METHODOLOGY FOR DETERMINING DRAWABILITY OF HIGH STRENGTH MATERIALS TO VEHICLES CONSTRUCTION

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Abstract

The work presents the results of a study on drawability evaluation methodology of thin sheet metals of high strength. Materials of high strength are used for the construction of car and aircraft components. Those components are responsible for the safety of the construction of vehicles and thus for the safety of passengers. The high strength of the thin metal sheets creates limitations in their deformability. Due to the limited deformability, development of the drawability evaluation methodology is particularly desirable by designers and manufacturers. Automotive industries have many manufacturing problems with so-called advanced high-strength steels (AHSS), while the aerospace industries - with heat resistant and creep resistant alloys, and e.g. nickel superalloys. In these cases, the standard procedure for the qualification of stamping materials has been found to be insufficient. Due to this both industrial problems have been undertaken research on drawability evaluation of selected high-strength thin sheet metals made of DP steel (AHSS representative) and Inconel 625 (nickel superalloy representative). These studies allowed formulating guidelines to methodology of drawablity evaluation of high-strength thin sheet metals. The drawability of these sheet metals has been comprehensively defined by forming limit curves designation, while modern AutoGrid® digital local strain analyzer and the method of image analysis of deformed coordination nets has been applied. Hereby quantitative and qualitative drawability have been evaluated. The results of the project N R15 0042 06 under the title: “Development of methods for computer-aided design process of stamping products for the aerospace industry”, carried out in 2009-2013, gave rise these guidelines.

Keywords: Drawability evaluation, Inconel 625, AHSS, forming limit curve, strain analyzer Auto Grid

1. INTRODUCTION

The need of drawability evaluation is due to the design requirements of the thin sheet metal fabrication technology. Standard delivered charges for stamping are only supplied with the characteristics of the chemical composition, certified with basic mechanical properties (UTS, YS, elongation, hardness) and according to the technical conditions of delivery for sheets in coils or sheets. In modern product designs more advanced materials with special properties are used. Most often charges for stamping are steels of increased strength, light metal alloys, heat resistant and creep resistant metal alloys, or heterogeneous materials as tailor welded blanks and multilayer materials like sandwich blanks [1-4]. Good industrial practice includes the use of computer-aided engineering techniques for the design of press processes in the automotive and aerospace industries. As a result, numerical simulations of forming processes using e.g. finite element method (FEM) are used [5, 6]. To complete the material model data set, the basic characteristics of the charge material approvals are insufficient, especially for materials with increased strength. This is where the material characteristics developed in accordance with the proposed drawability evaluation guidelines are added. The basic procedure for the designation of forming limit curves GKT was developed and shown in the development project final report [7]. These activities were supported by AutoGrid strain analyzer.

2. DETERMINGING DRAWABILITY

The drawability evaluation can be carried out on three levels: at the basic level, determining the formability based on the strength properties of the sheet; at the expanded level, using selected drawability evaluation tests corresponding to simple technological operations (stretching, compression and stretching with compression) and at the complex level, setting the forming limit curve for the tested charge. Described assessment can also be executed ad hoc or as a planned evaluation, according to the form of its use. With the planned drawability assessment we are already dealing with the design phase of the new product and the selection of material for this product. For this purpose we have to have the results of the planned evaluation of the actual pressures of the sheets, among which we choose those with optimum characteristics for our project. On the other hand, on an ad hoc assessment we will speak at the start of production and at the need to control the technological formability of delivered charges. Hence, the task of evaluating drawability is particularly important because it enables efficient production. Too wide assumptions at the process design stage can generate production constraints, or prevent production from too roughly-machined charges, just as with too short a rough estimate of drawability.

2.1. Basic methods of drawability evaluation

The basic mechanical properties of the sheet metals determined in a uniaxial tensile test serve as a rough estimate of the drawability. The principle is simple, the higher the strength, the lower the plasticity and thus the lower drawing properties. However, already for high strength steels, this rule is no longer useful, as is maintaining the YS/TS ratio below value 0.7. (**Figure 1**). For non-ferrous metal alloys, this simple evaluation is not enough.

