FORMING STAINLESS STEEL

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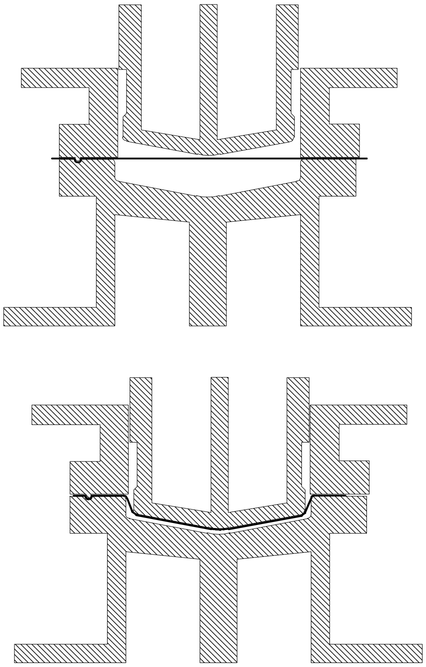
FORMING

The techniques used for forming stainless steel sheet are basically the same as those used for forming carbon steel. There are, however, certain important differences due to the special deformation and surface properties of stainless steel. A brief summary explaining how stainless steels are formed, together with development trends, is given below. Comparisons of forming carbon steel are also given where differences exist.

Forming methods

The methods used for forming stainless steel are the same as those used for carbon steel. The most common methods are deep drawing, hydroforming, bending, roll forming and spinning. Figure 1 through to Figure 3 illustrate the principles behind some of the different forming techniques. The demands placed on equipment, however, are more stringent than those applying to carbon steel, as higher forming forces are required. This is in turn due to the significant strain hardening properties of austenitic stainless steel and the high strength of duplex steels.



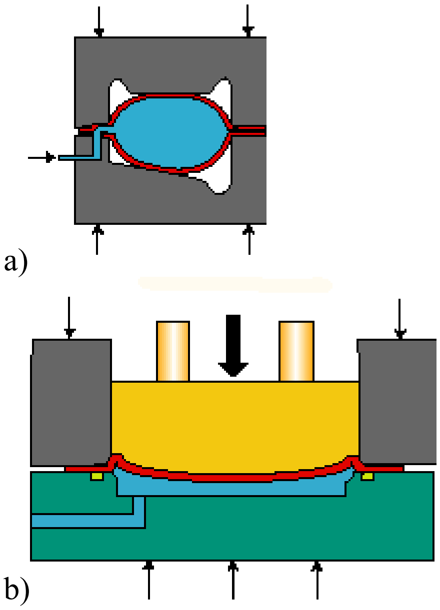


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Figure 1 Deep drawing

Figure 2 Hydroforming
a) a) hydrostatic forming
b) b) hydromechanical forming.

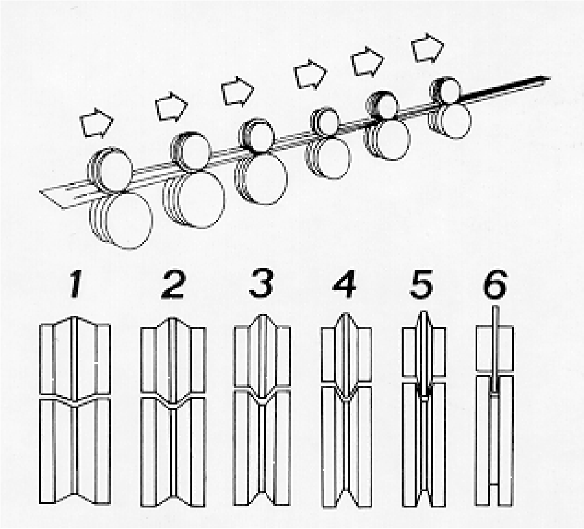

Figure 3 Roll forming

The ideal deep drawing operation involves no reduction in sheet thickness and the shape of the work piece is obtained by drawing material from a blankholder. When stretch forming, on the other hand, it is this reduction in the thickness of the sheet that is used to obtain the desired shape. Actual forming operations may include a combination of these basic elements.

