



**American  
Iron and Steel  
Institute**

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# **Advanced High Strength Steels**

## **Formability**

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**U. S. Steel Automotive Center**

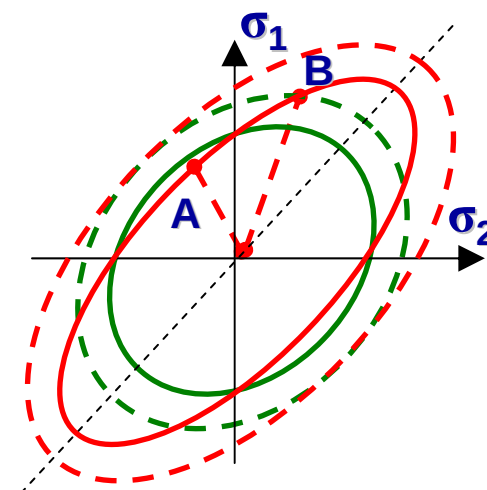
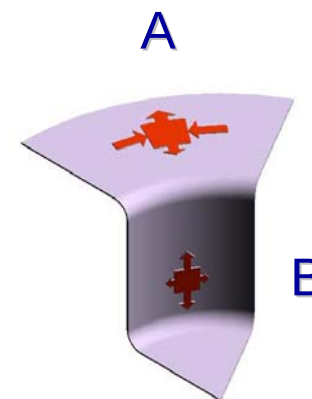
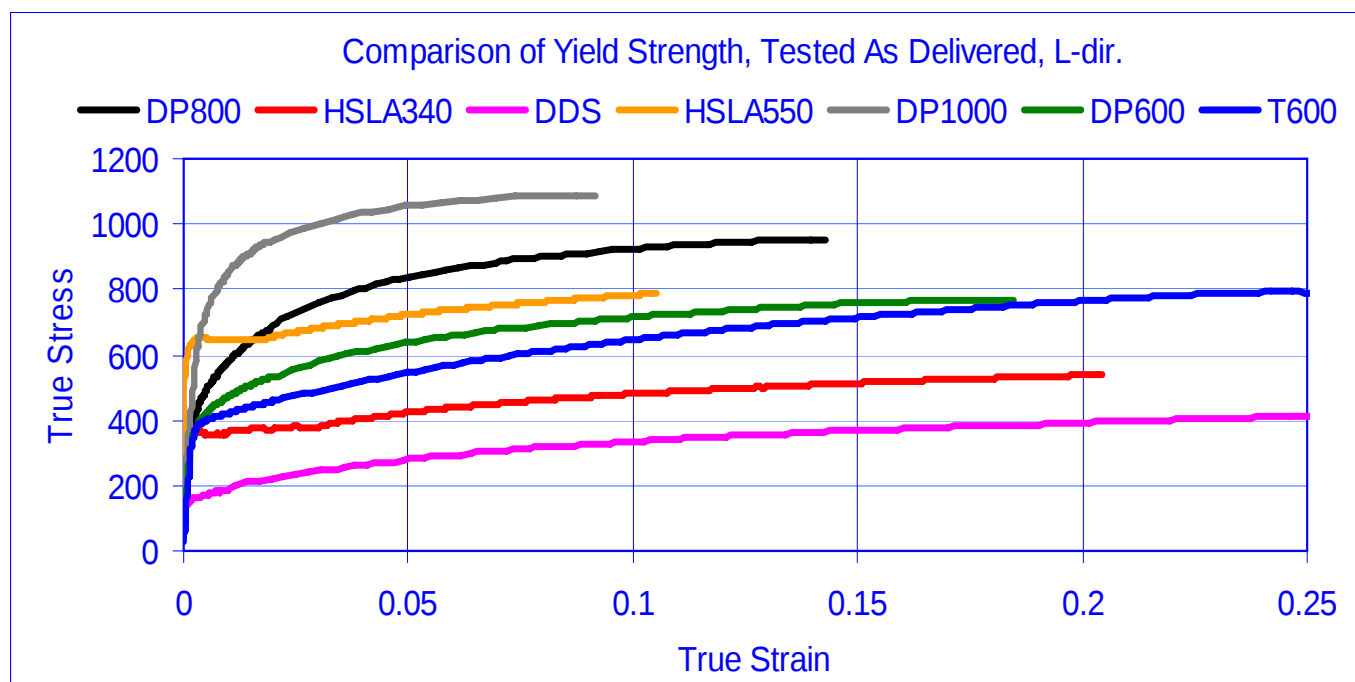
**February 19, 2003**

**Great Designs in Steel Seminar**

**Livonia, MI**



- Formability
- Experimental Forming Limit Diagrams
- Bendability Test
- Other Forming Tests



DDS  $r \gg 1$  DP  $r = 1$



# Typical Mechanical Properties

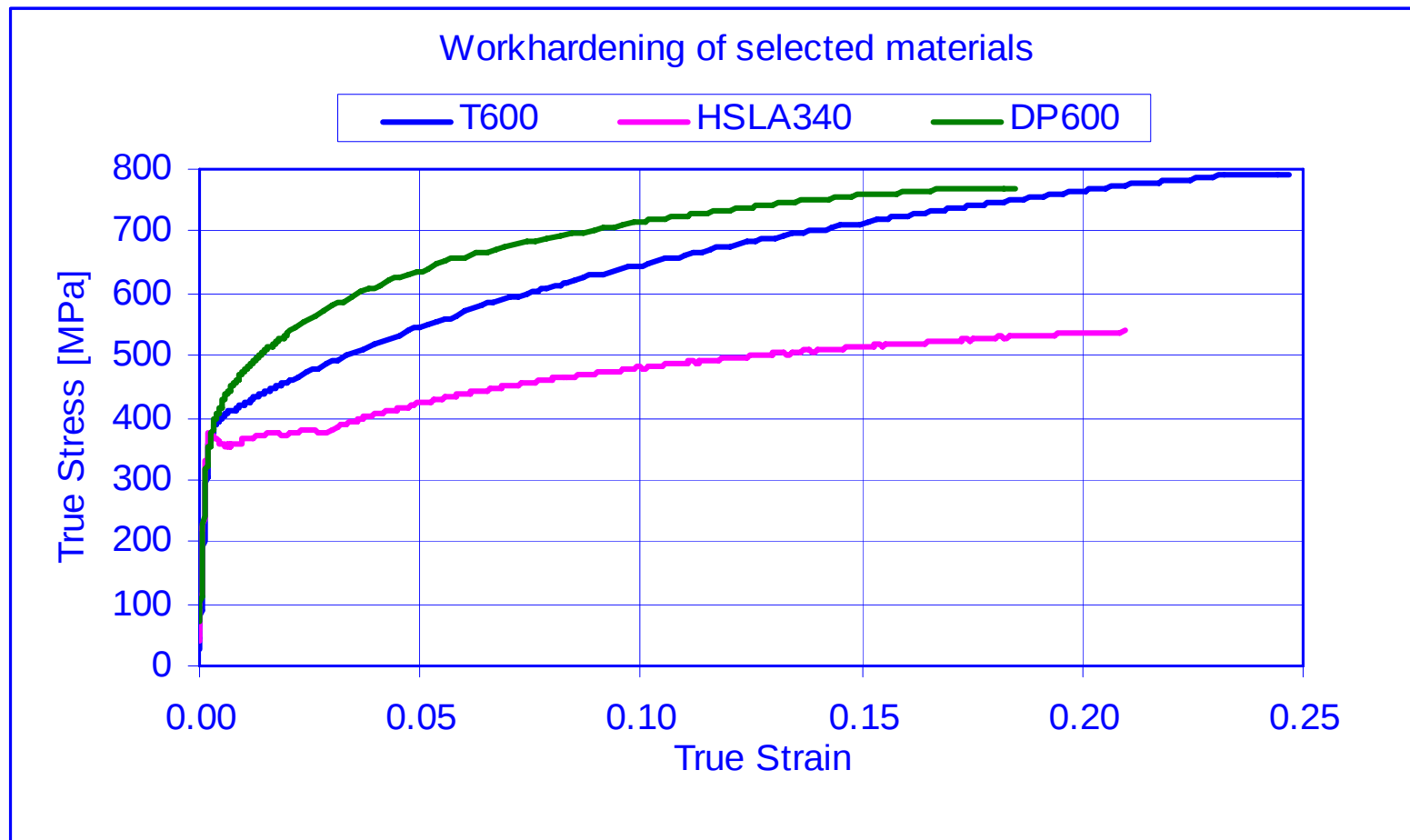
## Example of Typical Mechanical Properties

