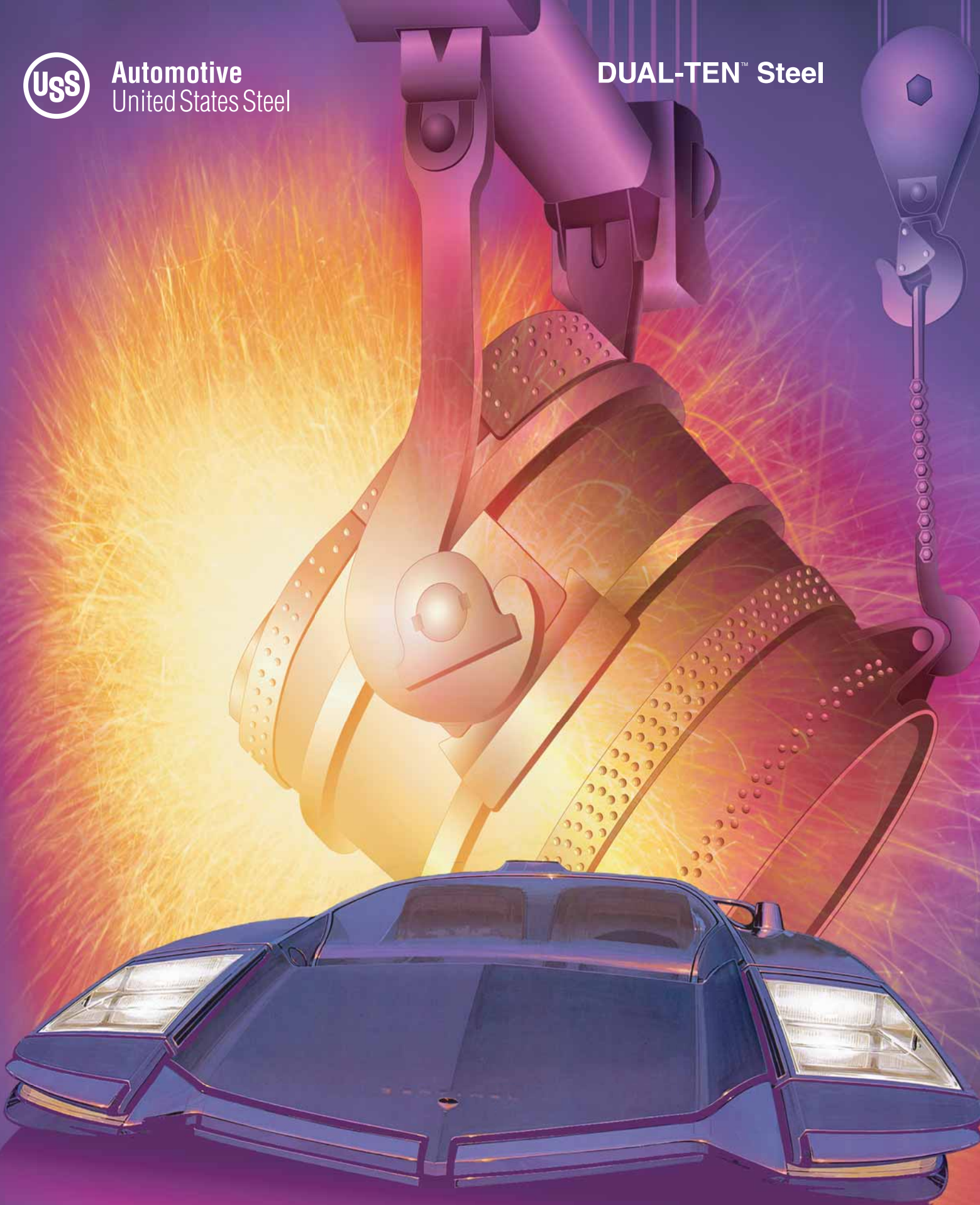




Automotive
United States Steel

DUAL-TEN™ Steel



Introduction

U. S. Steel's DUAL-TEN™ steels have a remarkable combination of formability, strength, ductility, bake hardenability and strain rate sensitivity. These unique materials have been engineered to meet the demands of the automotive designer and will enable cost-effective vehicle weight reduction while improving vehicle safety.

