

# Formability Investigations of Advanced High Strength Steels

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**Abstract.** Car manufacturing has been significantly influenced by sheet metal forming developments, thus the requirements and developments in car manufacturing have decisive role in the development of sheet metal forming, too. The automotive industry is facing challenges of reducing body weight in consideration of environmental problems and higher collision safety. These requirements are being addressed by the application of various dual-phase steels, ultra and extra advanced high strength steels (UHSS, XAHSS). Forming Limit Diagrams (FLD) are the most appropriate tools to characterize the formability of sheet metals. Theoretical and experimental investigations of forming limit diagrams are in the forefront of today's research activities. In this paper, an up-to-date research methodology elaborated and applied at the Department of Mechanical Technology at the University of Miskolc will be shown.

## 1. Introduction

Sheet metal forming is one of the most important manufacturing processes. This is particularly valid for the automotive industry, where sheet metal forming has an even more important key position. The automotive industry is the leading sector in many countries and the main driving force behind the sheet metal forming developments as well [1].

As automakers are challenged to improve safety and fuel economy, they search for new materials to meet higher standards. Advanced high-strength steels (AHSS) help engineers meet requirements for safety, efficiency, lower emissions, manufacturability, durability, and quality at a low cost [2].

AHSS are a newer generation of steel grades that provide extremely high-strength and other advantageous properties, while maintaining the necessary formability required for manufacturing. They have been on the road for many years, but with additional research and development, automakers are using these newer grades in more applications [2].

## 2. Advanced High Strength Steels

The AHSS may be distinguished based upon the strength properties that roughly can be defined: 1500 MPa < Rp0.2 (tensile strength). As opposed to the conventional high strength steels, in which ductility decreases by the increase of strength but they have better formability even at higher strength properties, modern AHSS steels combine high strength and formability/ductility [3].

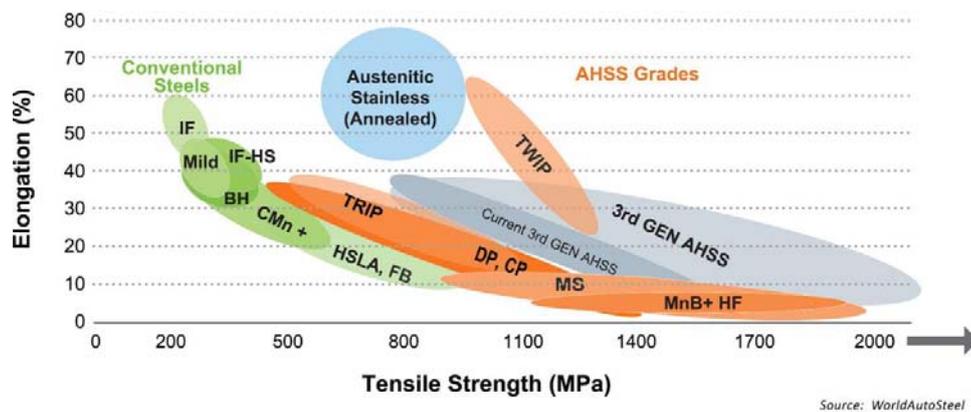
General classification of these steels is as follows:

- High strength steels with a high energy absorption potential (DP and TRIP steels with UTS < 1000 MPa), for dynamic loading occurring during car crashes or collisions.
- Extremely high strength steels, typically martensitic steels, with a very high UTS (>1200 MPa), providing high stiffness, anti-intrusion, load-transferring barriers for the protection of automotive passengers.
- The rationales for increased use of the AHSS in the automotive industry are as follows:
  - The reduction of the car weight resulting from the use of high strength thinner gauge sheet steel, reducing the fuel consumption.
  - Increased passenger safety by an improved crash worthiness.
  - The strong competition from the light-weight materials, such as Al and Mg alloys and plastics [3].



AHSS derive their properties from multi-phase complex microstructure. Since these steels are relatively new, their classification differs from conventional high strength steels and was developed by Ultra-Light Steel Automotive Body – Advanced Vehicle Concept (ULSAB-AVC) Consortium [1]. The accepted practice involves specification of both yield strength (YS) and ultimate tensile strength (UTS) in the following way: XX aaa/bbb, where XX is type of steel, aaa is minimum YS in MPA and bbb is minimum UTS in MPA.