| GRADE   | YS<br>(MPa) | UTS (MPa) | EI (%) | YPE (%) | n-value<br>(10%-UE) | n-value (4-6%) |
|---------|-------------|-----------|--------|---------|---------------------|----------------|
| IF      | 163         | 282       | 49.0   | -       | 0.240               | -              |
| DDS     | 183         | 314       | 42.9   | -       | 0.230               | -              |
| CMn440  | 354         | 455       | 39.0   | 3.6     | 0.156               | -              |
| HSLA340 | 377         | 443       | 28.4   | 2.8     | 0.170               | -              |
| SF600   | 490         | 615       | 28.6   | 3.2     | 0.148               | -              |
| HSLA480 | 487         | 604       | 28.0   | 2.2     | 0.128               | -              |
| HSLA550 | 641         | 672       | 13.5   | 3.3     | 0.040*              | -              |
| DP600   | 340         | 602       | 29.0   | -       | 0.170               | 0.208          |
| T600    | 393         | 631       | 34.0   | -       | 0.230               | -              |
| DP800   | 459         | 838       | 17.2   | -       | 0.115*              | 0.168          |
| T800    | 475         | 822       | 28.0   | 0.6     | 0.240               | -              |
| DP1000  | 726         | 1003      | 10.8   | -       | 0.060*              | 0.08           |