U. S. Steel's automotive group is one of the primary steel technical resources to the automotive industry and a participant in new vehicle design activities. Our automotive team, a centralized sales, technology and research organization, has the resources and expertise to help OEMs utilize steel solutions in future vehicle designs.

Computer simulations and physical testing in our automotive center laboratories played a substantial role in our development and qualification of DUAL-TEN™ steels, and will help bring to market other engineered steels currently under development for automotive applications.

DUAL-TEN™ is an example of U. S. Steel's commitment to providing cost-effective steel solutions to the automotive industry.



For additional automotive steel information, please visit us at www.ussautomotive.com. This website consists of steel technical information and specifications intended to assist the automotive designer in optimizing steel in their designs for tomorrow.

The vehicle illustrated on the cover of this brochure was designed by Syd Mead for U. S. Steel in the early 1960s. The advanced design demonstrates U. S. Steel's long heritage of involvement in advanced vehicle design concepts.

U. S. Steel DUAL-TEN™

DUAL-TEN™ steels are being used for automotive underbody structural parts as well as exposed body panels. U. S. Steel's commercially available products include hot dip galvanized (HDG) DUAL-TEN™ and hot dip galvalume (HDGA) DUAL-TEN™. The major benefit of DUAL-TEN™ is enhanced crash performance with relatively good formability when compared to conventional high-strength, low-alloy (HSLA) steels. This bulletin summarizes some key properties and data for HDG DUAL-TEN™ and HDGA DUAL-TEN™.

Mechanical Properties

The following table summarizes minimum mechanical properties of commercially produced DUAL-TEN™ using ASTM test methods.

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)	n-value 10% to Uniform Elongation
DUAL-TEN™ 500	300	500	27	0.19
DUAL-TEN™ 590	340	590	25	0.15
DUAL-TEN™ 600	340	600	25	0.15
DUAL-TEN™ 780	400	780	16	0.12
DUAL-TEN™ 800	500	800	16	0.12
HSLA 340	340	430	27	0.16

Strain Aging

U. S. Steel's HDG DUAL-TEN™ and HDGA DUAL-TEN™ will not age at room temperature. Figure 1 shows after pre-straining the yield strength change over 60 days. No change in yield strength occurs even with 2% pre-strain. However, unlike conventional HSLA steels, DUAL-TEN™ shows bake hardening.

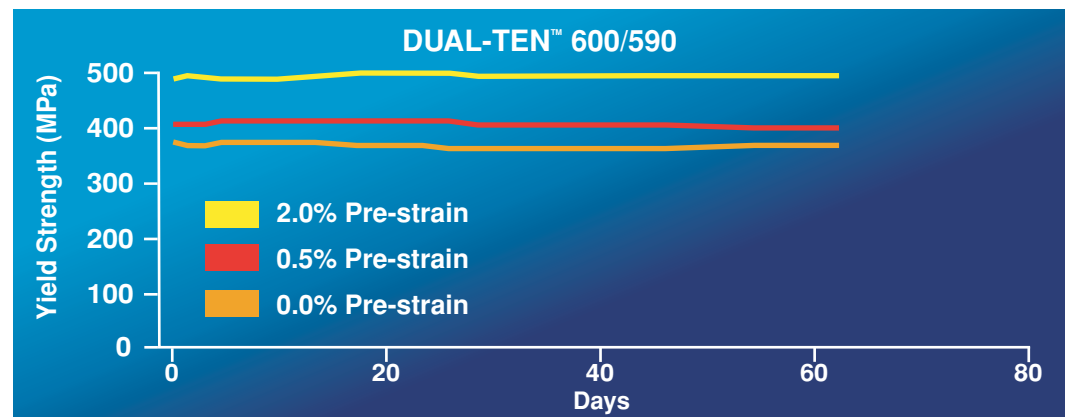


Figure 1: Room Temperature Strain Aging

Figure 2 shows yield strength change from strain hardening and bake hardening for DUAL-TEN™. The data were obtained from a 2% uniaxially pre-strained specimen after baking at 175°C (350°F) for 30 minutes. For comparison, data for HSLA 340 are also included. DUAL-TEN™ shows significantly higher bake hardening and strain hardening than HSLA.