Deep drawing is the method most commonly used in the high volume production of complex three-dimensional work pieces. Typically, annealed material is used, since deep drawing operations typically demand a sheet material that is highly susceptible to deformation. One typical adaptation of the deep drawing method to suit the special forming properties of stainless steels is the fact that stretch forming (a reduction in sheet thickness) is used to a greater extent for austenitic stainless steels than for carbon steels, where deep drawing can be used to a greater extent. This is due to the fact that the r-value (normal anisotropy) is lower for austenitic stainless steels (typically $r\sim1$ for austenitic stainless steel and $r>2$ for carbon steel), whereas the strain hardening n-value is significantly higher ($n>0.4$ for austenitic stainless steel and $n<0.3$ for carbon steel). Due to the lower r-value, it is not possible to draw work pieces as deeply by drawing material from the blankholder (=deep drawing). Instead, one tends to make use of the possibilities of reducing the thickness of the material, perhaps with an intermediate annealing.

The process of hydroforming sheet is usually divided into hydrostatic forming and hydromechanical forming, see Figure 2. Moreover, some variations of these techniques have been patented, e.g. flex forming and the SMG method. Hydroforming techniques have been around for many years but have perhaps not been exploited to their full capacity in an industrial context. However, it now seems as if the technique is gaining ground. The good stretch forming properties of austenitic stainless steel should yield significant benefits when hydroforming as the technology is largely based on optimising and controlling the reduction in thickness of sheet, particularly in the case of hydrostatic forming, see Figure 2a. As with deep drawing, annealed material is typically used when hydroforming.

The main advantage of hydroforming compared with deep drawing is that it is possible to draw deeper work pieces (for example, the draw ratio for stainless steel can be increased from a typical 2.0 to more than 2.5 with hydroforming), which in the case of stainless steel can be useful for compensating for the lower r-value. It is also possible to achieve a more even reduction in the thickness of the plate, which probably creates greater opportunities for stainless steel than for carbon steel. The main disadvantage of hydroforming is that it results in significantly lower productivity.

Roll forming involves bending the blank between rotating rolls, see Figure 3. Whilst bending primarily involves the piecewise production of parts, roll forming is typically a continuous process from coil. The choice of method must be determined from case to case, and based on the availability of equipment, batch sizes, the need for subsequent processing, shape of the work piece, etc. Roll forming can be carried out on both annealed and tensile material (up to a yield point of 1400 MPa has been tested). For edge bending, greater limitations apply to tensile material as regards the minimum radius of the bend.

In the field of roll forming tensile stainless steel, intense development work is currently under way and this will probably lead to entirely new methods of developing lightweight high-strength constructions.

Tool design

As has already been mentioned, the use of stainless steel typically requires greater forming forces and accordingly leads to greater tool stresses. This means that an upgrade of the material used in the tools and/or some form of surface coating may be necessary to ensure the service life of tools. If this is not possible, it may be necessary to increase tool radii to reduce tool stresses. In blanking tools, PM steels are commonly used for high volume production. It may also be necessary to reinforce the entire tool structure to compensate for higher deflection compared with the forming of carbon steels.

Stainless steel has a greater tendency to gall, which also places greater demands on tool design and on the materials used in the manufacture of tools. In addition to high-performance PM steels, bronze alloys are commonly used to address this problem. However, these have the disadvantages of inferior workability and resistance to wear compared to tool steels. Intense developments are ongoing, using PM steel technology, aimed at resolving the galling tendency of stainless steels.

Draw beads are not used as frequently for forming stainless steel sheet due to the higher material cost which the bead entails, but probably also due to the considerable stress on tools and the problem of galling. Here, a development project is probably required for stainless steels, as draw beads are probably difficult to eliminate entirely.

One example of a proposal on how to eliminate draw beads has been published for the manufacture of sink units with double sinks. By using a flexible die-plate and locally concentrated blank holding underneath where the draw bead would normally be placed, it is possible to obtain sufficient blank holder force locally to guide the complex material flow around the sinks.

Lubricants

The protective oil currently used for forming carbon steels is not suitable for use with stainless steels. Typically, a more high performance lubricant is required; synthetic lubricants are often used. However, there have been intense development activities to develop dry lubricants for both carbon steel and stainless steel. Commercial products already exist for aluminium. The most promising lubricant consists of a polymer film that is applied in layers of around 1 g/m^2. The thickness of the layer has been chosen to ensure that spot-welding can be carried out without impairing the effect of the lubricant.