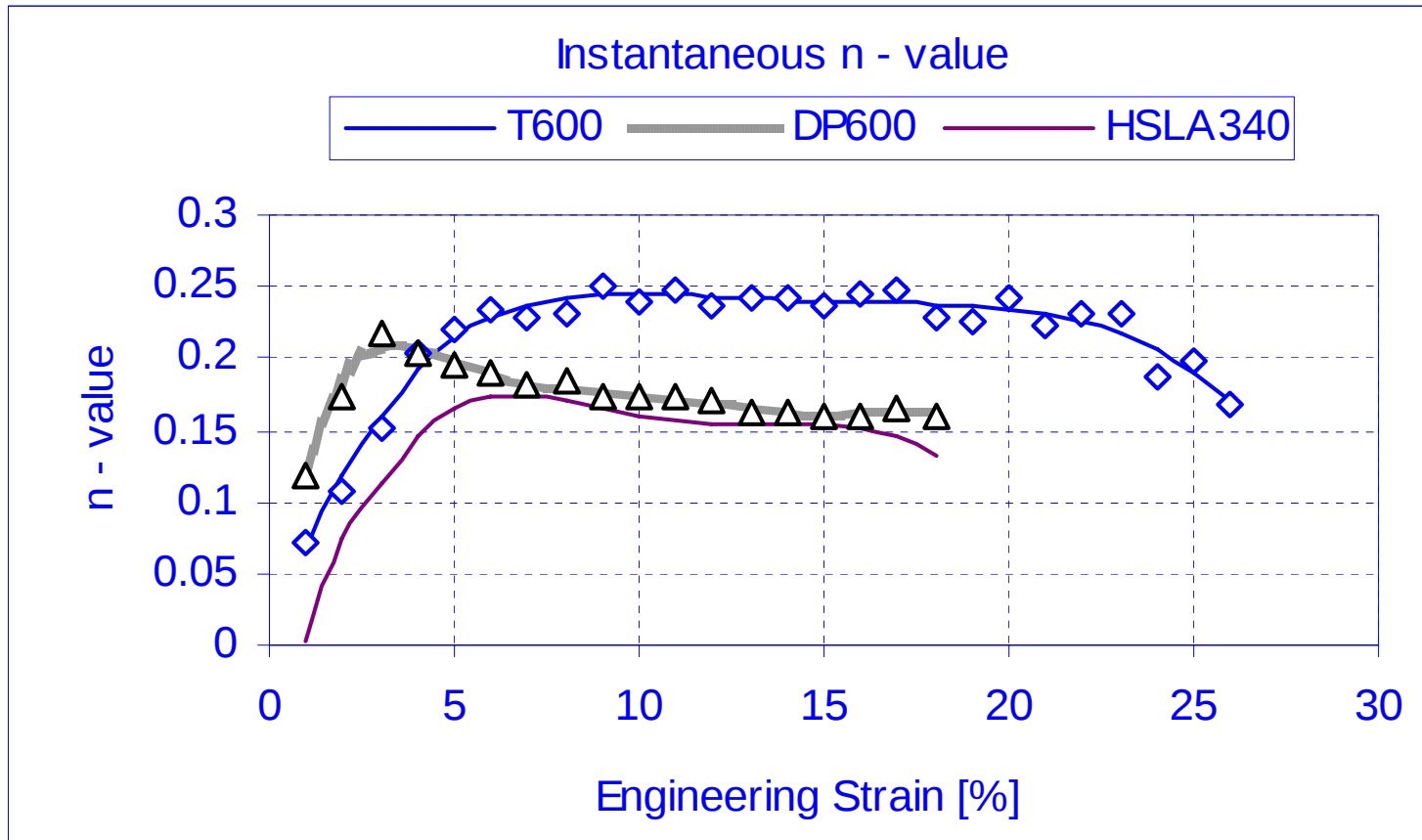


# True Stress – Strain Curves

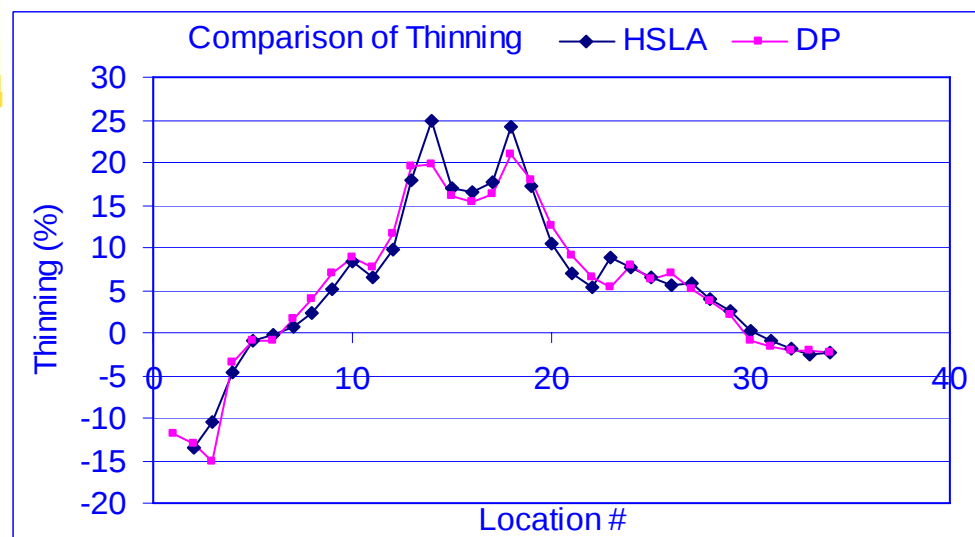
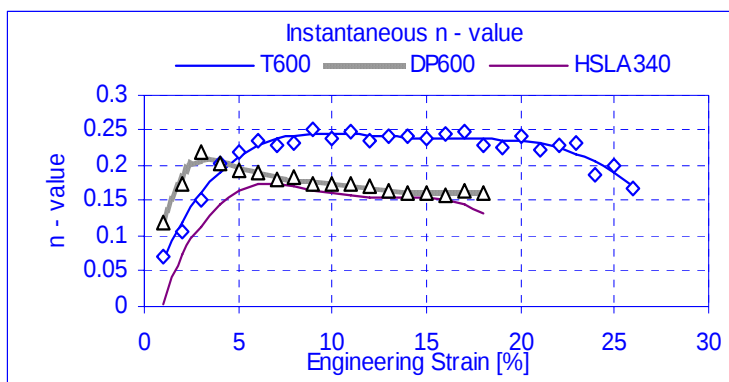
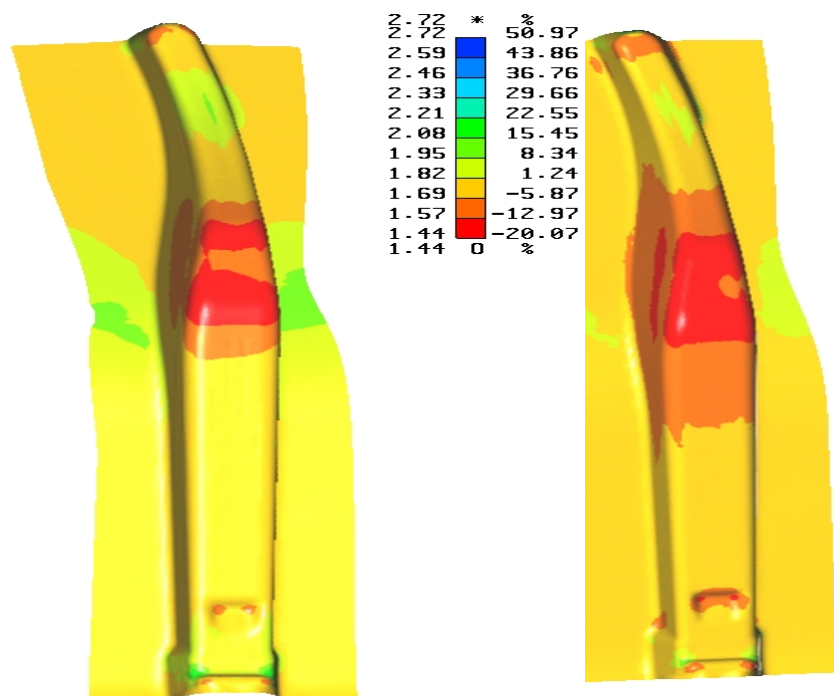




