CONSIDERATIONS ON THE SELECTION OF MATERIALS FOR THE
REALISING OF DEEP-DRAWN BIMETALLIC PARTS

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Abstract
The paper presents a method for the global assessment of a material's formability and weldability, in order to allow the realising of deep-drawn parts made of two or more metal sheets joined together by welding. Such an assembling method is useful in the case of large parts of which only small segments are subjected to a higher stress, thus allowing the reduction of production costs. The paper analyses the various parameters that contribute to a material's formability and weldability and proposes a unique parameter that can be used to describe a given material's behaviour when subjected to the indicated assembling and processing technology. This will allow a producer to select the right materials for such procedures in a more rational manner.

1. INTRODUCTION
The complexity of the instruments, machines and structures that are in use today implies also a great variety in the types of forces acting on a certain part, either during its manufacturing, or during its actual usage. This fact has a direct effect on the materials of which these objects are made.

For example, in the case of parts that are subjected to high forming stresses, during rolling, deep-drawing, stretching etc., it is sought to realise these parts of materials that display high mechanical strength, on the one hand and a good plasticity behaviour on the other hand. Unfortunately, however, such materials tend to be very expensive, and if the parts are relatively large, this can develop into a real economic problem.

A solution for this problem would be to adopt an idea already used in the manufacturing processes on lathes, milling machines etc., where only the actual cutting area of the cutting tool is realised of a high-strength, expensive material, while most of the tool body consists of a common steel type.

Similarly, parts that are subjected to high forming stresses could be made of two materials: a relatively cheap material, with weaker properties in the least stressed areas and another, stronger but also more expensive material in the areas where it is expected to see the largest stresses, the two materials being attached to each other by butt welding.

This idea requires, however, that the materials employed for this purpose display both a good formability and a good weldability.

Finding materials with both these characteristics is a rather difficult process if done in a disorganised manner. While there exist, of course, tables comparing the values for a certain property of a group of materials, it is still difficult to correlate the various values and assess the importance of the different properties for the selected task. And, of course, it would be very difficult to assess the suitability of materials based (solely) on direct experimental tests, which would take up a long time.

Therefore, the authors of this paper have developed a combined parameter that, in connection with a database containing various characteristics of a large number of materials (especially steels), could be used to better assess the suitability of these materials for the presented purpose.
2. PARAMETERS INFLUENCING THE FORMABILITY OF STEELS

The concept of sheet-metal forming process comprises a large family of different forming operations, ranging from simple bending to stamping and deep drawing of complex shapes. Since the formability of a sheet metal depends greatly on the nature of the forming operation, separate determinants must be considered for each type of formability.

In simple stretching operations, for example, the forming limit is determined by the uniform elongation of the metal as it is related to the strain-hardening exponent \( n \).

Because most sheet forming operations usually involve stretching and some shallow drawing, the product of the strain hardening exponent, \( n \), and the normal anisotropy, \( R \), of the sheet has been shown to be a significant parameter.

In the following, we will study only the case of parts formed through deep-drawing, so we will try to assess drawability as a variant of formability.

Deep drawing of sheet metals has been studied extensively (ASM INTERNATIONAL Vol. 14, 1996), and the concept of "limiting drawing ratio" (LDR), the ratio of maximum blank diameter to punch diameter, is currently the most used to define deep drawability. Several parameters are involved in deep drawing, and their control is important in avoiding the tearing of the formed part, the wrinkling of the flange, or the appearing of other defects.

Several researches have attempted to establish a relationship between the LDR and some mechanical properties of the sheet metal.

Thus, it has been shown that for pure drawing, the important parameter in deep drawability is the normal anisotropy of the sheet, \( r \). This parameter, also called strain ratio or plastic anisotropy, is the ratio of width to thickness strains in a simple tension test and it is generally measured at an elongation of 15 to 20% of the sheet specimen:

\[
r = \frac{\varepsilon_w}{\varepsilon_t},
\]

where \( \varepsilon_w \) is the elongation on the width direction and \( \varepsilon_t \) is the elongation on the thickness direction (KALPAKJIAN 2003).