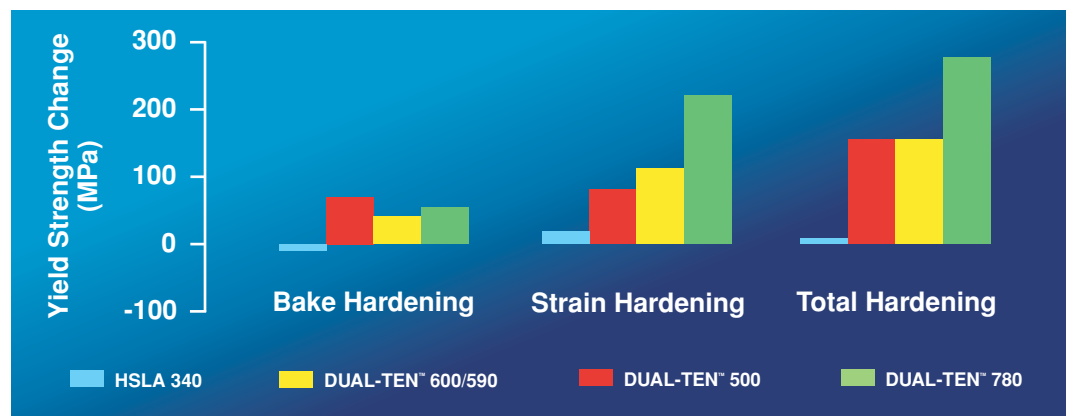


Figure 2: Strain and Bake Hardening Behavior

Strain Hardening and Forming Properties

DUAL-TEN™ steel has a higher tensile-to-yield strength ratio than conventional high-strength steels. This greater strength ratio, coupled with zero YPE, enables DUAL-TEN™ to have rapid strain hardening at lower strain levels. Figure 3 shows the instantaneous n-value change with strain. DUAL-TEN™ exhibits superior initial strain hardening behavior when compared to HSLA.

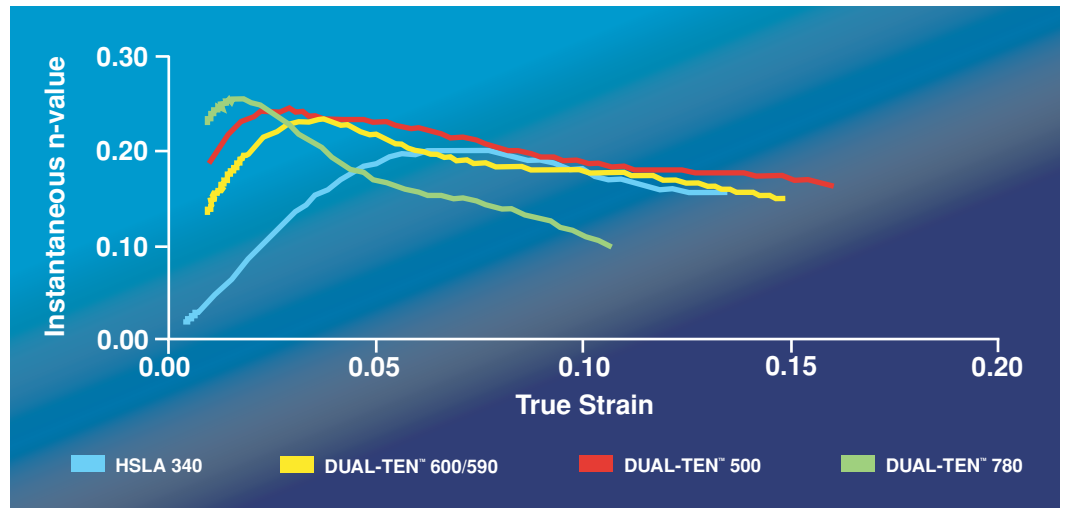


Figure 3: Instantaneous n-value Change with Strain

The initial high strain hardening behavior of DUAL-TEN™ enhances strain distribution ability during stamping and limits buckling during end feeding in a hydro-forming process. Figure 4 shows that DUAL-TEN™ 600/590 has increased draw depth capability as compared to HSLA 340 under the same forming conditions using a T-channel test.

