Proceedings of the 17th International Conference on Manufacturing Systems – ICMaS
ISSN 1842-3183
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COMPUTER-AIDED SELECTION OF STEELS FOR THE REALISING OF BIMETALLIC DEEP-DRAWN PARTS

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Abstract: *The current paper presents a method for the global assessment of a material's formability and weldability, in order to allow the realizing of deep-drawn parts made of two or more steel sheets, the one made of plain carbon steel and the other of high-quality alloyed steel joined together by welding. 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. Furthermore, a computer-aided material selection approach for this application is described. This will allow a producer to select the right materials for such procedures in a more rational manner.*

Key words: *deep-drawing, steel, formability, weldability, computer-aided selection*.

1. INTRODUCTION

Nowadays, engineers involved in industrial production and development processes are confronted with a double problem. On the one hand, they have to chose the right material or materials for a specific application from a huge range of available possibilities. On the other hand, they have to reach a compromise between the technical and the economic characteristics of the employed material or materials.

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 area of machining processes on lathes, milling machines etc., where only the actual cutting area of the cutting tool is realized of a high-strength, expensive material, while most of the tool body consists of a common steel type.

Similarly, parts that would be subjected to high forming stresses during their manufacturing or actual usage 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 in the conditions of the already mentioned huge range of available options 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.

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), allows a computer-aided approach to the problem and could be used to better assess the suitability of these materials for the presented purpose.

In order to obtain this parameter, in a first stage the authors have analysed separately the factors influencing the material's formability, the factors influencing the material's weldability and combined their findings in a single formula. Finally, a suitable database structure for this application was created.

2. PARAMETERS INFLUENCING FORMABILITY

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, 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 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:

$$R = \frac{\varepsilon_w}{\varepsilon_t}\,, \qquad (1)$$

where ε_w is the elongation on the width direction and ε_t is the elongation on the thickness direction [2].

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:

$$R = \frac{R_0 + 2R_{45} + R_{90}}{4}\,. \qquad (2)$$

In addition to the type of sheet metal and its processing history, the magnitude of the average normal anisotropy also depends 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 with direction in low-carbon steel and effect of average the strain ratio on the drawability of cylindrical cups [2]

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

$$\Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2}\,. \qquad (3)$$

When ΔR is zero, there is no earing. Deep drawability is thus enhanced by high R values and low ΔR 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.

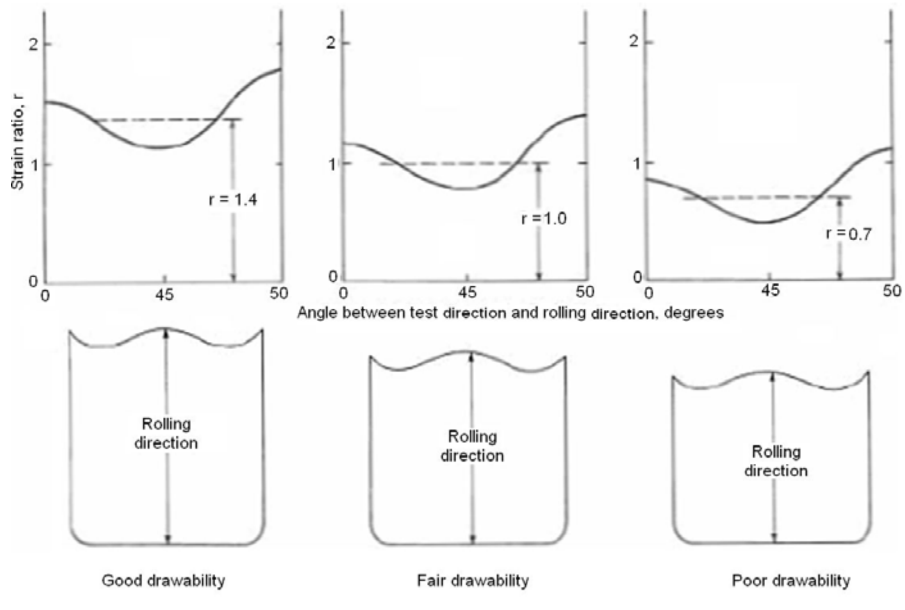

Fig. 1. Variation of the strain ratio with direction in low-carbon steel and effect of average the strain ratio on the drawability of cylindrical cups [2].

3. PARAMETERS INFLUENCING WELDABILITY

According to the current views on production and processes, found in the technical literature, weldability can be divided into two main classes: fabrication (or manufacturing) weldability and service weldability [1].

Fabrication weldability addresses the problem of joining the analyzed materials by welding without introducing detrimental discontinuities such as hydrogen-assisted cold cracks, hot cracks, reheat cracks, lamellar tearing or porosity. Whether or not these discontinuities are considered as acceptable depends to a large extent on the requirements set for the particular welding application. The fabrication weldability of a steel may be adequate for a noncritical application, but the same steel might require special precautions such as preheating when welding or might not be recommendable for critical applications at all.