For determining this parameter globally, knowing that differences may occur in planes situated at angles of 0°, 45°, and 90° with regard to the direction of the main force, normal anisotropy has to be determined in each of these planes, resulting in the values noted \( r_0 \), \( r_{45} \), and \( r_{90} \), respectively. The average normal anisotropy is then given by the expression:

\[
r = \frac{r_0 + 2r_{45} + r_{90}}{4}.
\]

The size of the average normal anisotropy depends on the type of sheet metal and its processing history, but also on the grain size, increasing as the grain size increases.

The normal anisotropy value for a specific material can be found as such in some tables or can be obtained practically through tensile tests on the analysed sheet metal, but it can also be easily calculated starting from the other basic parameters of this material. Therefore, it can be used as a reliable parameter also for the purpose of determining a combined drawability and weldability coefficient.

Figure 1 presents as an example the variation of the strain ratio \( r \) with direction in low-carbon steel and effect of average the strain ratio on the drawability of cylindrical cups (ASM Vol. 14, 1996)
Fig. 1 Variation of the strain ratio $r$ with direction in low-carbon steel and effect of average the strain ratio on the drawability of cylindrical cups

Another way to express drawability is by means of analysing earing. Earing can be predicted from the expression for planar anisotropy, $\Delta r$:

$$\Delta r = \frac{r_{50} - 2r_{45} + r_{00}}{2}$$

When $\Delta r$ is zero, no earing occurs in the part. Thus, deep drawability increases with high $r$ values and low $\Delta r$ values.

Also, especially for steels, there is a relationship of proportionality between the modulus of elasticity, $E$, and the $r$ value of the sheet, so this parameter too can be used to assess drawability.

The formability of all metals decreases as the yield strength increases. Therefore, in press-brake forming, power requirements and springback problems increase and the degree of bending that is practical decreases as the yield strength of the work metal increases.

Of course, formability and deep drawability in particular are influenced also by the state of the material and by any other treatments that were applied to it before the forming operation. Therefore, since it would be very difficult to define a parameter, or even several parameters that would allow the quantifying of these effects on drawability, each state of the material would have to be considered separately in the attempt to determine a combined formability-weldability parameter.

3. PARAMETERS INFLUENCING THE WELDABILITY OF STEELS

Weldability can be divided into two general classes: fabrication weldability and service weldability (ASM Vol. 6 1996).

Fabrication weldability tries to answer the question whether the analysed materials can be joined by welding without introducing detrimental discontinuities such as hydrogen-assisted cold cracks, hot cracks, reheat cracks, lamellar tearing, and porosity. The acceptability of these discontinuities depends on the requirements for the particular welding application. The fabrication weldability of a steel may be adequate for a noncritical application, but the same steel may not be recommended for a critical application, or one would need to take special precautions, such as preheating, when welding.

Service weldability concerns the extent to which the joined part has adequate properties for the intended function. An important aspect of service weldability is the comparison of properties in the
heat-affected zone (HAZ) with those of the unaffected base metal. The real meaning of service weldability too depends on the intended application. The service weldability of a particular steel may be acceptable for an application where corrosion is of prime importance and toughness is secondary. However, the same steel may be unacceptable for an application where toughness is most important. Service weldability may determine the range of heat inputs allowable for a particular steel. Low heat inputs may introduce unacceptable low-toughness microstructures, as well as cracking. On the other hand, high heat inputs can introduce coarse microstructures with both low toughness and low strength. The heat input alone does not control the resulting microstructure and HAZ properties, but the induced thermal cycle controls the microstructure and properties. Therefore, both heat input and thickness should be considered.