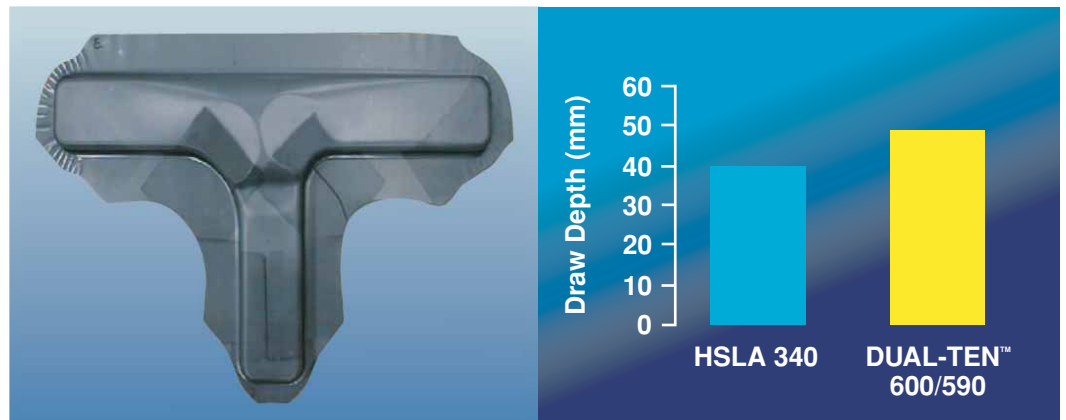


Figure 4: Draw Depth from a T-Channel Test [7]

Forming Limits

As shown in Figure 5, the ASM standard shape of the forming limit curve for steel can be used for DUAL-TEN™ steel, and the equation for the FLC calculation using n-value and sheet thickness is still valid for DUAL-TEN™. The n-value used for the FLC calculation should be determined from stress and strain data from 10% strain to end of uniform elongation.

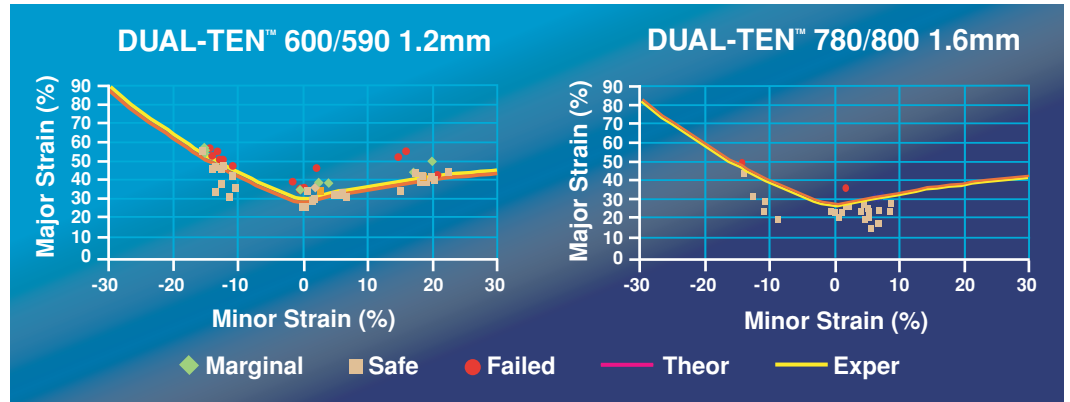


Figure 5: The Experimentally Determined Forming Limit Diagram for DUAL-TEN™ 600/590 and DUAL-TEN™ 780/800 [4]

Dent Resistance

DUAL-TEN™ 500 has been considered for potential exposed body panel applications. Due to the high initial yield strength of DUAL-TEN™, both static and dynamic dent tests have shown superior dent resistance performance for DUAL-TEN™. Figure 6 shows the dent resistance performance of DUAL-TEN™ 500 using the pie pan panel with 2% biaxial stretch. For comparison, dent resistance data from two bake hardenable steel grades (BH210 and BH250) are also included in the figure. The dent resistance performance of DUAL-TEN™ is much better than both bake hardenable steel grades.