# Work Hardening Index

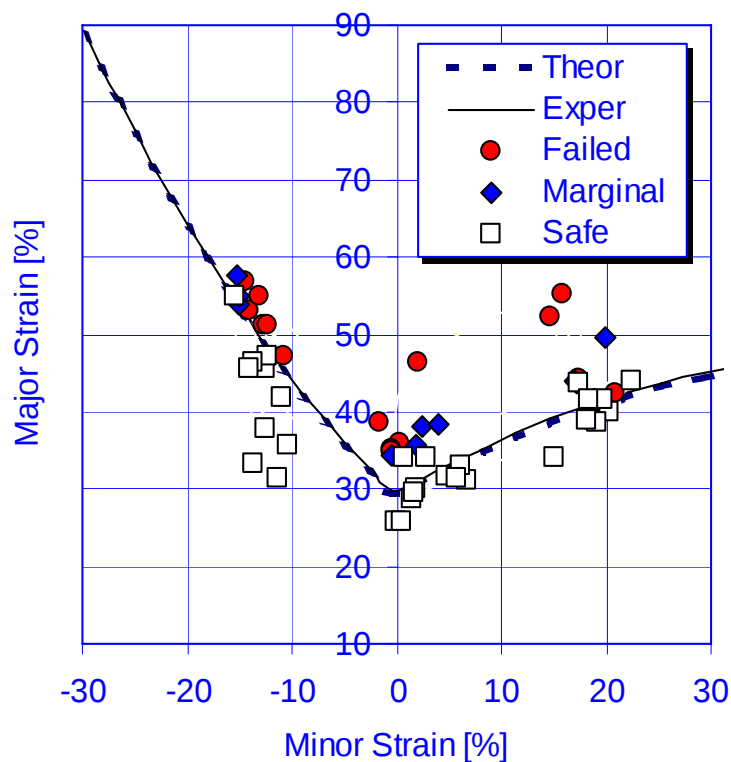


# Strain Distribution Ability

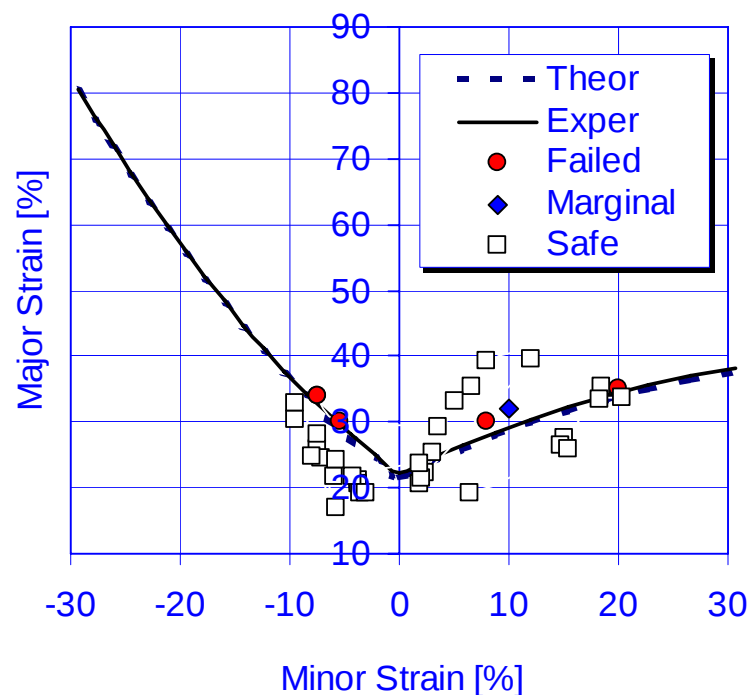


# Experimental FLDs for Dual Phase Steel

Forming Limit Diagram for DP600  
1.2 mm

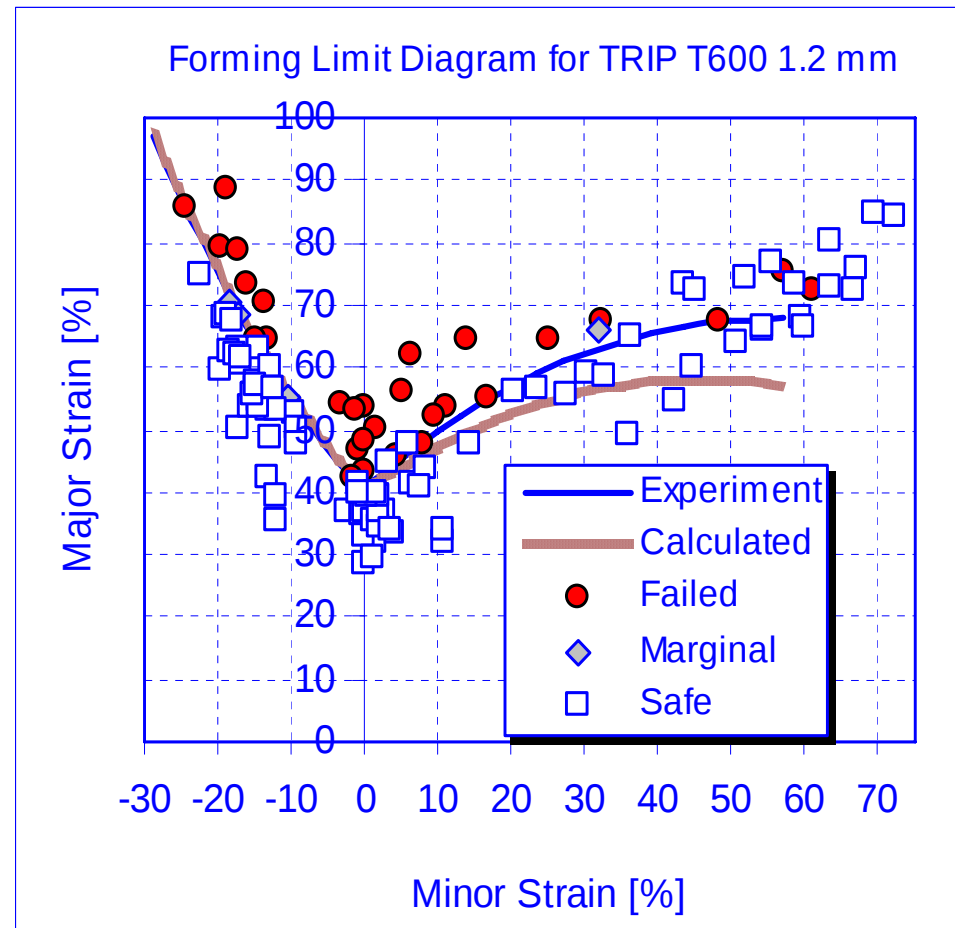
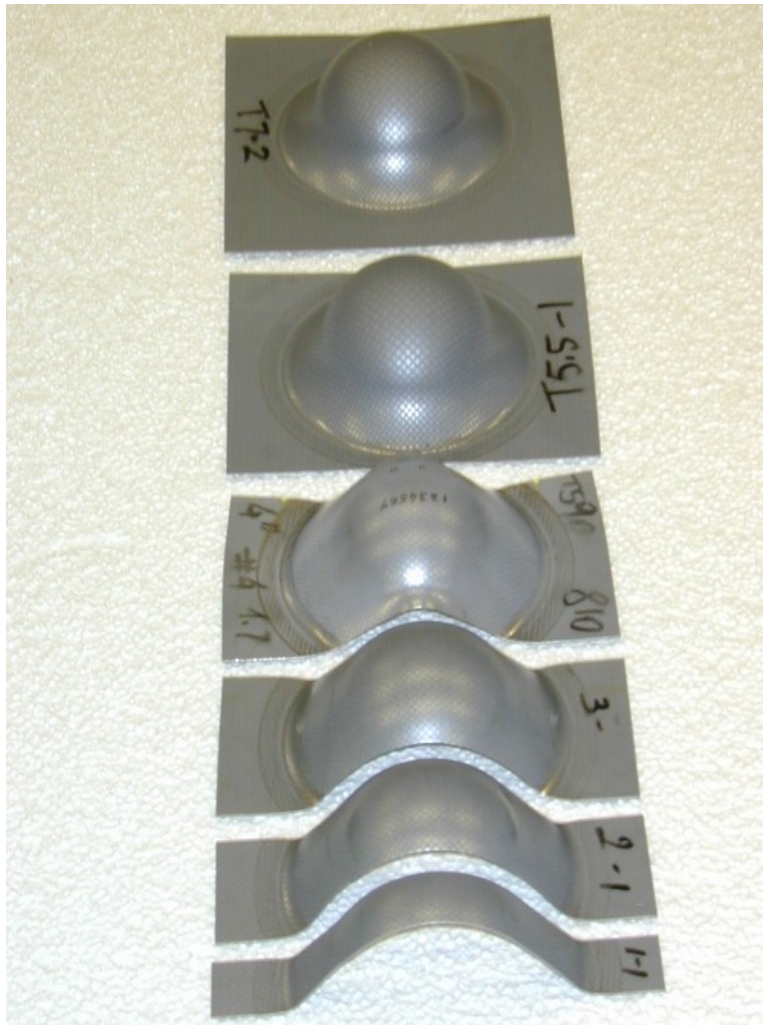