The Advanced High Strength Steels family includes Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Martensitic (MS), Transformation-Induced Plasticity (TRIP), Hot-Formed (HF), and Twinning-Induced Plasticity (TWIP). These 1st and 2nd Generation AHSS grades are uniquely qualified to meet the functional performance demands of certain parts. For example, DP and TRIP steels are excellent in the crash zones of the car for their high energy absorption. For structural elements of the passenger compartment, extremely high-strength steels, such as Martensitic and boron-alloyed Press Hardening Steels (PHS) result in improved safety performance. Recently there has been increased funding and research for the development of the “3rd Generation” of AHSS. These are steels with special alloying and thermo-mechanical processing to achieve improved strength-ductility combinations compared to present grades, with potential for more efficient joining capabilities, at lower costs [4].



**Figure 1.** Steel Strength Ductility Diagram, illustrating the range of properties available from today’s AHSS grades [4].

The broad range of properties is best illustrated by the famous Steel Strength Ductility Diagram (often cited as the banana diagram, captured in Figure 1). Where we have the elongation percentage in function of tensile strength, and in which we could recognize the difference between the low strength (which are known as conventional steels e.g: Mild steels and interstitial free), and advanced high strength steels family (transformation induced plasticity, Dual phase) [4].

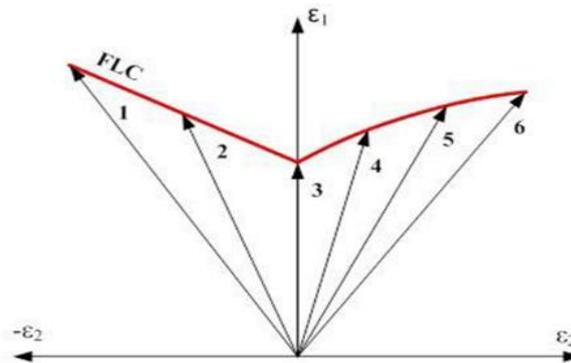
Generally, steels with yield strength exceeding 750 MPa are referred as HSS, and in case these steels have a tensile strength exceeding 1500 MPa are called UHSS.

### 3. Formability of sheet metals

In general formability is the ability of sheet metal to undergo shape changes (plastic deformation) without failure by necking or tearing.

The most appropriate tool to characterize the formability of sheet metals is the Forming Limit Diagram (FLD).

Applying the Forming Limit Diagram, we can reliably estimate the forming behaviour of metallic materials under various stress- and strain state as shown in Figure 2.



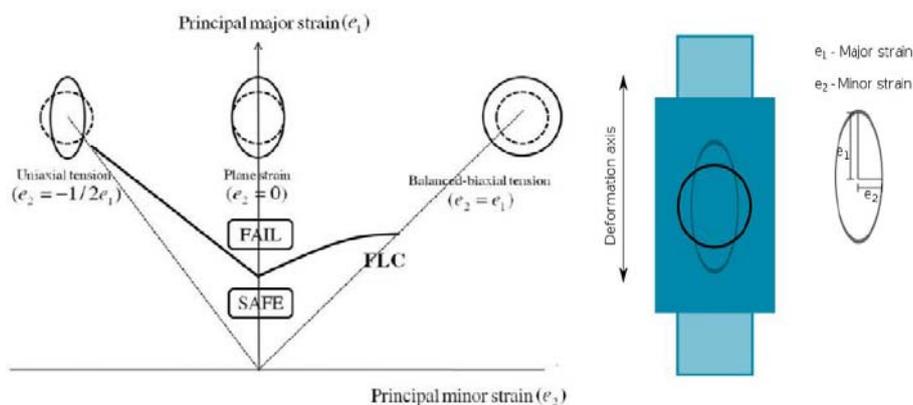
**Figure 2.** Forming Limit Diagram for various strain paths (1-pure shear, 2-uniaxial tension; 3-plain strain; 4, 5 6-different biaxial tension) [5].

#### 4. Basic understandings concerning the forming limit diagrams

Forming limit diagrams (FLD's) offer a convenient and useful tool in sheet products manufacturing analysis. They show the critical combinations of major strain and minor strain in the sheet surface at the onset of necking failure. Formability in the context of multiple phase operations strongly depends of the deformation history and therefore demands an investigation of every particular case. This makes the experimental determination of FLD's unappreciative expensive and causes the necessity to develop an accurate and efficient theoretical method for formability prediction [6].

The basic concept of the FLD was first introduced by Keeler and Backofen, who developed the right-hand side of the FLD. Goodwin extended this diagram to the left-hand side. Figure 3 illustrates the FLD which is divided into two regions separated by a curve, called the forming limit curve (FLC). The region below the FLC corresponds to safe strain states whereas that above the FLC represents failure strain states. Even though the strain states of the sheet metal forming processes are complex, FLDs are often constructed using tensile and biaxial stretch tests.

