ADVANCED HIGH-STRENGTH STEELS (AHSS)

Subject: Materials Science

MSc presentation
Széchenyi István University

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SOURCE OF THIS LESSON:

Advanced High Strength Steel, Application Guidelines, Version 6.0, 2017


Advanced High-Strength Steels
Application Guidelines Version 6.0

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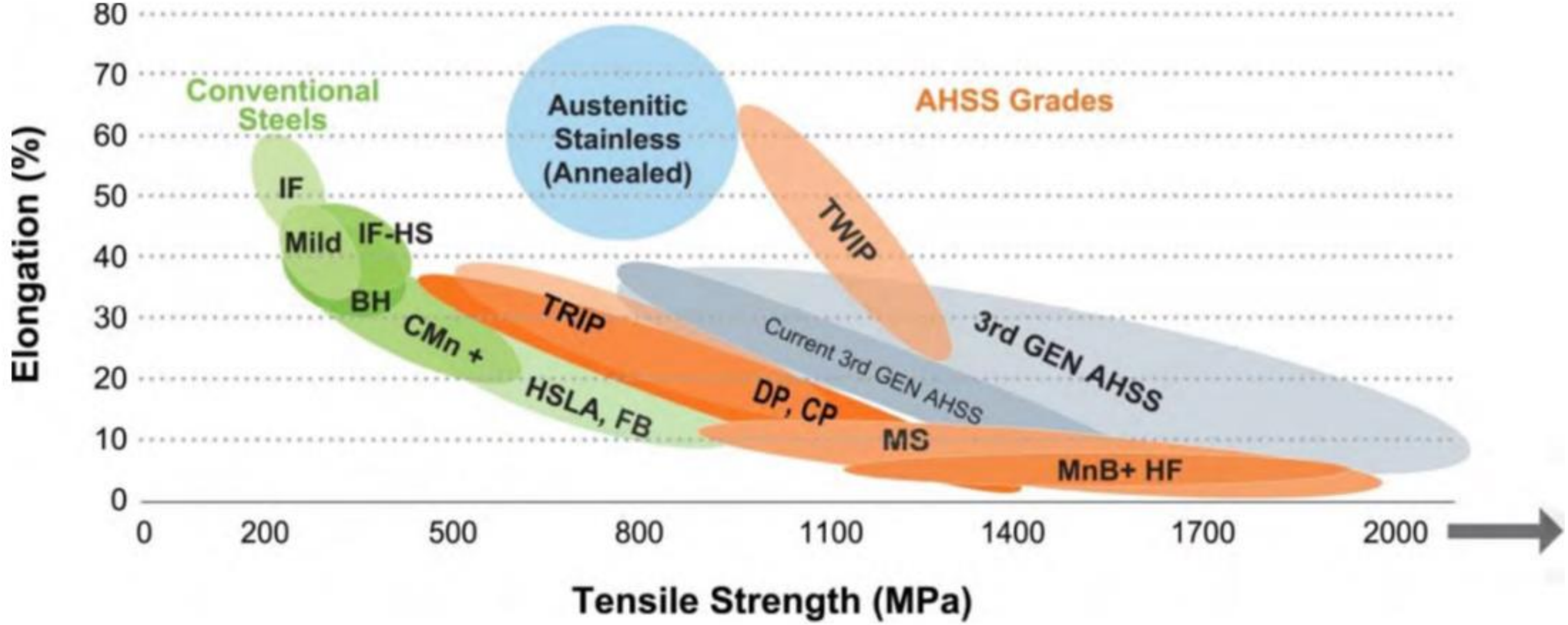
WorldAutoSteel

It can be downloaded free from:
http://www.worldautosteel.org/projects/advanced-high-strength-steel-application-guidelines/