Forming Limit Diagram for DP800  
1.2 mm

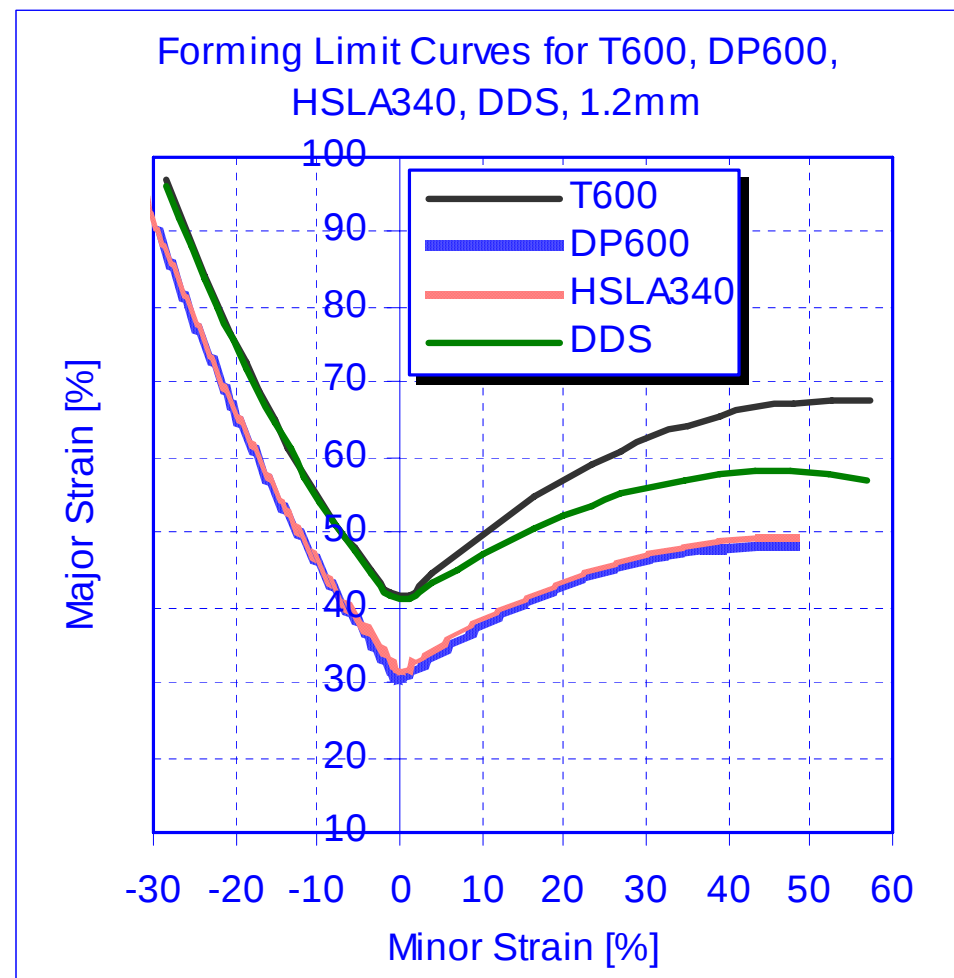


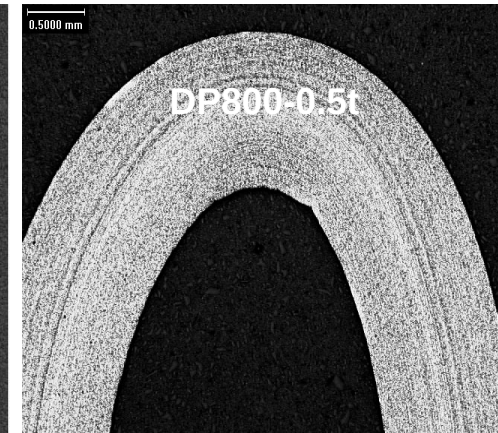
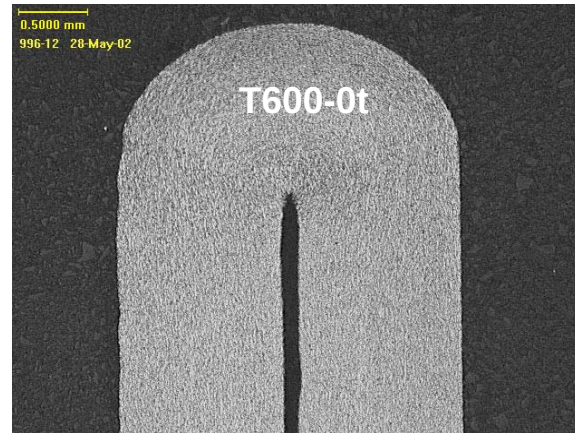
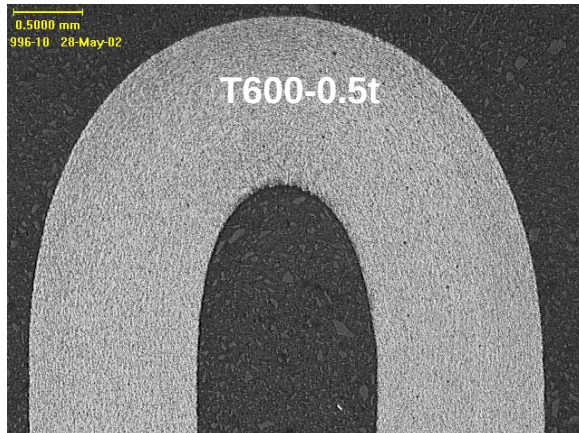
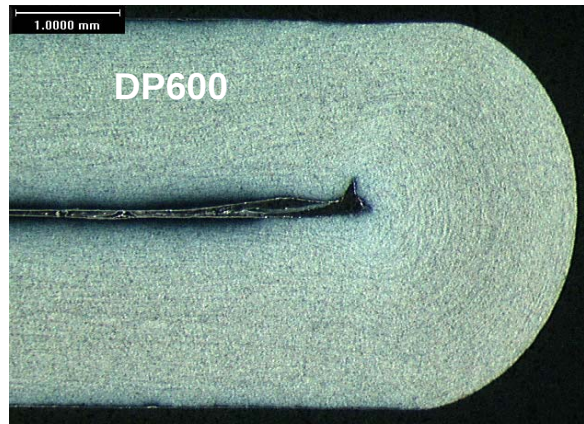