The weldability of steel is inversely proportional to its hardenability, which indicates the ease of martensite forming during the heat treatment of this material. The hardenability of a steel type depends on its chemical composition, with greater quantities of carbon and other alloying elements resulting in a higher hardenability and thus a lower weldability. In order to be able to assess alloys consisting of many distinct materials, a measure known as the equivalent carbon content is used to compare the relative weldabilities of different alloys by comparing their properties to a plain carbon steel. The effect on weldability of elements like chromium and vanadium, while not as great as carbon, is more significant than that of copper and nickel, for example. As the equivalent carbon content increases, the weldability of the alloy decreases.

While formerly the usage of carbon and low-alloy steels in welding applications was somewhat restricted due to their lower mechanical strength, the relatively recent introduction of high strength, low-alloy (HSLA) steels has changed this, and HSLA steels are now widely used in welded structures.

Stainless steels tend to behave differently with respect to weldability than other steels, because of their high chromium content. Austenitic grades of stainless steels tend to be the most weldable, but they are especially susceptible to distortion due to their high coefficient of thermal expansion. Other types of stainless steels, such as ferritic and martensitic stainless steels are not as easily welded, and must often be preheated and welded with special electrodes.

It can thus be seen that of all parameters influencing weldability, the most important and quantifiable one related strictly to the material's properties is the equivalent carbon content.

A commonly used formula for calculating the equivalent carbon content in carbon or low alloy steels is:

\[ C_e = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \text{ [\%]}, \]

where C, Mn, Cr, Mo, V, Ni and Cu represent the actual percentage of the respective elements in the steel's composition.

It has been shown (OATES 1998) that for equivalent carbon contents above 0.4, the danger of cracks forming during welding becomes very high, so special precautions would need to be taken in order to successfully weld such materials. Other authors use a separate indicator for the susceptibility to cracking, but it too is based exclusively on the chemical composition of the steels.

When using oxyfuel welding, a condition for good weldability is also that the difference between the materials temperature of burning in oxygen has to be smaller than the melting temperature. The temperature of burning in oxygen varies lineary with the carbon content and is smaller than the melting temperature for steels with maximum 0.9 % C, so this condition too can be resolved by using the equivalent carbon content as indicator.

4. INTRODUCING THE COMBINED FORMABILITY-WELDABILITY PARAMETER

A combined formability-weldability parameter, or, in the more specific case discussed in this paper, a combined drawability-weldability parameter, has to take into account both the dominant factors influencing drawability and those influencing weldability.

The above considerations have shown that finding steels that display both a very good drawability and a very good formability is rather difficult.

As indicated above, drawability can be assessed by resorting to the material's strain ratio and to the modulus of elasticity.
On the other hand, weldability has been shown to depend on the equivalent carbon content, \( E_c \). As opposed to drawability, where no clear limit between drawability and "non-drawability" has been determined, weldability is limited by the \( E_c \) value after which cracks could form in the material. Therefore, the authors consider their idea of a combined drawability-weldability parameter as justified and propose following formula for it:

\[
C = \frac{r \cdot E}{H(0.4 - C_e)}
\]

where:
- \( r \) = the material's strain ratio
- \( E \) = the material's modulus of elasticity (in kN/mm\(^2\))
- \( H \) = the material's Vickers hardness
- \( C_e \) = the material's equivalent carbon content

The material's Vickers hardness was introduced as a means to quantify the material's state (e.g. cold-rolled, annealed etc.). The higher this parameter's value, the better the material's suitability to both deep drawing and welding should be. Also, a negative coefficient (resulting from an equivalent carbon content higher than 0.4), would indicate that the material cannot be used for the intended purpose.

5. CONCLUSIONS

The present paper has shown some efforts by the authors to find a theoretical way for detecting steel grades that can be both deep-drawn and welded with good results.

The obtained combined parameter can, if combined appropriately with a database containing the most important properties of commercial steel types, lead to a quick hierarchisation of steels with regard to their behaviour during these two manufacturing processes. Moreover, in the case when the base material has already been selected, it would allow a manufacturer to choose the other material for a bimetallic part so that the latter's characteristics match the relevant ones of the base material as good as possible, i.e. so that the values of the combined parameters are as close as possible.

LITERATURE REFERENCES


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