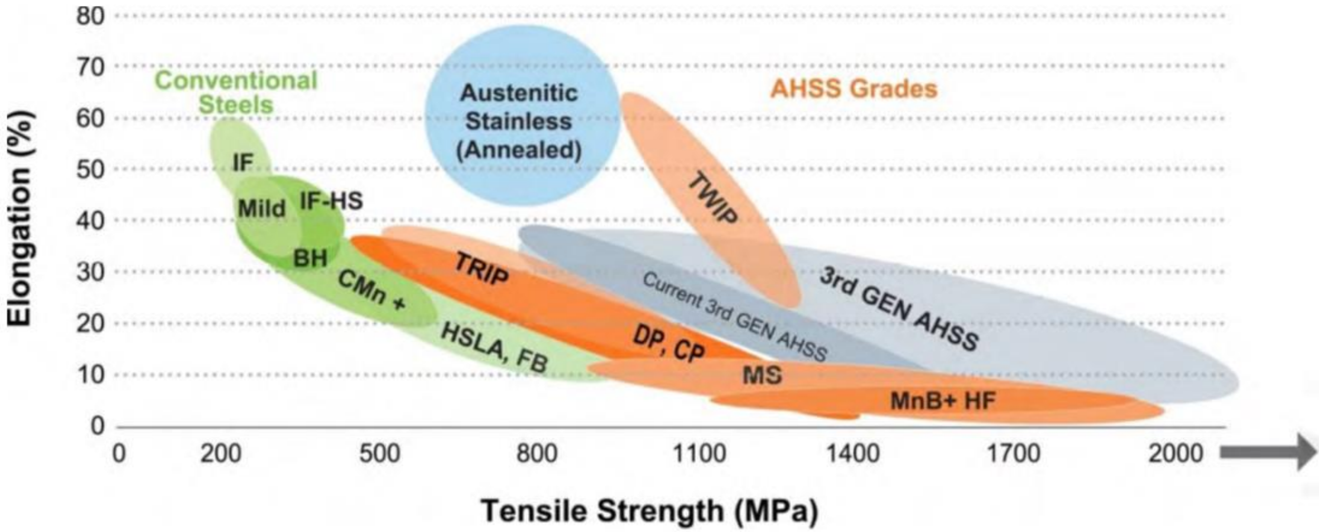
DEFINITIONS:

Global Formability Diagram for Today's AHSS Grades



(includes comparison of traditional low-strength and high-strength steels)

DEFINITIONS:

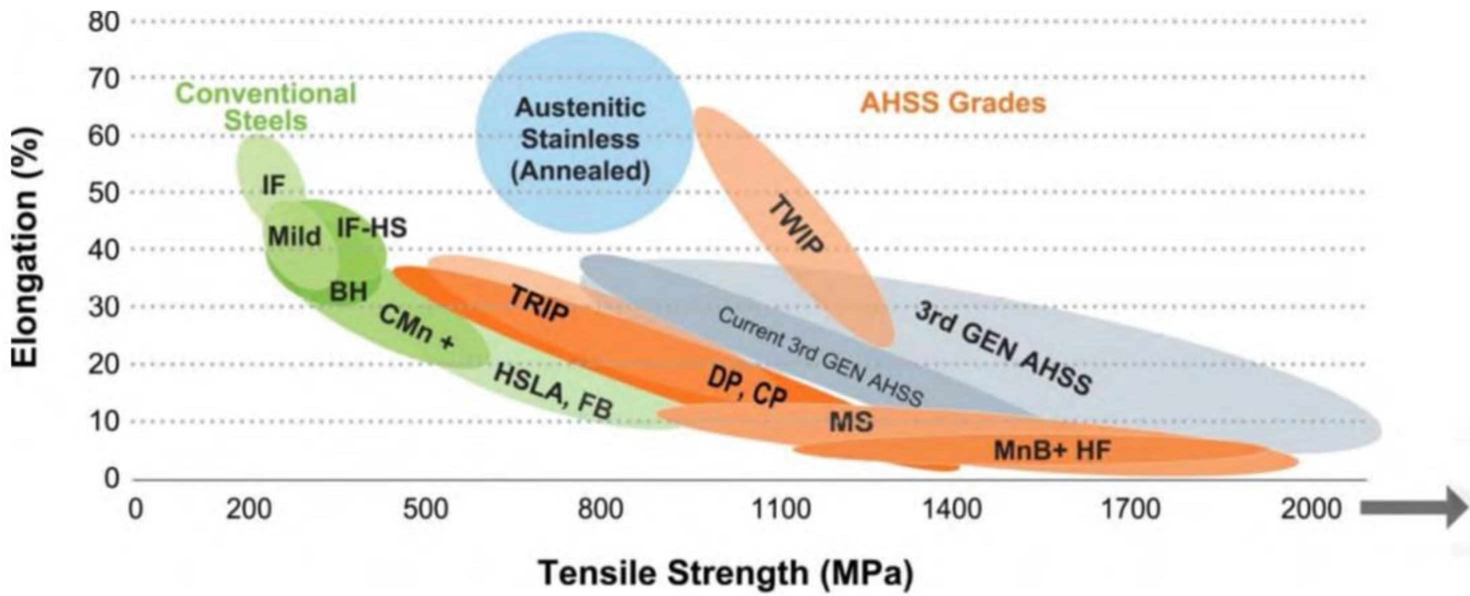


The principal **difference between conventional HSLA steels and AHSS is their microstructure**.

HSLA steels are single-phase ferritic steels with a potential for **some pearlite** in C-Mn steels.

AHSS are primarily steels with a **multiphase microstructure containing one or more phases** other than ferrite, pearlite, or cementite - for example **martensite, bainite, austenite**, and/or retained austenite in quantities sufficient to produce unique mechanical properties.
Some types of AHSS have a higher strain hardening capacity resulting in a strength-ductility balance superior to conventional steels. Other types have ultra-high yield and tensile strengths and show a bake hardening behavior.

DEFINITIONS:



Knowledge learnt in Lesson 1. was applied to develop the conventional HSLA.

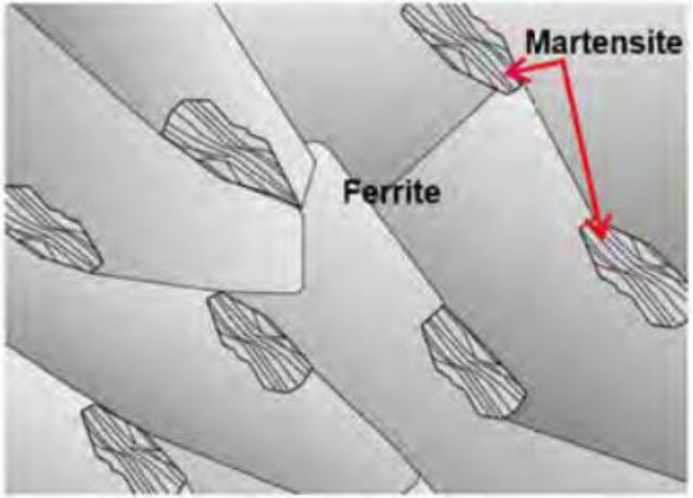
In order to develop AHSS and understand them, additional knowledge is needed.

These are detailed in this lesson at the different examples of the AHSS , in the following slides.