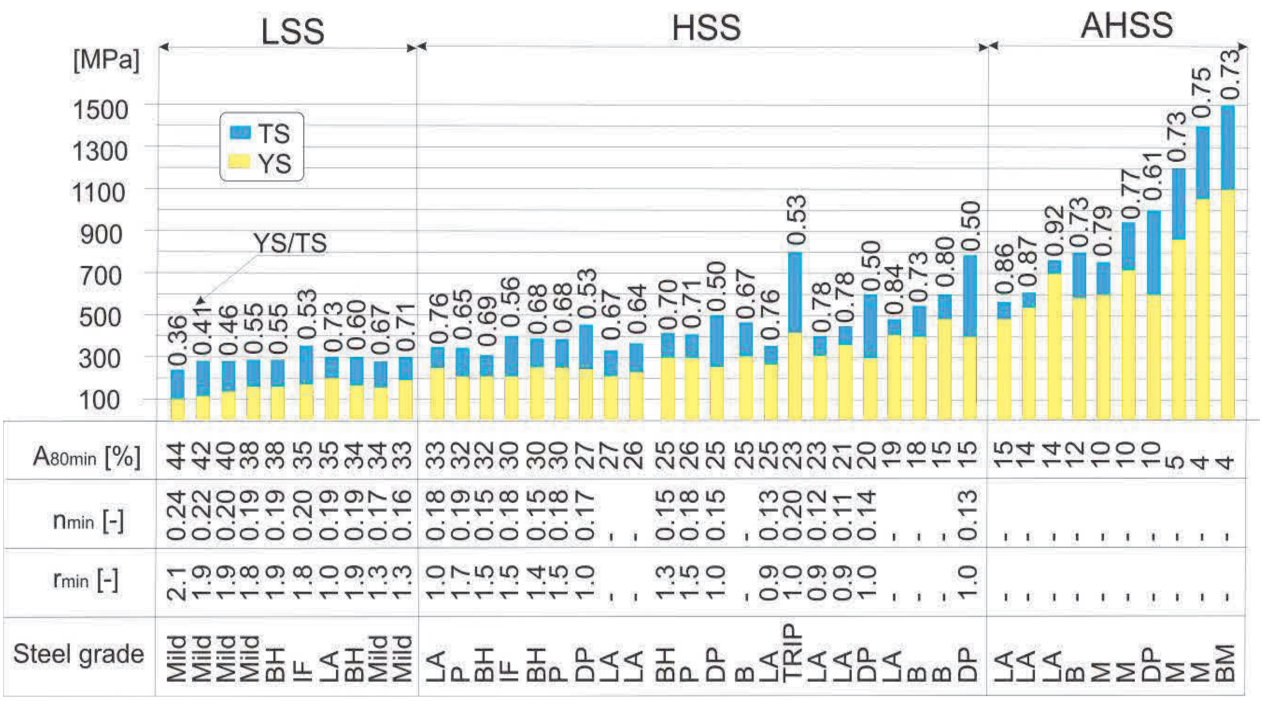
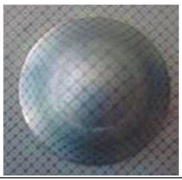


Figure 1 Comparison of different steel sheet metals mechanical properties

It is possible to increase the drawability rating and to perform a basic drawability test - Erichsen's cupping test [8]. This test allowed classifying charge sheet blank to the proper drawability grade and defines the susceptibility of the sheet to deformation at the expense of thickness. Other technological tests, corresponding to the basic mechanical states scheme of pressing process may also be done. Their review is summarized in **Table 1.**

Table 1 Drawability tests review

Test	Coefficient of drawability	Photo of sample after test
Erichsen's cupping	**IE = H_{min}** H_{min} - minimal height of drawpiece	
Swift or AEG cup forming	**M = d/D_{max}** d - dimension of punch D_{max} - dimension of charge	
KWI or Hole expansion	**KWI=(D-d)/d*100%** d - dimension of punch D - dimension of charge	
Fukui	**m = d/D** d - dimension of punch D - dimension of charge	
Engelhardt's	**T = $(F_1-F_2)/F_1$*100%** F_1 - 1st drawing force F_2 - 2nd drawing force	
Hydroforming or Bulging	**HW = H_{max}** H_{max} - maximal height of drawpiece	
Pushing	**K = d/D_{max}** d - dimension of punch D_{max} - dimension of charge	
Inversion drawing	**N = d_{min}/D_{max}** d_{min} - dimension of punch D_{max} - dimension of charge	

2.2. Complex drawability definition

For a complex assessment of the technological susceptibility of a sheet metal, a forming limit curve (FLC) is determined. Examples of experimental FLC's are shown in **Figure 2**. Determination of those curves was based on the bulging with a punch tests made for a sheet metal specimens of different widths. Complete procedure of FLC appointing was described in detail in [9]. The photograph of the different width sample set used to FLC preparation is shown in **Figure 3**.