The diagram attempts to provide a graphical description of material failure tests, such as a punched dome test. In order to determine whether a given region has failed, a mechanical test is performed. The mechanical test is performed by placing a circular mark on the workpiece prior to deformation, and then measuring the post-deformation ellipse that is generated from the action on this circle. By repeating the mechanical test to generate a range of stress states, the formability limit diagram can be generated as a line at which failure is onset [6].



**Figure 3.** Forming limit diagram and the definition of the deformation axes in forming limit diagram measurement [6].

## 5. Experimental determination of Forming Limit Diagrams

The sheet metal forming particularly in the vehicle industry, the computer aided technology and tool design, requires more and more precisely characterized formability of the sheet materials to be processed.

Therefore, an integrated Sheet Metal Formability Testing System (SMFTS) was installed at the Department of Mechanical Engineering at the University of Miskolc with the financial support of several national and international projects. It consists of an electro-hydraulic, computer-controlled testing machine with an optical strain measurement system as shown in Figure 4. According to its nominal loadability ( $F_{max} = 600$  kN), this system is suitable to perform sheet metal testing up to 3 mm thickness.

The applied punch diameter is a standard  $d = 100$  mm, the velocity range is  $v = 0\div 5$  mm/s. The computer control can provide the harmonized operation of the formability and optical strain measurement system [7].



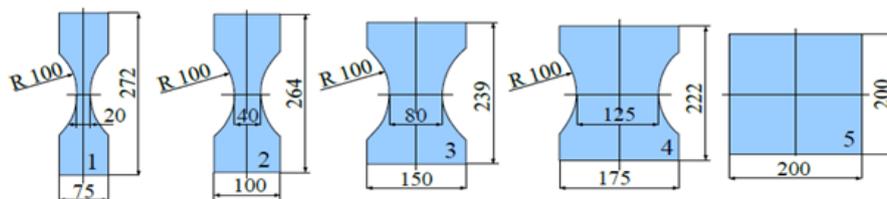
**Figure 4.** The Universal sheet metal formability testing system equipped with optical strain measurement system.

For the measurement of the strain distribution over the whole part, a printed grid is applied on the surface of the part before the forming operation. In our experiments, regular, square grid is applied as the carrier of the measuring information in the AutoGrid® strain measurement system.

The applied Vialux-AutoGrid optical strain measurement system is capable for inprocess and post-process evaluation of grid deformation. In the determination of forming limit diagrams, usually the post-process evaluation is applied; however, it is often combined with the in-process capabilities of the system for more precise detection of the onset of necking or the rupture itself.

### 5.1. Experimental specimen

The specimens proposed by Nakazima are generally used for the determination of forming limit diagrams. In our experiments, we applied a modified version of Nakazima specimens of for DC04, DC05 and DD14. They are steels for cold forming, having good formability. These modified specimens are shown in Figure 5.



**Figure 5.** Modified Nakazima specimen

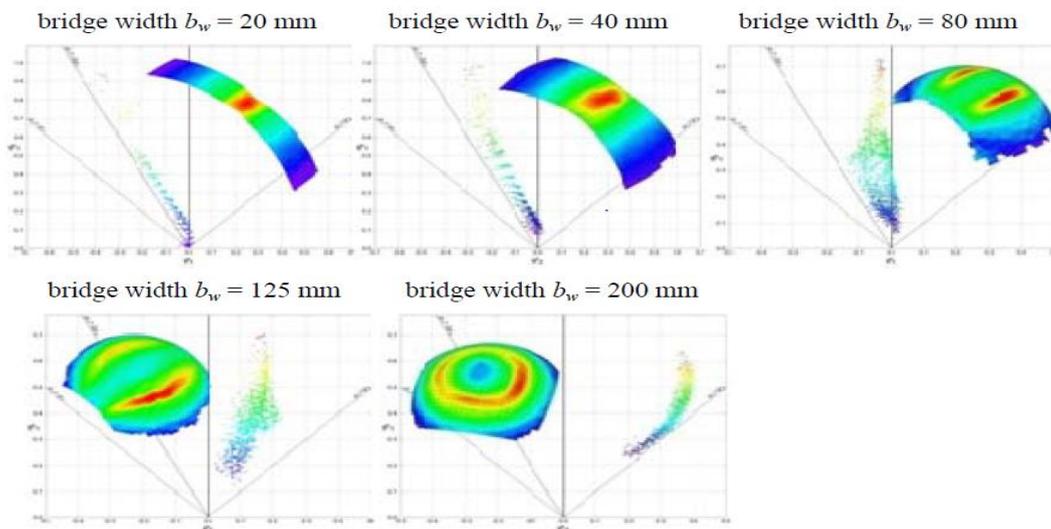
A printed regular square grid is applied on the surface of the specimen as the carrier of the measuring information.