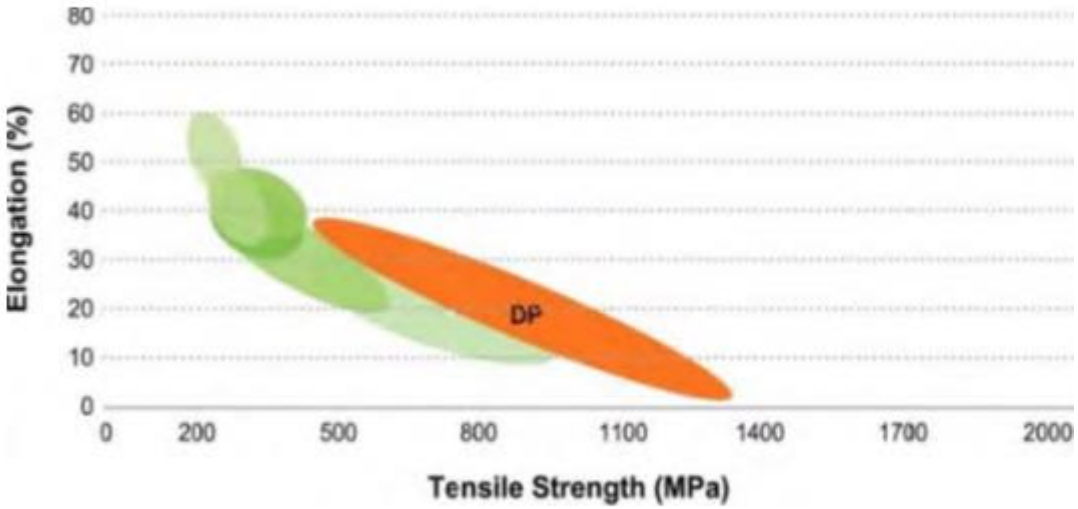
DUAL PHASE (DP) STEEL

DP steels consist of a **ferritic matrix containing a hard martensitic second phase** in the form of islands.

Increasing the volume fraction of hard second phases generally increases the strength.



Schematic shows islands of martensite in a matrix of ferrite.

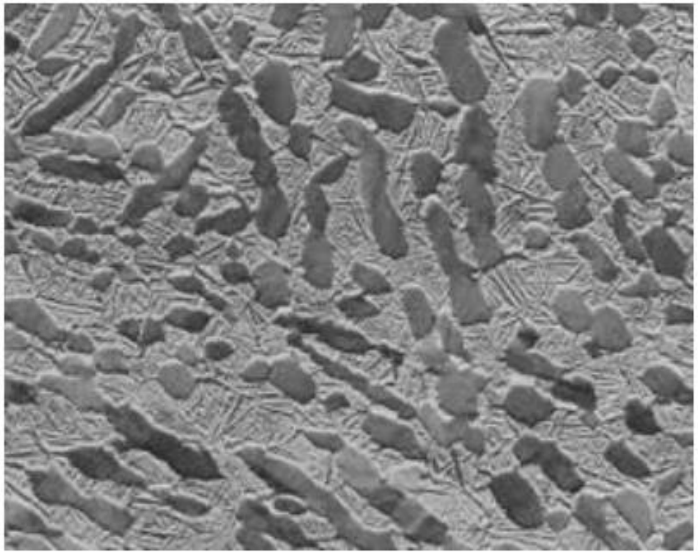


DUAL PHASE (DP) STEEL

DP (ferrite plus martensite) steels are **produced by controlled cooling from the austenite phase** (in hot-rolled products)

or from the two-phase ferrite plus austenite phase (for continuously annealed cold-rolled and hot-dip coated products) to **transform some austenite to ferrite before a rapid cooling** transforms the remaining austenite to martensite.

Due to the production process, a small amount of other phases (bainite and retained austenite) may be present.



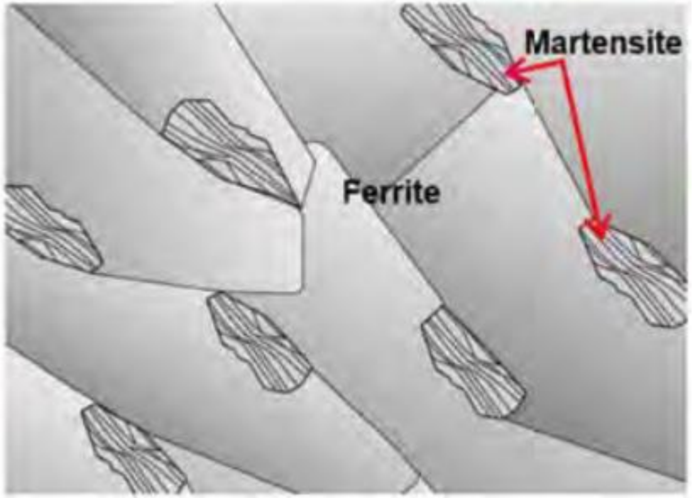
Micrograph of DP steel.