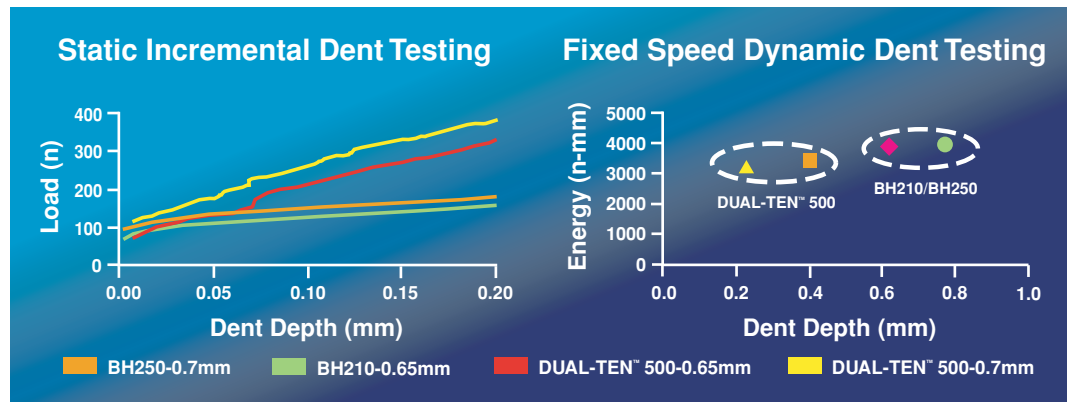


Figure 6: Dent Resistance Performance of DUAL-TEN™ 500 When Compared to BH210 or BH250

Springback

Due to the high-strength nature of DUAL-TEN™, springback is taken into consideration at product and process design stages.

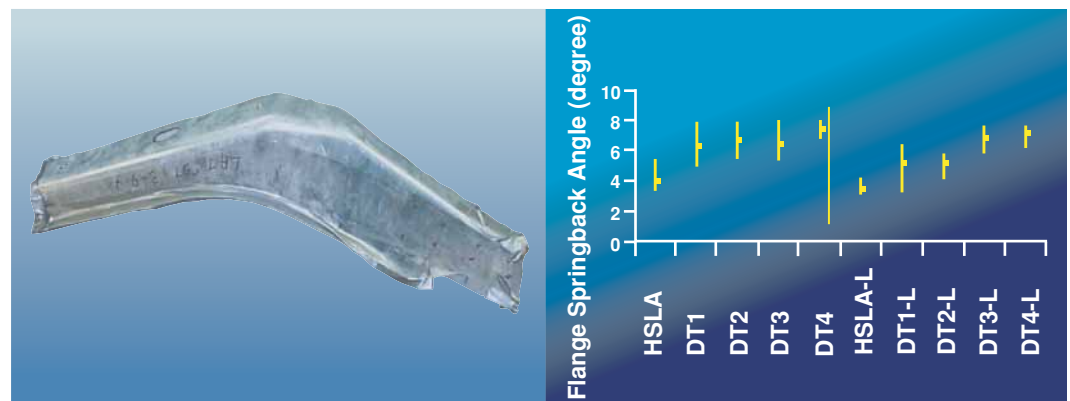


Figure 7: Springback Angle Measures from an Automotive Rail Stamped on Tools Designed for HSLA [2]

Figure 7 shows the springback angle measures from an automotive rail. DT1, DT2, DT3 and DT4, DUAL-TEN™ steels with minimum tensile strength of 590 MPa, are compared with HSLA 340. This analysis shows that DUAL-TEN™ has a higher springback angle than HSLA. However, springback can be controlled by modified part design and die design. DUAL-TEN™ is more formable than conventional high-strength steel (as shown in Figure 4), and offers flexibility in part and die designs to control springback. Figure 8 illustrates the effect of die radius and restraint force on sidewall curl and springback angle, measured from a strip drawn over a die radius. By using an appropriate die radius and restraint force, springback of DUAL-TEN™ can be controlled. Preliminary data also show that DUAL-TEN™ has less springback variation than conventional HSLA.