The development work carried out so far has produced very promising results for stainless steel. Many of the difficulties that have been discovered for carbon steel, e.g. corrosion protection, do not apply to stainless steel. There is therefore a realistic likelihood that a commercial product for stainless steel will be developed shortly. A considerable advantage with such a lubricant would be that the level of friction would be largely independent of substrate, i.e. carbon steel and stainless steel produce more or less the same level of friction, see Figure 4. Another advantage is that the level of friction can be varied by modifying the friction additive, see Figure 5.

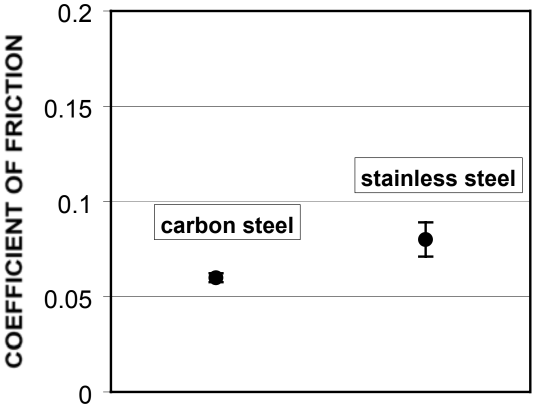

Figure 4 Comparison of friction levels for carbon steel and stainless steel when using the same dry lubricant.

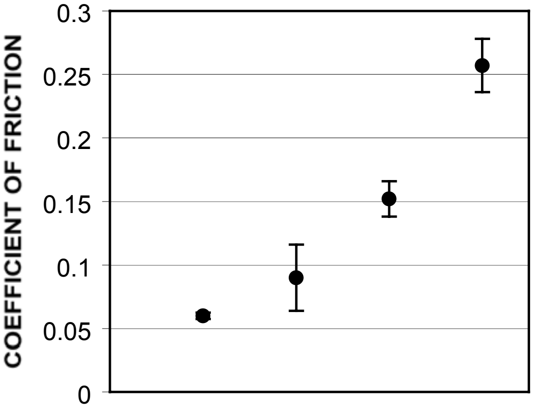

Figure 5 The possibility of varying the friction level with a dry lubricant.

It will also be possible to use the same lubricant for both stainless steel and carbon steel, which is not presently the case.

It remains to be seen whether the positive lubrication properties hitherto established for this new lubricant also apply to high volume production. There is, however, nothing to suggest that this will not be the case. Note that the aforementioned problems concerning galling of tool surfaces with stainless steel will also be eliminated with this lubrication concept.

Conclusions

1. Stainless steels can be formed using the same techniques as those used for carbon steel. Certain modifications are, however, required with regard to tool selection, tool material and lubricant in order to exploit the full potential of stainless steel's forming properties. The developments accomplished in recent years have made it considerably easier to solve some of those problems normally associated with forming stainless steel. Examples worthy of a mention in this context include the development of modern PM steels for pressing tools and dry lubricants.
2. The roll forming technique offers new possibilities for forming stainless steels with extremely high-strength properties. Ongoing development projects will demonstrate how these possibilities can be put to use in future designs.

FORMABILITY OF STAINLESS STEELS

Introduction

The formability of sheet is primarily determined by its work hardening (n-value), strain rate dependence (m-value) and anisotropy (r-value). The higher these values are the better. Austenitic stainless steel is above all characterised by its high work hardening and strain rate dependence, whereas its anisotropy is low, compared to that of carbon steel. It is the high work hardening properties of stainless steel that give it its superior combination of strength and formability.

The formability of sheet material is usually described using a number of laboratory tests; to demonstrate deep drawing properties (the Limiting Drawing Ratio, or LDR test), stretch forming properties (the Erichsen test) and the material's ultimate failure limit in different modes of deformation the Forming Limit Diagram (FLD) test. The idea here is that these laboratory tests give an overall presentation of the behaviour of sheet metal in actual drawing operations that involve a mixture of stretch forming and deep drawing. Although a more detailed study might lead to the results being brought into question, these tests nevertheless make it possible to gain an overall view of the formability of different types of sheet metal.

Deep drawing properties

Deep drawing properties are usually described by drawing cylindrical cans with successively larger blanks. The relation between the diameter of the largest possible blank and the diameter of the punch produces the LDR value. As illustrated in Figure 6, there is a clear link between the LDR value and normal anistropy, r–value. It is also clear that the maximum size of the blank that can be drawn is larger for carbon steel than for austenitic stainless steel. However, this does not necessarily mean that carbon steel cans can undergo much deeper drawing. The material's superior resistance to thinning (high n-values) means that the same blank size can be used to form deeper cans in austenitic stainless steels, and this can to a certain extent compensate for the lower LDR value. Naturally, this presumes that it is permissible to reduce the thickness of the material from a functional viewpoint. However, there is no systematic data available for this.