DUAL PHASE (DP) STEEL

The figure shows a schematic microstructure of DP steel, which contains **ferrite plus islands of martensite**.

The **soft ferrite phase is generally continuous, giving these steels excellent ductility**.

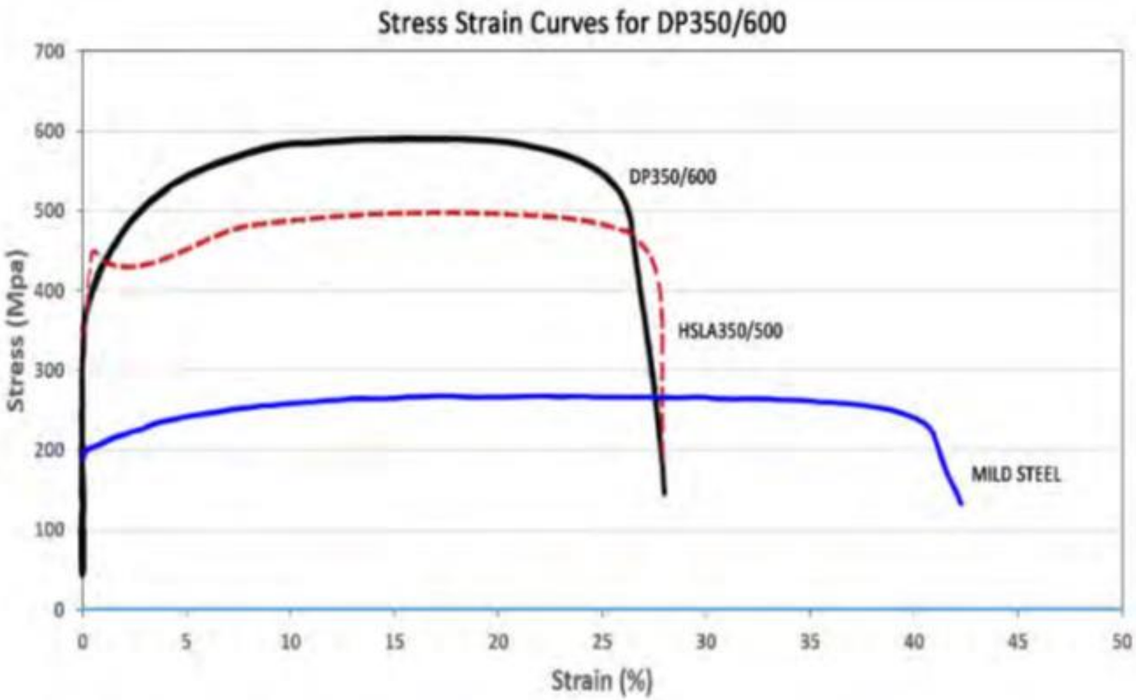
When these steels deform, strain is concentrated in the lower-strength ferrite phase surrounding the islands of martensite, creating the **unique high initial work-hardening rate** (n-value) exhibited by these steels.



DUAL PHASE (DP) STEEL

The work hardening rate plus excellent elongation creates DP steels with **much higher ultimate tensile strengths than conventional steels of similar yield strength**. The figure compares the engineering stress-strain curve for HSLA steel to a DP steel curve of similar yield strength.

The DP steel exhibits **higher initial work hardening rate**, **higher ultimate tensile strength**, and **lower YS/TS ratio** than the HSLA **with comparable yield strength**.



DUAL PHASE (DP) STEEL

DP and other AHSS also have a **bake hardening effect** that is an important benefit compared to conventional higher strength steels.

The bake hardening effect is **the increase in yield strength resulting from elevated temperature aging** (created by the curing temperature of paint bake ovens) **after pre-straining** (generated by the work hardening due to deformation during stamping or other manufacturing process).

The extent of the bake hardening effect in AHSS depends on an adequate amount of forming strain for the specific chemistry and thermal history of the steel.

DUAL PHASE (DP) STEEL

In DP steels, **carbon** enables the **formation of martensite at practical cooling rates** by increasing the hardenability of the steel.