# Experimental FLD for T600



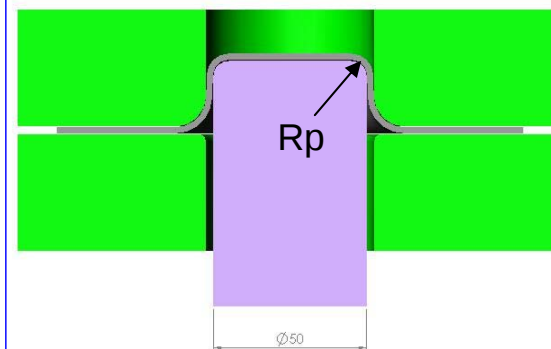
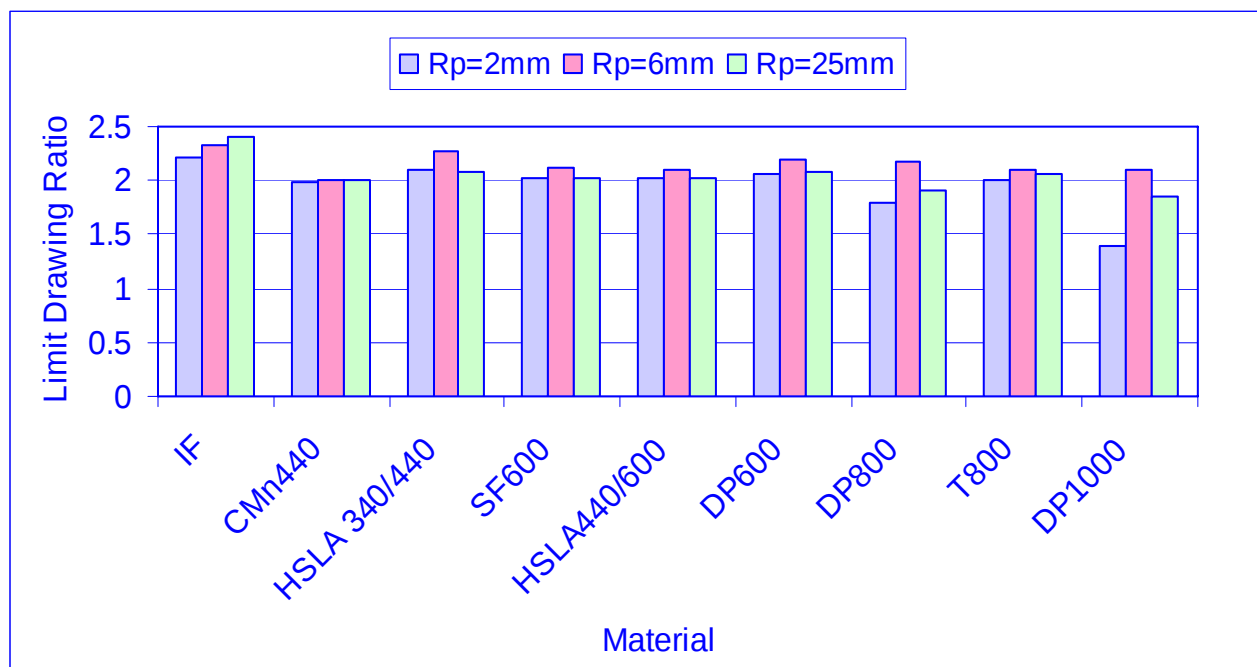
- **The FLC of T600 is comparable to DDS steel in draw forming area, and exceeds DDS steel formability up to 10% in balanced biaxial forming**
- **Influence of strain rate, temperature and stress state on TRIP steels formability is different than for other steels**

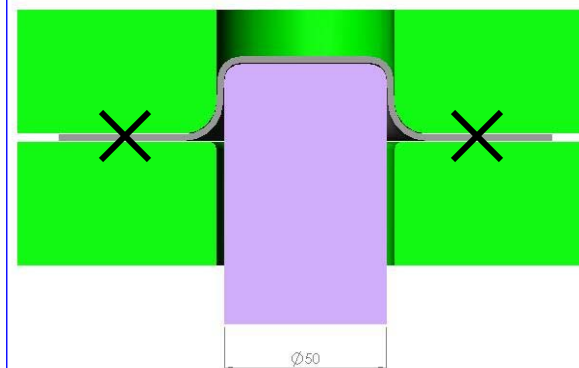
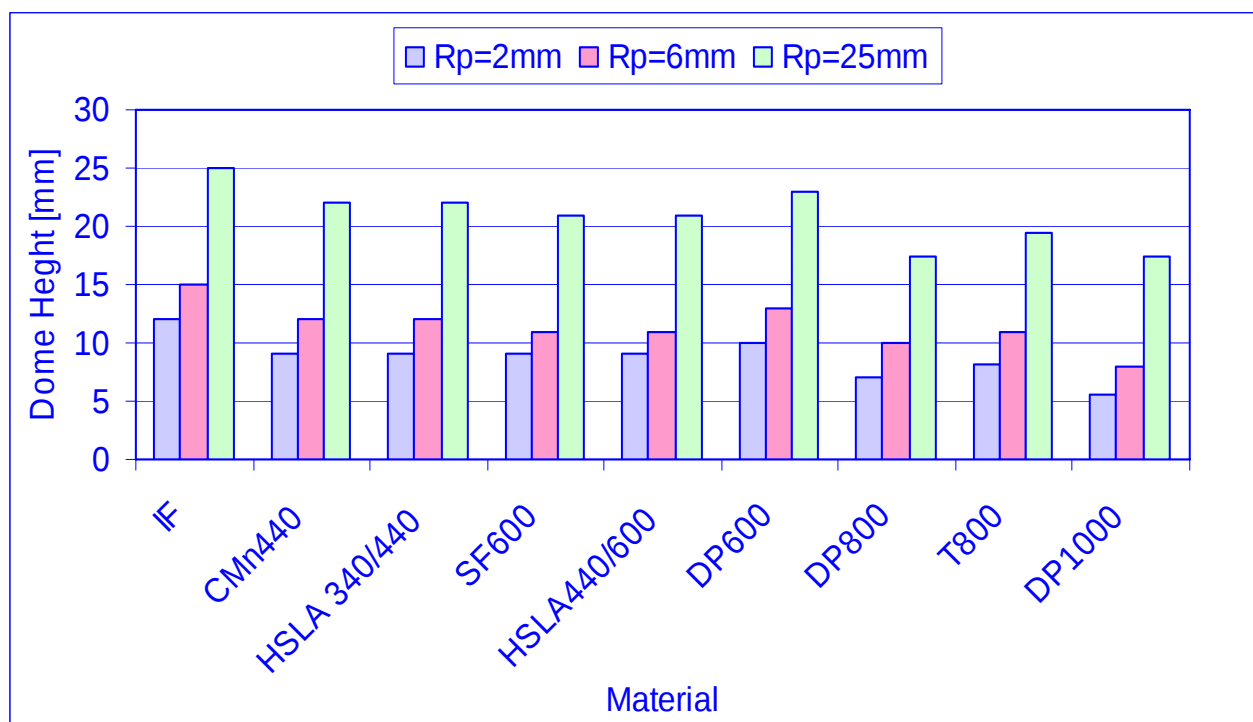