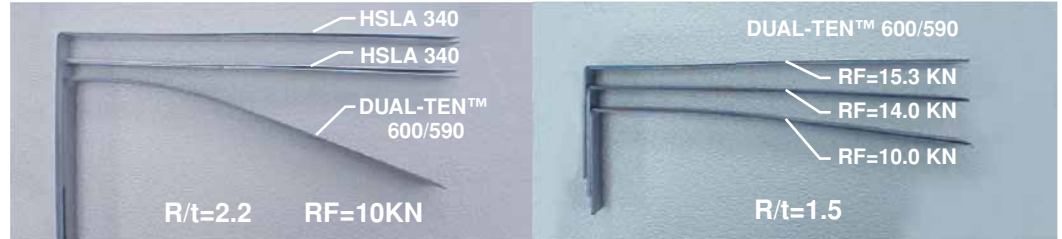


Figure 8: Effects of Die Radius (R/t) and Restraint Force (RF) on Springback [8]

Crash Performance

Due to its higher tensile-to-yield ratio, DUAL-TEN™ has demonstrated enhanced crash performance when compared to conventional HSLA steel with similar yield strength and formability. Using samples cut from a stamped automotive rail, as shown in Figure 9a, a drop tower test shows that DUAL-TEN™ 600/590 has at least 10% less crash distance, as shown in Figure 9b, when total drop energy is absorbed by the material at 46 km/hr drop speed. It has also been shown that at least 10% downgauging is feasible when DUAL-TEN™ 600/590 replaces HSLA 340.



Figure 9a: Drop Tower Sample [3]

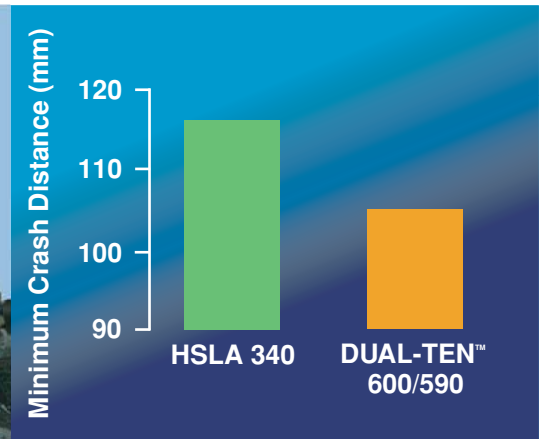


Figure 9b: Maximum Crash Distance from Drop Tower Test

The ability of DUAL-TEN™ steels to absorb more energy during crash is demonstrated in Figure 10. It is clearly shown from this hydro-formed rail that DUAL-TEN™ 600/590 absorbs more energy than HSLA 340 during the crash testing.

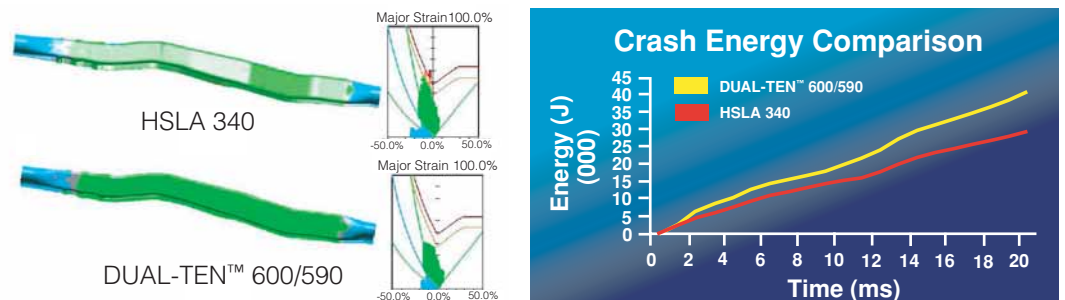


Figure 10: Energy Absorption of a Hydro-formed Rail During Crash [5]

Weldability

DUAL-TEN™ products utilize a weld current range similar to conventional HSLA products. However, DUAL-TEN™ products have displayed no hold time sensitivity.

Bendability

DUAL-TEN™ products have demonstrated good bendability. The material can be bent into 0.5t radius for DUAL-TEN™ 600/590 and 1.0t radius for DUAL-TEN™ 780/800 without any outer radius cracking. The appearance after bending DUAL-TEN™ 600/590 and DUAL-TEN™ 780/800 is shown in Figure 11.



Figure 11: Bendability of DUAL-TEN™ Products [4]

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For more information:

Please review: www.ussautomotive.com
"Steel Solutions for the Automotive Industry"

or contact: Director - Product Technology
United States Steel
Automotive Center
5850 New King Court
Troy, MI 48098 USA

1 248 267 2528
e-mail: ussautomotive@uss.com



United States Steel
Automotive Group
5850 New King Court
Troy, MI 48098-2692
1 248 267 2500
1 800 521 4270