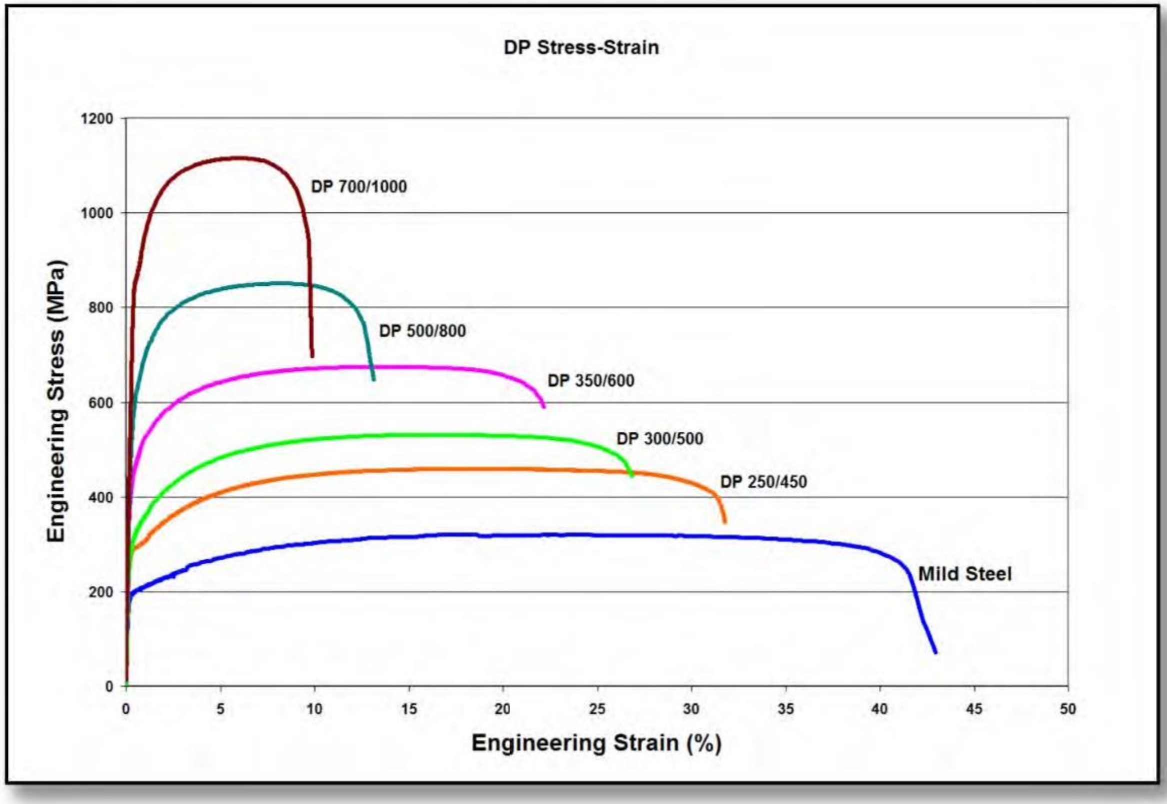
Manganese, chromium, molybdenum, vanadium, and nickel, added individually or in combination, also help **increase hardenability**.

These additions are carefully balanced, not only to produce unique mechanical properties, but also to maintain the generally **good resistance spot welding capability**. However, when welding the higher strength grades (DP 700/1000 and above) to themselves, the spot weldability may require adjustments to the welding practice.