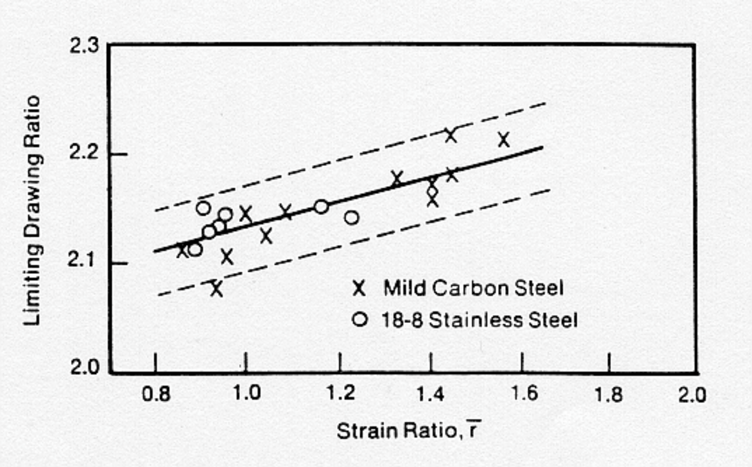

Figure 6 Relation between deep drawing properties and normal anisotropy, r-value.

Note also that if a comparison is made for the same level of strength, carbon steel also has an r-value close to 1, which means that its deep drawing properties are comparable to those of austenitic stainless steel.

Stretch forming properties

The Erichsen value is a typical method for measuring stretch forming properties. Similar tests include the Olsen, LDH, LDH_0 and OSU tests. One factor common to all these tests is that the punch depth obtained is determined merely by the thinning of the material, i.e. no material is drawn in from the blank holder area. Examples of differences between the methods include eg. the stress state being tested.

Many projects have revealed a close link between high elongation values in tensile testing or n-values and stretch forming properties. An analysis of this kind illustrates why austenitic stainless steels have such good stretch forming properties. It is also interesting to analyse the combination of stretch forming properties and mechanical strength, which is reported in Figure 7. This demonstrates that a better combination of stretch forming properties and mechanical strength can be achieved with austenitic stainless steels than with carbon steel. In concrete terms, this means that these steels are suitable candidates for weight saving applications, since they have high formability despite also having high strength, particularly if the choice is one of carbon steel and stainless steel, where both materials have the same degree of strength.

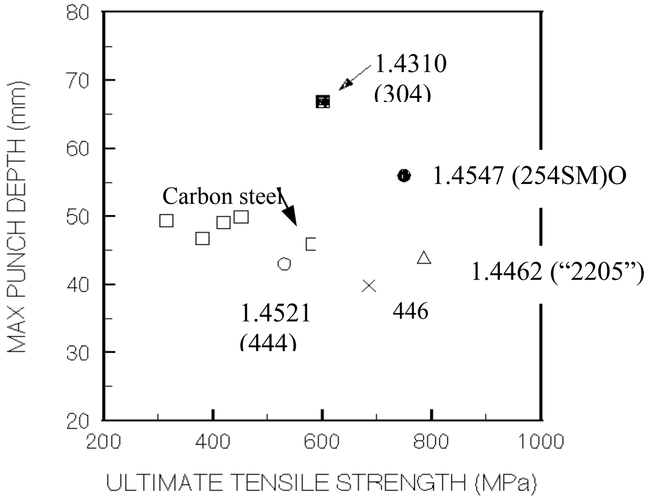

Figure 7 Relation between stretch forming properties and mechanical strength

Forming limit diagrams

The forming limit diagram is a measure of the sheet's ability to resist localised thinning and fracture in the stress-strain condition that is typical for sheet forming. Many projects have revealed that a high FLD level is dependent on a high n-value, a high m-value and a low density of defects (impurities, cavities, etc). In addition to these material properties, the FLD level is sensitive to sheet thickness, tool geometry and the size of the measuring circle, and suffers from the lack of a standardised evaluation methodology. This makes it difficult to compare FLD levels for different projects. Note that the sensitivity to sheet thickness and tool geometry also applies to the aforementioned techniques for determining deep drawing and stretch forming properties. The difference, however, is that for some of these methods, unity has been reached regarding standardised testing procedures.