On the other hand, the so-called service weldability assesses the existence of adequate properties in the joined part 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 service weldability of a particular steel may be acceptable for an application where wear resistance is the main concern and mechanical strength only secondary, but the same steel may be unacceptable for an application where the mechanical behaviour is the most important criterion. Service weldability may determine the amount of heat that can be induced in a particular steel type. Low heating temperatures might lead to the appearance of unacceptable low-strength microstructures, as well as to the formation of cracks. On the other hand, high heating temperatures can introduce coarse microstructures with low mechanical properties. The heating temperature (the heat input) alone cannot determine the resulting microstructure and properties in the heat-affected zone, but the induced thermal cycle controls the microstructure and properties. Therefore, both heating temperature and material thickness should be considered when assessing weldability.

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 quantifyiable 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:

$$E_c = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad [\%], \tag{4}$$

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

In [5], it has been shown that for equivalent carbon contents above a value of 0.4, there is an increased danger of cracks forming during or after welding, so handling such materials implies taking special precautions. Given the number of available options, materials that would lead to this type of problem should be identified and left out of the considered production process.

In the case of oxyfuel welding, an important condition for achieving a good weldability is also that the materials' temperature of burning in oxygen has to be smaller than the melting temperature. In the case of carbon (unalloyed) steels, 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, when defining a unique material-dependent welding parameter, this condition too can be solved by using the equivalent carbon content as indicator.

4. THE COMBINED FORMABILITY-WELDABILITY PARAMETER

A combined formability-weldability parameter (FWP), 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 the ones influencing weldability.

The previous paragraphs have shown that finding steels displaying both a very good drawability and a very good formability is a rather difficult process if one needs to search separately for the fulfillment of both requirement sets.

As indicated above, drawability can be assessed by means of the material's strain ratio and to the modulus of elasticity.

On the other hand, weldability has been shown to depend on the equivalent carbont 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 of the current paper consider their idea of introducing a combined drawability-formability parameter, for the described application but certainly expandable also to other situations, as being fully justified and propose following formula for it:

$$FWP = \frac{R \cdot E}{H(0.4 - E_c)}, \tag{5}$$

where:

R = the material's strain ratio,
E = the material's modulus of elasticity (in N/mm^2),
H = the material's Vickers hardness,
E_c = the material's equivalent carbon content.

The higher this parameter's value, the better the material's suitability to both deep drawing and welding should be. Also, a negative FWP (resulting from an equivalent carbon content higher than 0.4), would automatically indicate to the user that the respective material cannot be used for the intended purpose.

5. USING OBJECT-ORIENTED DATABASES FOR THE COMPUTER-AIDED SELECTION OF MATERIALS

In order to simplify the selection process of a material for using it in a welded and deep-drawn assembly and to facilitate th implementation of the above-determined parameter the authors have created an object-relational database, *steeldata.dbc*, which comprises 3 separate data files, for the material's general characteristics, for its physical-chemical properties and for the mechanical properties, respectively, using as software Microsoft Visual FoxPro 7.0.

Object orientation is a technology that makes it easy to construct and maintain complex system from individual components. Object-oriented databases remove the so-called semantic gap between an application domain and its representation in persistent storage, achieving their modeling capability through the object oriented concepts of abstract data typing, inheritance, and object identity [5].

The developed software system for the selection of suitable steel types can access material data stored in the three database files (material name, manufacturing company, material type, chemical composition, melting range, yield strength etc.). However, it allows also the manual introduction of parameters, especially of parameters depending on direct experimental results. Based on this information, it then uses the above-mentioned formula for the calculation of the combined formability-weldability parameter. Also, it can order the FWP of the various materials, indicating the ranking of each material with regard to the exact conditions required. Furthermore, starting from a given material (a certain steel type), it allows also to identify materials with similar values of the FWP, which indicates a better compatibility and increases the chances of obtaining a bimetallic system that can satisfy all constructive and functional conditions imposed on it.

6. CONCLUSIONS

The present paper has shown some efforts by the authors on the one hand to find a theoretical way for detecting metallic materials, and especially steels, that can be both deep-drawn and welded with good results and on the other hand, to implement the determined FWP parameter in such manner that a quick and easy determination of this parameter and a reliable relative comparison of the available materials based on the FWP becomes possible.

Furthermore, it has been shown that, while the structure of the parameter itself is not a very complicated one, it allows a hierarchisation of the suitable material solutions, but at the same time it helps eliminating from the start the materials that are not suitable, especially from the point of view of weldability. Moreover, in the case when the base material has already been selected, it would allow the manufacturer of bimetallic parts to choose the other material 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.

The main condition for this is the existence of an appropriate database containing the most important properties of commercial steel types. This database has to contain accurate and complete data on as many materials as possible.

This paper has treated formability and weldability strictly from the point of view of the material's intrinsec properties, trying to assimilate when possible the effects of heat treatments, machining processes etc. on these properties. The current approach requires, for example, a hardened steel and a normalised steel to be treated separately within the database and for the calculation of the FWP. Therefore, it is sought to follow the current attempts at matematical modelling of the properties' variations under various conditions and to introduce the results in the FWP's calculation procedure.

Also, in future, the authors intend to expand the considerations outlined in the current paper by determining a similar way for assessing the compatibility, especially in terms of drawability and weldability/solderability, of materials belonging to different material classes, given the fact that many nonferrous alloys are currently cheaper than steels with equivalent physical, mechanical or technological properties and thus can be regarded as replacements even in the applications presented in this paper.

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