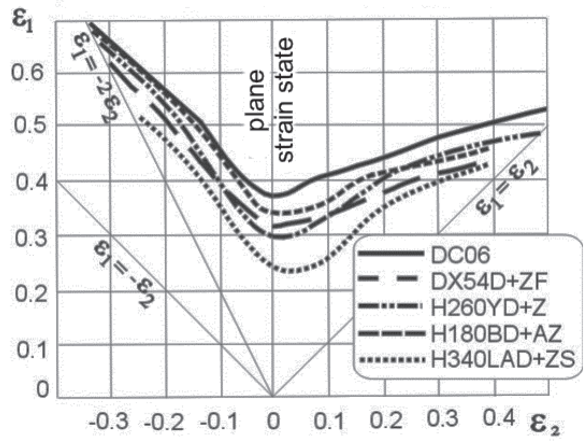


Figure 2 Forming limit curves for different steels appointed experimentally

Figure 3 A set of drawpieces to determining forming limit curve

2.3. Methodology and guidelines for drawability evaluation of hard formable materials

Guidelines for drawability evaluation are given as following procedure.

- Define whether the charge material is conventional or limited in deformability.
- Perform basic mechanical properties evaluation tests and draw up a strain-stress curve.
- Performing technological drawability evaluation tests [10-12].
- Prepare the standard forming limit curve according to standard [9] and using the mesh method and automatic strains analyzer, e.g. Auto Grid analyzer [15, 16].
- Perform numerical simulation of the deformation process using the developed material characteristics, taking into account the specificity of the selected manufacturing technology [13, 14, 17, 18] and using dedicated simulation software, e.g. Eta / Dynaform.
- Analysis of formability tests results.

There are present the studies and results of the described procedure for examining and evaluating the drawability of the various materials in numerous, own publications [15, 16, 19, 20]. Selected charge materials were determined according to the definition as follow, limited formability.

3. PRACTICAL EXAMPLE USING OF DRAWABILITY EVALUATION GUIDELINES

The elaborated procedure was tested for nickel superalloy sheet blank and cone drawpiece manufacturing technology. Looking on mechanical properties of nickel superalloy and sellected Inconel 625 alloy sheet blank, it was define as the charge material with limited deformability. Basic mechanical properties of Inconel 625 are as follow: TS = 907 [MPa], YS = 465 [MPa], elongation A_{80} = 44 [%] and Langford's anisotropy coefficient R = 0.49 [-]. To check out technological properties, Erichsen's cupping test was selected. Coefficient of drawability was measured IE = 11.8 [mm] at thickness 0.9 [mm] of sheet blank. There is forming limit curve of Inconel 625 alloy sheet blank showed in **Figure 4**. There is also showed the FLC for Inconel 718 alloy sheet blank thickness 0.9 [mm] to compare drawability of both alloys. The FLC's was prepared according to standard [10] and using the mesh method and automatic strains analyzer Auto Grid. Next stage cone drawpiece designing was selection of manufacturing method, which types are showed in **Figure 5**. Using numerical simulation software Eta/Dynaform 5.9 and experimental data in material model selection of manufacturing method was done. The punch method was used in practical tests of cone drawpiece hydroforming. The final cone drawpiece was measured again using Auto Grid strain analyzer to validate if it is safety deformable. Measurement results are shown in **Figure 6**.

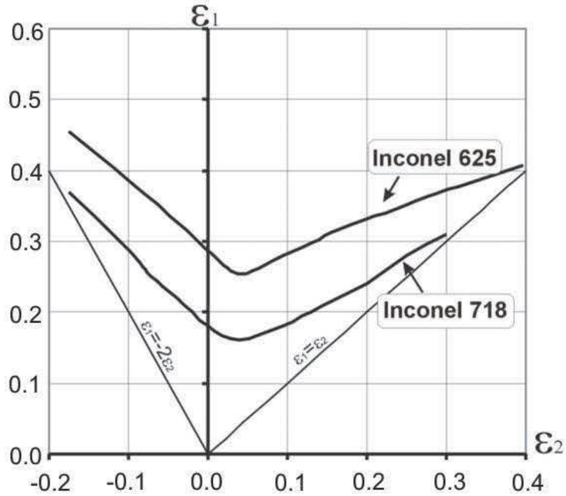


Figure 4 The forming limit curves of nickel superalloys determined experimentally