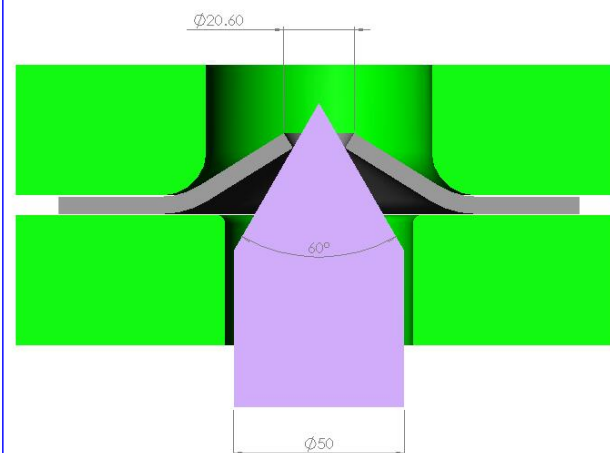
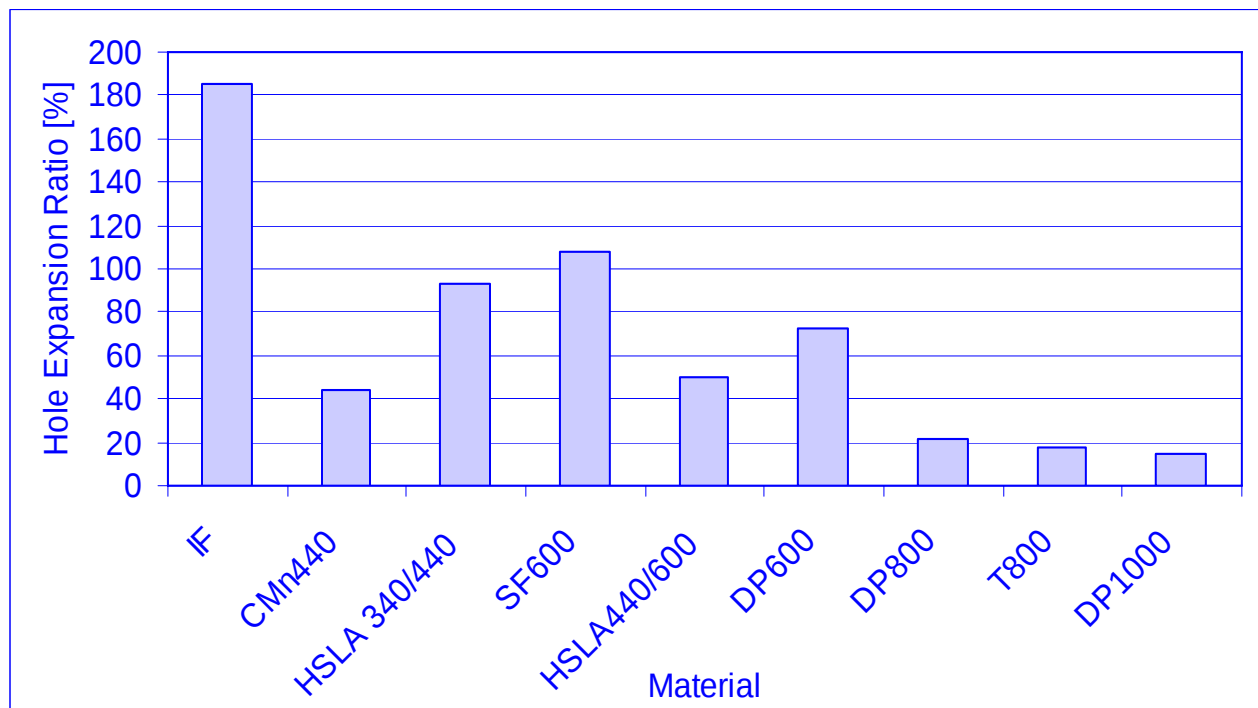
**Bendability is needed for dimensional accuracy control in stamping**



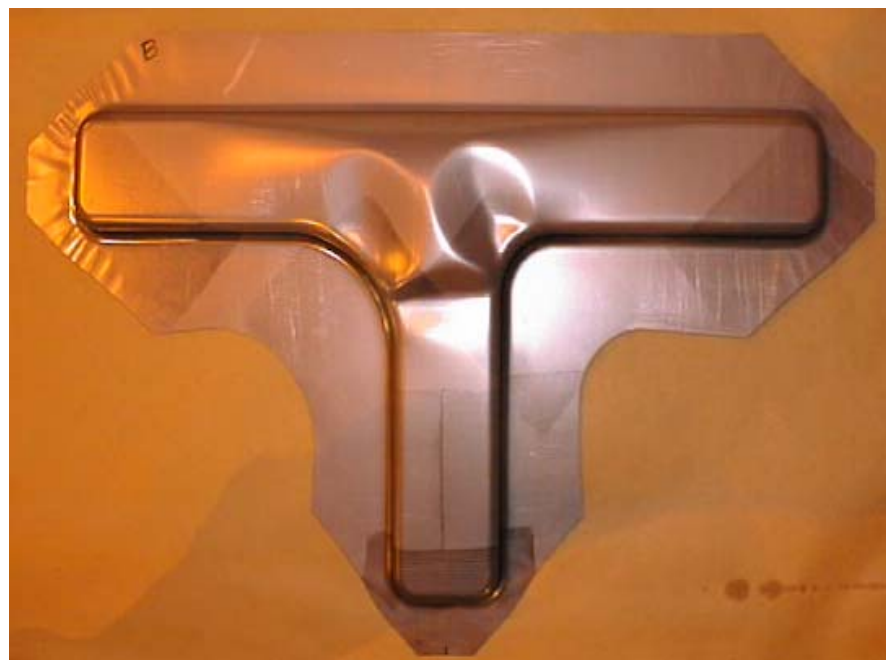
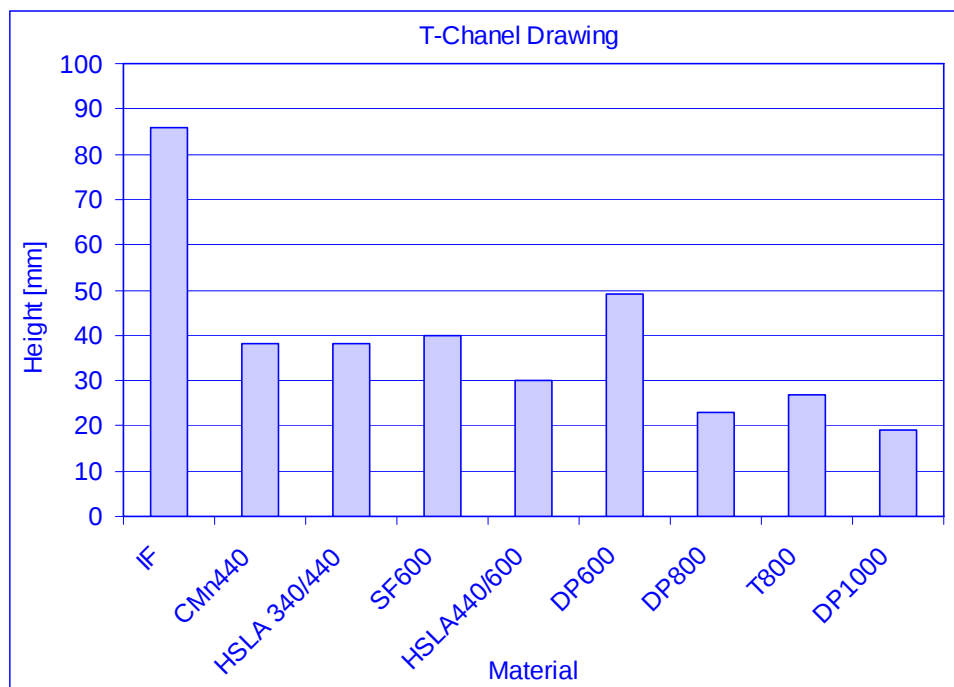




