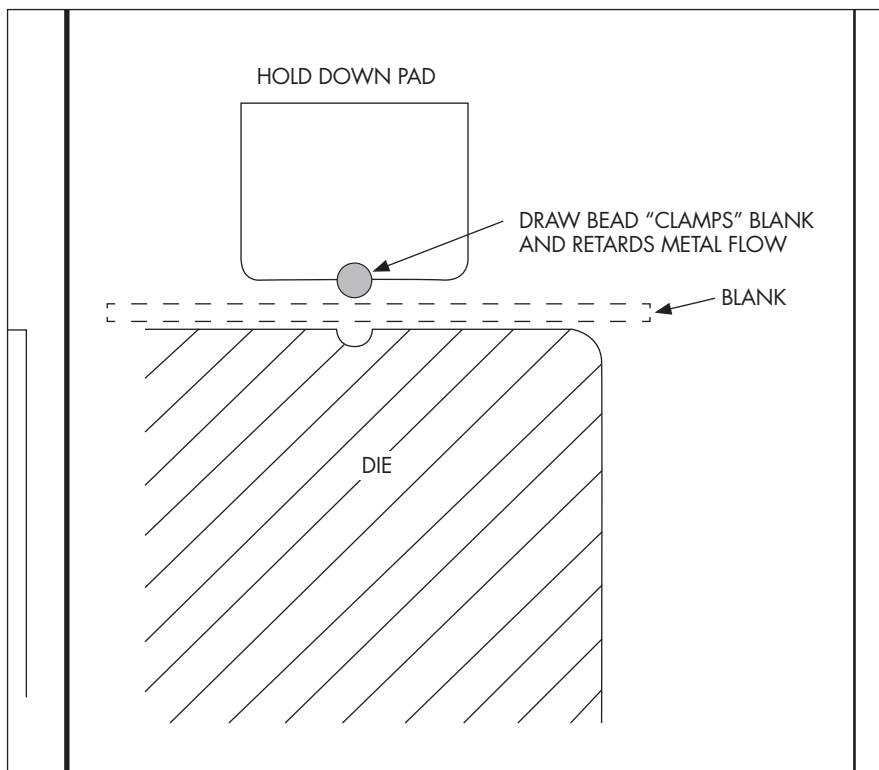


Figure 4

### WRINKLING AND PUCKERING

A hold-down die or blank holder is used to prevent the formation of wrinkles caused by the compressive stresses generated as metal from the blank moves radially inward over the die ring. Wrinkling usually starts due to non-uniform movement of the metal or lack

of support in the die ring. A hold-down force is usually applied to the blank to either control or compensate for this non-uniform movement. The forces exerted on a blank-holder can be controlled in a number of ways other than by changing the pressure. Firstly, hold down pads can be flat, so that as the metal flows out from under the pad, the pressure increases. A

more constant pressure can be achieved by providing a relief angle on the hold-down pad - as illustrated in figure 3.

This will allow a more uniform draw, but wrinkling can still take place in the blank outside the draw ring. This should not be a problem if the flange is to be cropped or removed. This design of pad effectively "irons" the metal as it enters the draw ring.

Metal flow into the die can be further retarded by inserting a "draw bead" in the ring with a corresponding groove in the lower pad, as illustrated in figure 4. Pads of this design are used to increase stretching of the sidewalls in the die when required. With draw beads the metal flow can be retarded to the extent where shape change is achieved by stretching only. Hold-down pressures are usually found by trial and error although there are tables available which list pressures as a guideline.

Certain conditions exist whereby blanks can be drawn without the use of blank holders. These are dependent on blank diameter to cup diameter and blank diameter to material thickness ratios. Another problem that can occur during the drawing of shallow articles is that of "puckering". Whereas wrinkling occurs outside the die, puckering occurs inside the dies and is due to excessive die clearance. Puckering is characterised by the presence of wavy lines on the sidewalls and, even if very slight, is extremely difficult to remove.

Puckering can be prevented by using harder metals for the blanks, using slightly thicker metals or reducing the clearance between the punch and die.

### STAINLESS STEELS FOR DEEP DRAWING

Most metals can be drawn provided they have reasonable ductility. The austenitic stainless steels are particularly suitable for deep drawing as they have excellent ductility, and their work hardening properties allow for an even movement of material into the die.

The most commonly drawn stainless steels, together with their mechanical properties are listed below.