Figure 8 provides a comparison of the FLD levels for different stainless steel grades tested in the same manner. It is clear that the levels for austenitic stainless steels are higher than those for ferritic (A compared with F), that the FLD level decreases with increasing strength for austenitic stainless steels (A compared with HSA) and that the FLD level for the ferritic-austenitic (duplex) steel FA(50) lies somewhere between A and F.

Figure 9 illustrates a comparison of an austenitic stainless steel and one carbon steel with the same strength (arrows in Figure 7), tested using a slightly different technique than that seen in Figure 8. The FLD level of the austenitic stainless steel is higher in this comparison (note that the austenitic stainless steel is of the 316 type, i.e. not a high-strength stainless steel). If this comparison had instead been made with a mild carbon steel of the DC06 type, the difference would have been less pronounced, but the austenitic stainless steel would nevertheless have had a higher FLD level.

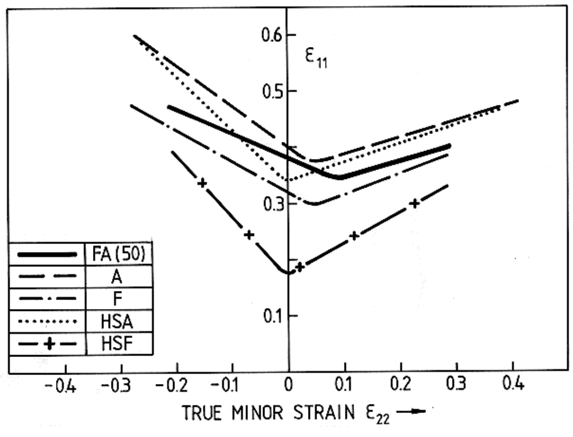

Figure 8 Comparison of the FLD level for different stainless steels. A=austenitic stainless steel, F=ferritic stainless steel, HSA=high-strength austenitic stainless steel, HSF=high-strength ferritic stainless steel, FA(50)=ferritic-austenitic stainless steel.

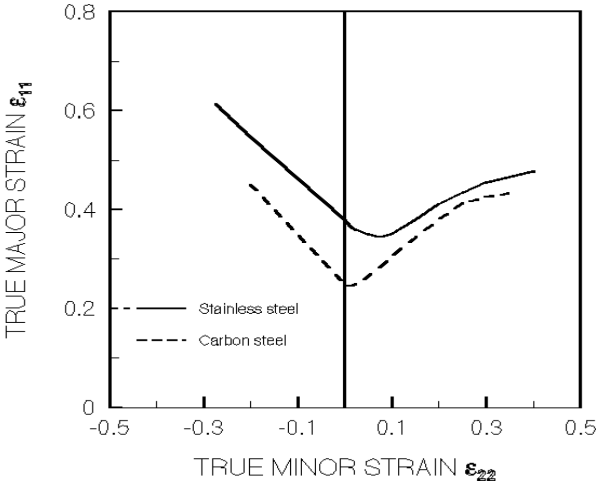

Figure 9 Comparison of an austenitic stainless steel and carbon steel of equal strength (arrows in Figure 7).

Conclusions

Austenitic stainless steel offers a superior combination of strength and formability than carbon steel due to its high work hardening properties. A comparison of an austenitic stainless steel and carbon steel of the same strength reveals that the materials have comparable deep drawing properties. However, austenitic stainless steel has inferior deep drawing properties compared to mild carbon steel. This can, however, often be compensated for by the improved ability of austenitic stainless steel to resist thinning.

TRIBOLOGICAL PROPERTIES OF STAINLESS STEELS

Introduction

It may generally be said that the tribological properties of stainless steel place greater demands on tool design and lubricants. Typically, this means that higher performance tool materials and lubricants are required to avoid excessive adhesive wear. The use of surface coated tools is also a common practice.

The reasons for the critical tribological properties for stainless steel have never really been satisfactorily explained, although the following explanations are probable (in no particular order):

- High tool pressure (which is in turn caused by the high work hardening properties) makes it difficult to lubricate the area of contact.
- Poor thermal conductivity increases the temperature on the area of contact, adversely affecting the lubricant's properties.
- The chemically inert surface ("stainlessness") adversely affects the lubricant's ability to wet the surface.
- No supplier of stainless steel sheet can supply surfaces with a roughness similar to that of carbon steel (that has been designed to facilitate lubrication).