**5.2. The experimental procedure**

As it was already mentioned, before the examinations a square grid was made on the surface of the specimens applying an offset printing technique. The deformation of the square grid was measured by the Vialux optical strain measurement system. The evaluation of the deformed grid is based upon the recognition of identical grid-crosses from the different views obtained by the four CCD cameras mounted on the testing machine.

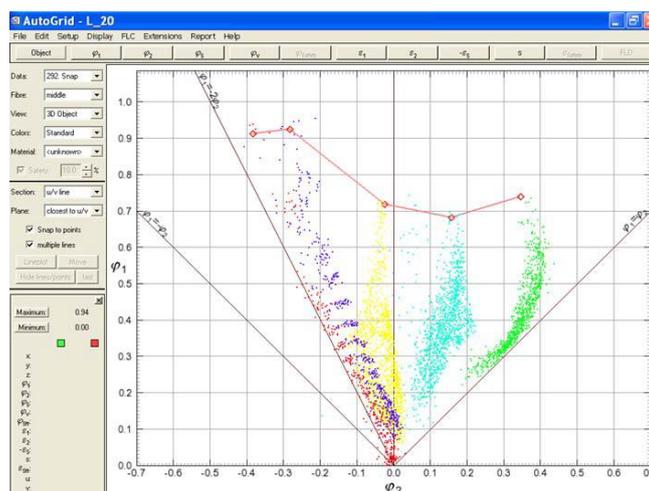
After printing the grid, the sheet specimen is firmly clamped between the die and the blank holder, while the hemispherical punch forces the specimen to deform in the space.

Performing the evaluation for all the applied specimens having different width, various and different strain path history ( $\epsilon_1, \epsilon_2$ ) can be obtained depending on the width of the specimen [7].



**Figure 6.** Results of strain measurements for various strain paths.[7]

When all the measurements and the evaluations are completed, they are simultaneously loaded into  $\epsilon_1, \epsilon_2$  coordinate system. To get the Forming Limit Curve (FLC) we have to connect the fracture points on each deformation path (Figure 7.) [7].



**Figure 7.** Graphical generation of FLC from the measured strains.[7]

## 6. Conclusion

A substantial progress has been achieved during last years in the development of AHSS for applications in the auto body construction. Forming AHSS involves several challenges, mainly due to its higher strength, lower formability and inconsistency of material properties [8].

The future of AHSS for automotive applications is bright. Many groups are researching these new steels to better understand their properties and to continue tailoring unique sets of characteristics. Others are focused on improving the technologies necessary for manufacturing parts made of AHSS. The steel and automotive industries have forged numerous partnerships to develop the materials and technologies necessary to put the next generation of safer and more environmentally friendly vehicles on the road [2].

Forming limit diagrams can be regarded as the most appropriate tools in the evaluation of sheet metal formability. Thus, theoretical and experimental investigations of forming limit diagrams as a special field of the formability of sheet metallic materials are in the forefront of today's research activities.

## 7. References

- [1] M. Tisza, P. Z. Kovács, Z. Lukács, A. Kiss, and G. Gál, "Formability of High Strength Sheet Metals with Special Regard to the Effect of the Influential Factors on the Forming Limit Diagrams," *Mater. Sci. Forum*, vol. 812, pp. 271–275, 2015.
- [2] C. M. Tamarelli, "AHSS 101: the evolving use of advanced high-strength steel for automotive applications," *Steel Mark. Dev. Inst.*, p. 42, 2011.
- [3] R. Kuziak, R. Kawalla, and S. Waengler, "Advanced high strength steels for automotive industry," *Arch. Civ. Mech. Eng.*, vol. 8, no. 2, pp. 103–117, 2008.
- [4] S. Keeler, M. Kimchi, and P. J. Mooney, "Advanced High-Strength Steels Application Guidelines Version 6.0," no. September, p. 314, 2017.
- [5] Prof. Dr. Miklós Tisza, "Formability investigations of Advanced High Strength Steels," *Res. plan*, no. University of Miskolc, 2017.
- [6] S. G. G. Singhji, "Study The Methods To Get Forming Limit Diagram From Experimental Data."
- [7] M. Tisza and Z. P. Kovács, "New Methods for Predicting the Formability of Sheet Metals," *Prod. Process. Syst.*, vol. 5, no. 1, pp. 45–54, 2012.
- [8] E. Billur and P. D. T. Altan, "Challenges in Forming Advanced High Strength Steels," *New Dev. Sheet Met. Form. Proc.*, pp. 285–304, 2010.