The Olsen Cupping test gives an indication of the degree to which a material can be stretched. In this test, a cylindrical blank is placed over a spherical punch. A hold-down die applies a force high enough to prevent any flange material from moving into the die while a cup is drawn. The



Typical Mechanical Properties						
Grade	Basic	Hardness	Tensile	Yield		Olsen Cup Value
	Composition (%)	(HBN)	Strength (MPa)	Strength (MPa)	Elongation (%)	
301	17 Cr 6.5 Ni	85	772	310	62	0.35-0.45
304	18 Cr 9 Ni	80	600	262	52	0.50-0.60
316	17 Cr 11 Ni 2 Mo	85	627	276	40	0.35-0.45
321	18 Cr 9 Ni + Ti	81	600	248	55	0.35-0.45
409	12 Cr + Ti	80	552	290	27	0.37-0.40
430	17 Cr	82	565	310	28	0.37-0.40

Table 1

Typical properties of austenitic and ferritic stainless steels		
Property	Austenitic Chromium	Ferritic Plain Chromium
Grade most commonly drawn	304	430
Corrosion resistance	Excellent	Good
Formability	Very good	Moderately Good
Drawability	Up to 50%	Up to 30%
Weldability	Excellent	Moderate

Table 2

criterion for the test is the height (or depth) of the cup that can be formed before fracturing. The ratio of blank diameter to cup height is then taken to be a measure of the steels "drawability".

The steels listed above, in Table 1, are by no means the only stainless steels that are deep drawn. Many other grades can be drawn, but they may be selected for specific properties eg: corrosion resistance, rather than drawability. Some typical properties of the 300 grades (chrome-nickel) and 400 grades (straight chromium) are also listed above, in Table 2.

The most commonly drawn austenitic stainless steel is grade 304, used for kitchen sinks, cookware and a variety of hardware items. Grades 301, 316 and 321 are deep drawn only when specific properties are required. Of the plain chromium grades 409, 441 and 430 are the most common. 409 and 441 are used extensively for catalytic converter and exhaust components, while 430 is used for lower grade cookware and hollowware items.

An important factor to consider when selecting an austenitic grade, is the response of the steel to work hardening. The lower nickel grades such as Grade 301 (6.5% Ni) have a high response

whilst the higher nickel grade 304 (8-10% Ni) has a low response to work hardening. The drawing procedures and depth of draw prior to annealing will therefore be different for each grade. A full description of the various grades can be found in Information Series No. 1.

## DIE CLEARANCE

Stainless steels are not suited to ironing (where the wall thickness is reduced) as their rapid response to work hardening can cause damage to the dies (high wear and marking). Die clearances are therefore generally larger than the blank or metal thickness.

Die clearances for ferritic stainless steels are similar to those for carbon steel, but the clearances for austenitic stainless steels are larger. A clearance of 10 to 15% of the metal thickness per side of the die is used for ferritic stainless steel, while

austenitics require 35 to 40% of stock thickness per side. The table below gives typical examples.

Generally, where deep drawn articles are to be formed, die and punch clearances are higher than for shallow-drawn cups. It should be noted that slight variations in metal thickness from one batch of steel to another can have an effect on drawing. Where long production runs are involved, die wear must be taken into account.

## DIE AND PUNCH RADII

These radii are determined by the gauge of the blank, the depth and severity of the draw and the grade of steel to be drawn. There is a practical limit to the radii that can be adopted. If the punch radius is too small, tearing will occur at the base and the base will separate from the cylinder. If the draw-ring radius is too tight, metal flow is inhibited and the sidewalls will be stretched, possibly to the point of fracture. The radius selected for the die ring is critical as this plays a large part in controlling metal flow into the die. The radius used is strongly dependent on the thickness of metal to be drawn.

As the metal flows over the draw ring, work hardening takes place, particularly in the case of Grade 301. This grade is able to resist fracture due to the work hardening that occurs and so is able to tolerate sharper draw ring radii, whereas the lower work hardening grades such as Grades 304 or 305 may fracture.

Too large a radius, on the other hand, will promote wrinkling due to the fact that there is a zone of unsupported metal between the punch and the die.

In the event of too large a radius, high hold-down pressures may assist in minimising the amount of wrinkling that occurs.

Experience has shown that with Austenitic Stainless Steels, a draw ring radius of between 4 and 8 times the blank thickness is satisfactory. The radius at the bottom of the punch is usually set at 4 to 6 times the blank thickness.