A brief summary explaining the friction properties of stainless steels and their adhesive properties, often referred to as galling properties, is given below.

Friction properties

The term friction properties refers to the level of friction for a particular material combination in a certain contact geometry, i.e. in circumstances where galling does not occur. In other words, it is vital to analyse the experimental equipment used to determine the friction and the testing parameters chosen, besides the material combination tested.

It cannot generally be stated that the level of friction differs for stainless steel and carbon steel provided that the materials are tested under the same conditions. Normally, however, carbon steel is tested using a protective oil, whereas stainless steel is tested using a more high-performance lubricant. In this case, the level of friction for stainless steel would typically be half that for carbon steel (non-coated). If the carbon steel was tested using the same lubricant, the difference would probably be less.

With wet lubricants, it is in other words difficult to find a universal lubricant that works equally well for both carbon and stainless steel. It is not possible to use a protective oil for stainless steel, and it is hardly advisable to encourage the use of high-performance lubricants for carbon steel. One solution would be to use the dry lubricant currently under development. This consists of a polymer film with a thickness of approximately 1 g/m^2.

The dry lubricant offers a series of benefits, e.g. a similar level of friction for both stainless steel and carbon steel, and that the contact of tools is eliminated, which limits galling (see below). The impact of the surface topography (probably minor) is currently under evaluation, as is the behaviour of the lubricant during high volume production. Further, the degree of corrosion protection is insufficient at the present stage of development, but this is naturally only a problem for carbon steel.

Galling

Sheet forming usually involves some difficult contact conditions due to a combination of high contact pressure and a considerable surface expansion of the work piece. This makes it virtually impossible to separate the tool surface totally from the surface of the sheet using a lubricant film. Irregularities in the tool surface will always come into contact with the sheet surface, resulting in scratches. This can occur at micro level at the beginning of a tool's service life. But if each forming operation leaves sheet fragments on the tool surface, a coating of sheet material will gradually form on the surface of the tool. This coating will form new hard irregularities on the tool surface that scratch the sheet surface and after a number of forming operations, deep scratches may be found on the formed components. At this stage, it is necessary to stop production in order to recondition the tool surfaces.

Galling occurs with most material combinations. Zinc-coated sheet, for example, is renowned for causing galling problems in certain circumstances. Stainless steel can give rise to substantial galling in just a few pressing operations if the wrong tool materials and/or lubricants are used. It is therefore essential to make use of the experience available in the field among major producers of stainless steel components.

Typically, one might say that a larger proportion of high-performance tool materials such as PM steels and tempered tool steels are used when forming stainless steel than when forming carbon steel. It is also necessary to ensure that the tool surfaces have a highly polished surface finish from the start to avoid metal-metal contact. Different types of surface coating, such as PVD and CVD coatings are common to further improve tool performance. In many contexts, the use of bronze has proven to be highly advantageous when forming stainless steel. However, one of the disadvantages of this material is its relatively limited resistance to wear.

As mentioned previously, high-performance synthetic lubricants are used far more extensively for forming stainless steels than they are for carbon steels. There are, however, examples of high volume products where relatively simple lubricants are used. However, these tend typically to be components with little drawing depth that are formed in tools manufactured in sophisticated surface coated tool steels.

As mentioned previously, the newly-developed dry lubricants will offer entirely new opportunities for the forming of stainless steel sheet. These enable an almost total separation of the tool surface from the sheet surface, i.e. galling cannot occur. To verify this, however, it will be necessary to evaluate the use of such lubricants in a production environment.

Conclusions

A general trend in press shops is to use low performance lubricants and to reduce the amount used. There are basically two options available: either use wet lubricants and improve tool performance (by changing to surface coated tempered tool steels or PM steels, the latter perhaps also surface coated) or use dry lubricants that do not require such high performance tool materials.

As the forming of stainless steel sheet demands greater care in the design of tools and in the choice of tool material and lubricant than is the case with carbon steel, the task of choosing an appropriate strategy from the above-mentioned options will be crucial, particularly for high volume products. The advantage of the first strategy is the widespread industrial knowledge of tool/lubricant solutions available. The strategy of using dry lubricants is partly new and untested.