# Hole Expansion Test

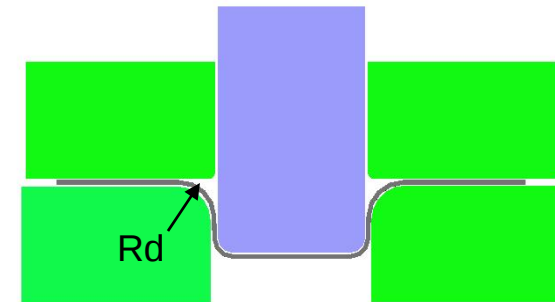
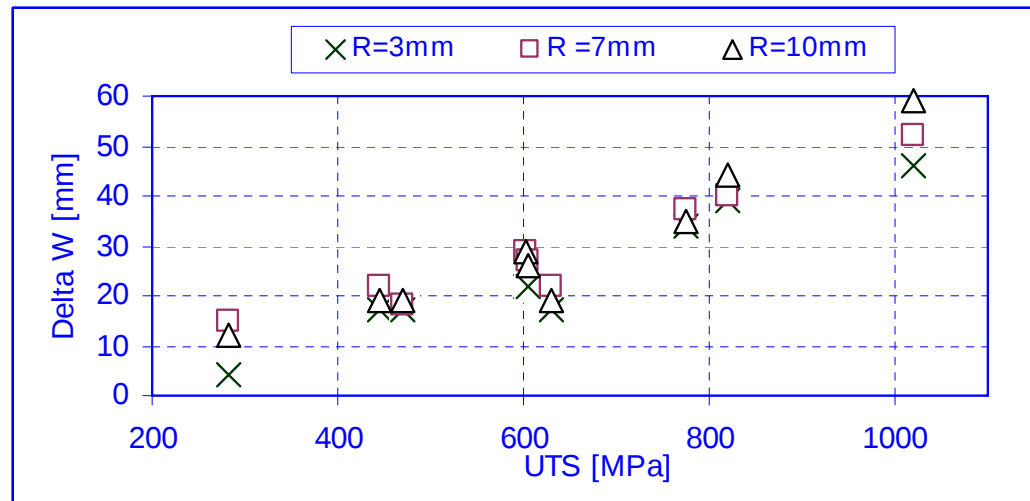
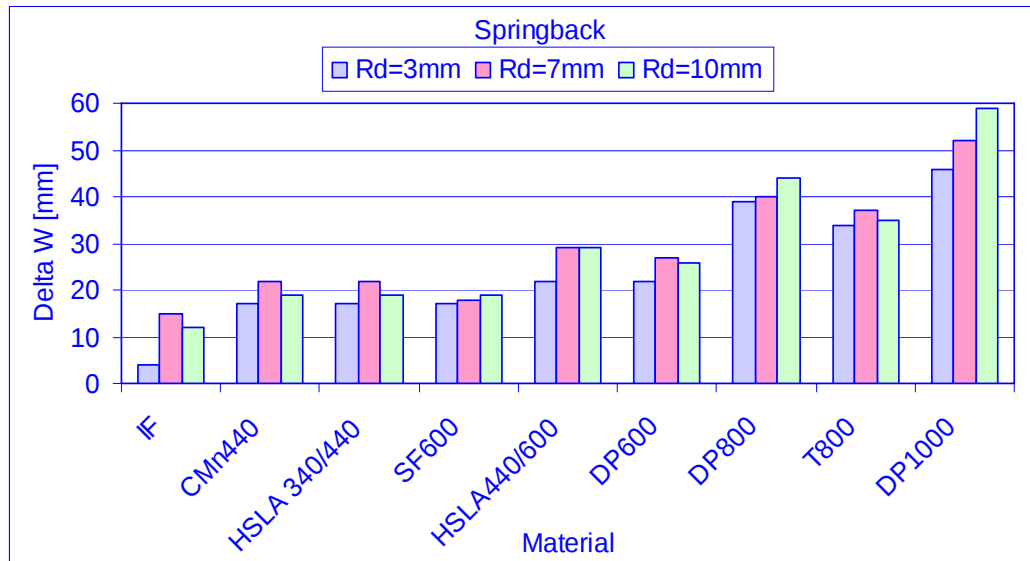


# T-Channel Drawing Test

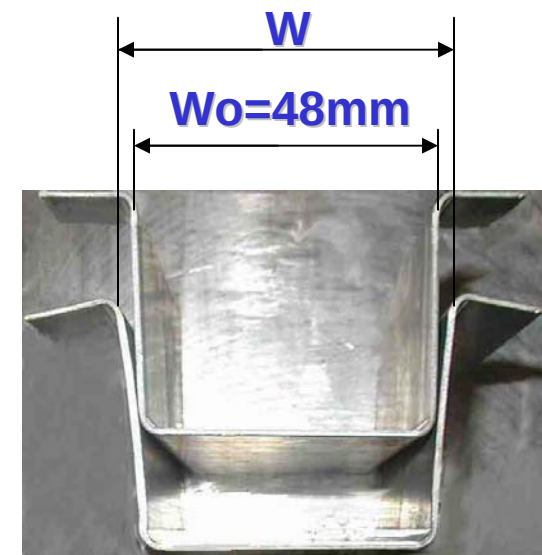




# Plane Strain Drawing Test



$$\Delta W = W - W_0$$





- DP and TRIP steels display excellent formability as compared to conventional HSS and better capacity to distribute strain over the part surface
- AHSS display very good bendability
- ASM FLC approximation (Keeler-Brazier) is applicable for DP and TRIP steels
- Due to excellent combination of strength with formability, TRIP steel has potential for economic application (possibility for reduction of the number of parts in the car)
- A need to understand AHSS unique characteristics to successfully make parts
  - One-for-one direct substitution with other HSS may cause issues





- 1. Konieczny, A. A., On the Formability of Automotive TRIP Steels, SAE, 2003-01-521**
- 2. Kamura M., Omija Y., Shaw J., Chen M., Formability and Springback Characterization of Advanced High Strength Steel, SAE, 2003-01-522**
- 3. Konieczny, A. A., An Overview of Formability, Technological and Microstructural Aspects of the Automotive TRIP Steels, Processing and Fabrication of Advanced Materials, 11th Int. Symposium 2002, ASM Materials Solution Conference and Exposition, 7-10 October, 2002, Columbus, Ohio**
- 4. Konieczny A. A., On Formability Assessment of the Automotive Dual Phase Steels, IBEC, 2001-01-3075**
- 5. Konieczny A. A., Hoydick D. P., An Overview of Formability, Technological and Microstructural Aspects of the Automotive Dual-Phase Steels, Processing and Fabrication of Advanced Materials, Ninth Int. Symposium 2000, ASM Materials Solution Conference and Exposition, 9-12 October, 2000, St. Louis, Missouri**
- 6. Shi M. F., Thomas G. H., Chen X. M., Fekete J. R., Formability Performance Comparison between Dual Phase and HSLA Steels, Process Symposium 43rd Mechanical Working and Steel Processing Conference, Iron & Steel Society, 2001**