Where shallow cups are being >

Blank Thickness	Clearance per Side (mm)		
	Carbon Steel	Ferritic S/Steel	Austenitic S/Steel
1.20 mm	1.32	1.32	1.68
0.8 mm	0.88	0.88	1.08

formed in an initial draw, the minimum die-ring radius is 4 times the stock (blank) thickness. For any subsequent draws where a large reduction in the workpiece diameter is expected, draw ring radii must be increased to as much as 8 times stock radius. In cases where a very sharp radius is required at the bottom of a work-piece, a redrawing operation can be carried out which, while reducing the diameter of the article slightly, will allow small radii to be formed without cracking or tearing. The radius at the bottom of the punch would be, for example, 6 times stock thickness for the first draw. Subsequent draws can then use tighter punch radii.

## BLANK DESIGN

Blank sizes or diameters are generally limited to twice the punch diameter. Larger blanks will tend to rupture because the inward radial flow of metal into the die is restrained by the material outside the die.

The size of blank used for cup-shaped parts is dependent on the final shape of the article, the drawability of the steel and whether the article is to have a flange and what size the flange is to be. Included in the blank size should be an allowance for trimming as well as any allowance for large radii.

Tables for determining blank sizes for thin gauge material are available. There are graphical methods for determining blank sizes for complex, symmetrical shapes but where blank sizes are to be determined for non-uniform shapes, trial and error is usually used. In this case, before a production run is started trial blanks are cut which, to the operator's judgment, will be of sufficient size.

## LUBRICATION

Lubrication is required to prevent galling, scoring or marking of the dies and workpiece during the metal to metal contact. A lubricant must be able to provide a film between the dies and the workpiece and must not break down when used under high pressure. A lubricant must also be able to preserve the surface finish on a stainless steel and must be easily removed from the workpiece after drawing. Residues of oil on a workpiece can lead to problems when the parts are to be heat treated, and so must be removed.

Chlorinated or sulphonated fatty oils and wax-based pastes are used for high pressure drawing operations. These

## MODERN TECHNOLOGY HAS REVOLUTIONISED THE PRODUCTION OF COMPLEX DEEP DRAWN PRODUCTS, FROM SINKS TO CATALYTIC CONVERTORS

provide a thin lubricating film on the surface of the steel which reduces friction and allows metal to flow into the dies.

Water soluble oils in the form of emulsions are used for general purpose work. In the case of light drawing, low viscosity liquid oil or emulsions and soap solutions are used.

Lubricants can be applied by brush, dipping, spraying or wiping, whichever is the most effective. Where metal flow into a die needs to be controlled, drawing compounds can be used selectively i.e. those parts where more stretching is required, little or no lubricant is applied to that area so that the higher frictional forces generated retard metal flow in that area.

Frequently, the plastic film (PVC) supplied on the stainless steel sheet from the mill is left in place, and provides an excellent lubrication film in addition to the above, and minimizes surface damage.

## PERCENTAGE REDUCTION

The more ductile austenitic stainless steel such as grade 304 can be drawn as much as 55% on the initial draw. Less ductile stainless steels may only be drawn 25% on the initial draw. The percentage reduction

in one draw is therefore dependent on a metal's ductility, thickness, die clearance and the radius of the punch.

Generally, for cup-shaped items, a draw depth of 45 to 50% of the blank diameter is possible. For rectangular or box-shaped articles a depth equivalent to 4 to 6 times corner radius is feasible.

## EQUIPMENT

Generally, stainless steels require as much as twice the forming pressure than carbon steel for a given thickness and depth of draw. The fact that higher strengths are achieved due to work hardening of the stainless steel, means that thinner gauges are usually used so that forming pressures do not differ greatly from those used for carbon steels. The hold-down pressures are very important and are determined by the way in which metal will be allowed to flow into the die. Hold-down pressures for stainless steels are in any event 50 to 100% more than those used for carbon steel. In addition, hold-down pressures must be evenly applied. Drawing speed too, must be controlled to roughly half that used for carbon steel and hence hydraulic presses are usually preferred as drawing speeds can be more easily controlled than in mechanical presses.

The descriptions above have given a general outline of the fundamentals of deep drawing. However, modern technology involving variable draw speeds, segmented and variable hold-down pressures and computer control have revolutionized the production of complex deep drawn articles such as double bowl kitchen sinks and intricately shaped shells used in catalytic converter manufacture. **SS**



Deep Drawn Stainless Steel Cylinders