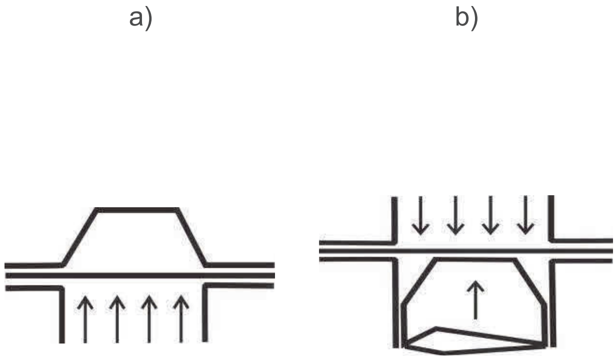


Figure 5 The types of manufacturing methods of cone drawpiece: b) die method, c) punch method.

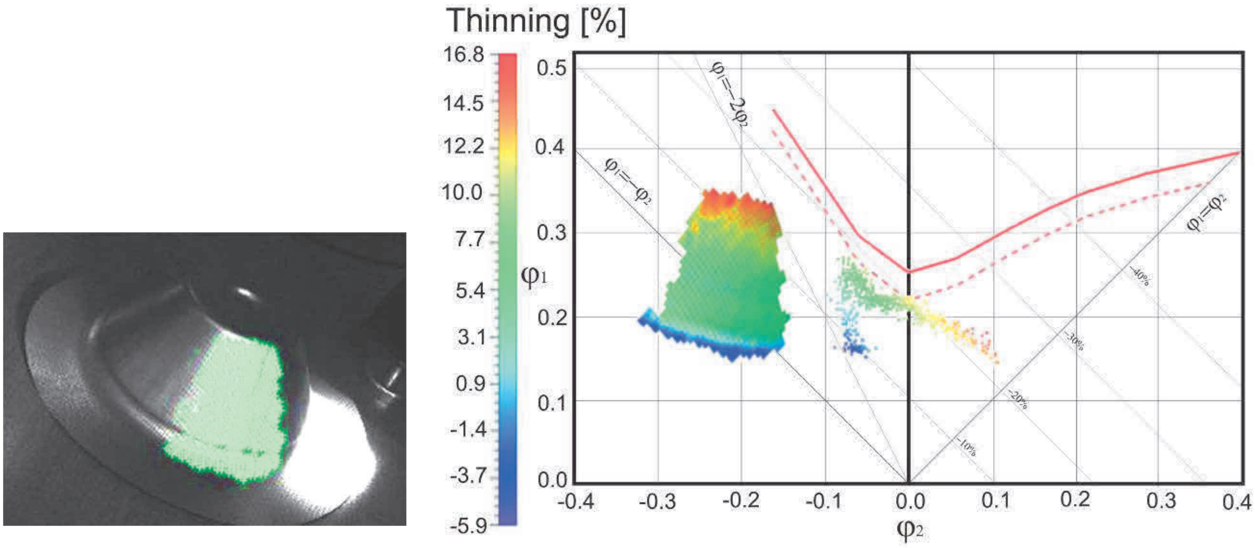


Figure 6 The result of the measurement of the local strain distribution on the peripheral surface of the cone obtained using the AutoGrid portable system with respect to the Inconel 625 alloy sheet FLC

4. CONCLUSION

Using the developed guidelines and the deformability evaluation procedure, the actual manufacturing process of the Inconel 625 alloy cover extrusion was effectively designed. Thus, the practical usefulness of such a method for evaluating the drawability of charge materials with limited deformability was effectively demonstrated. Moreover, it has been shown that the numerical coarse model compared to the fine model, extended by experimentally determined sheet deformation characteristics, and more accurately reproduces the plastic flow of high-strength steel (AHSS) [4, 7] and alloy steel plates. Thanks to the procedural approach to deformability evaluation and numerical modeling, the results of pressing can be effectively achieved. Even very complex products and technologically sophisticated shaping methods are designed. The sheet deformability testing in laboratory conditions allows us to identify and extend material models with complex characteristics of innovative, new materials and more efficient processing. Adapting this procedure in industry should be part of good industrial practice.

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