DUAL PHASE (DP) STEEL

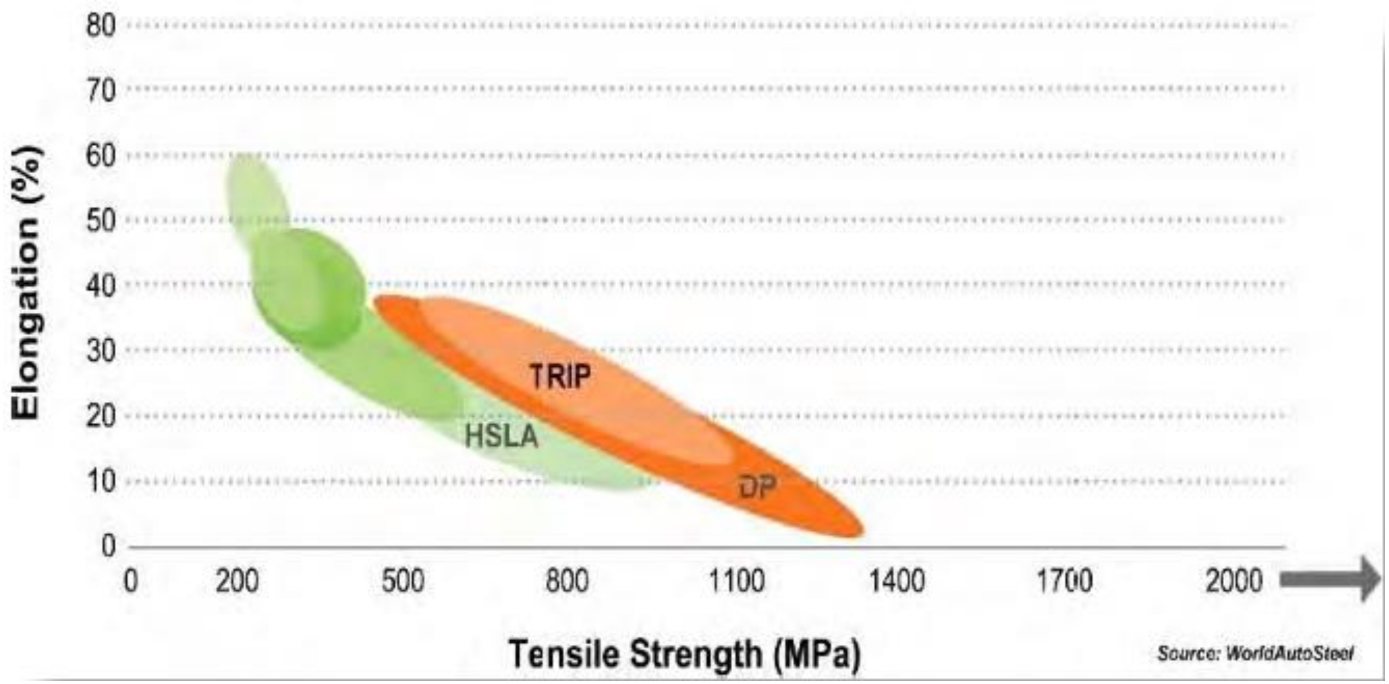
Examples of current production grades of DP steels and typical automotive applications are shown below:

DP 300/500, DP 350/600 etc. were developed for different application, for different part of the cars and other structures.



TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

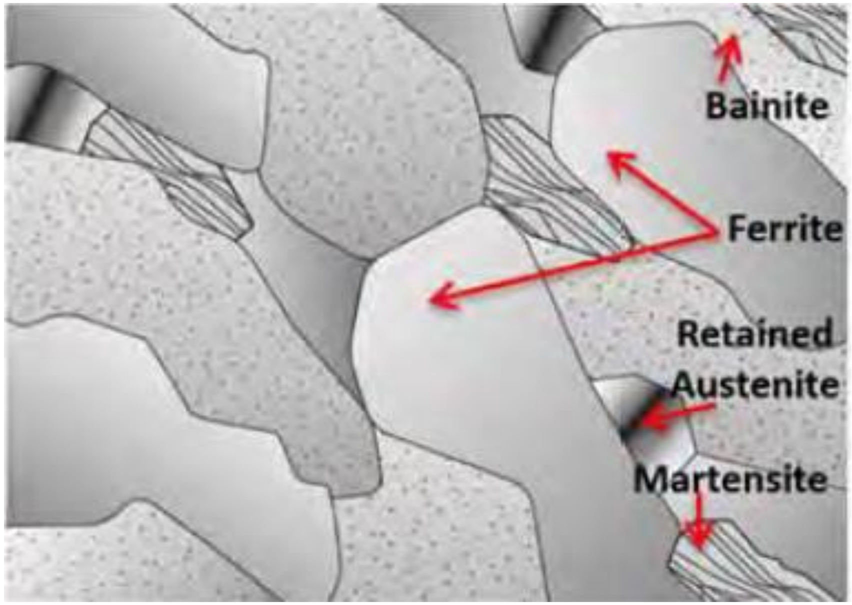
Their properties are better than for DP steels.
What is the cause?



TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

The microstructure of TRIP steels is **retained austenite embedded in a primary matrix of ferrite**.

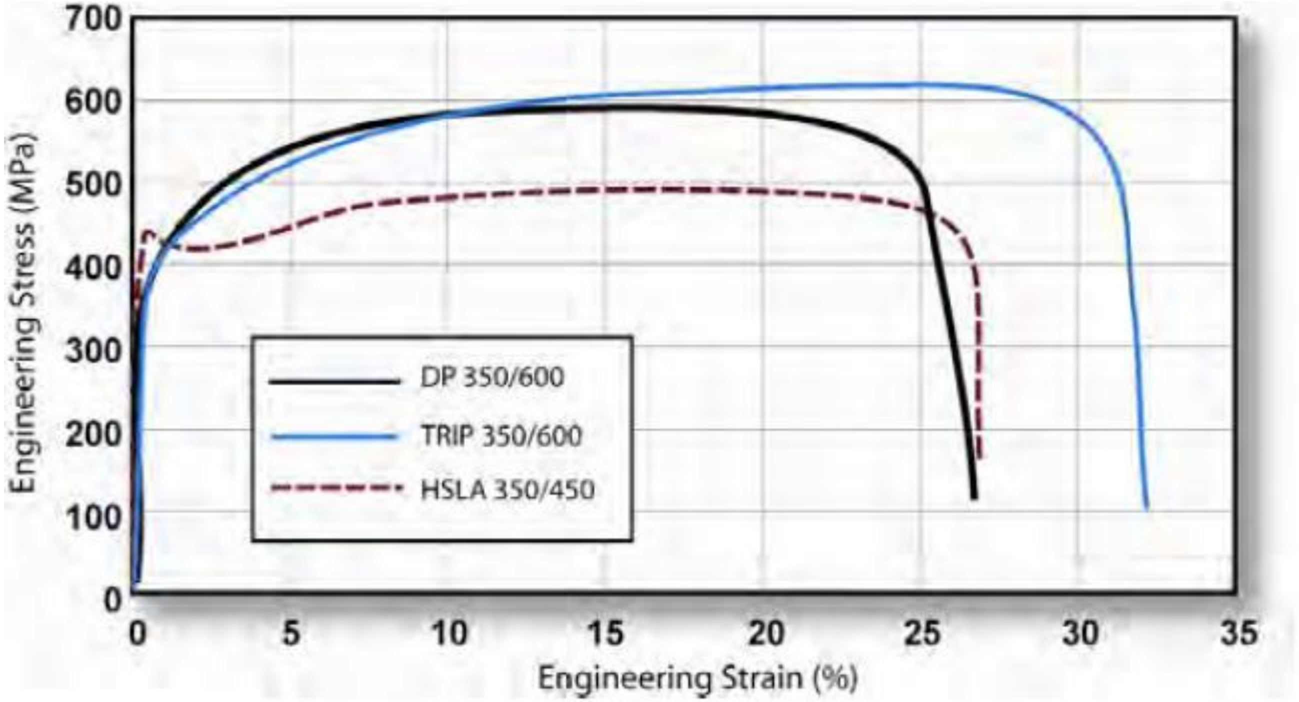
In addition to a **minimum of five volume percent of retained austenite**, hard phases such as **martensite and bainite are present** in varying amounts. TRIP steels typically require the use of an isothermal hold at an intermediate temperature, which produces some bainite.



The higher siliconand carbon content of TRIP steels also result in significant volume fractions of **retained austenite** in the final microstructure.

TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

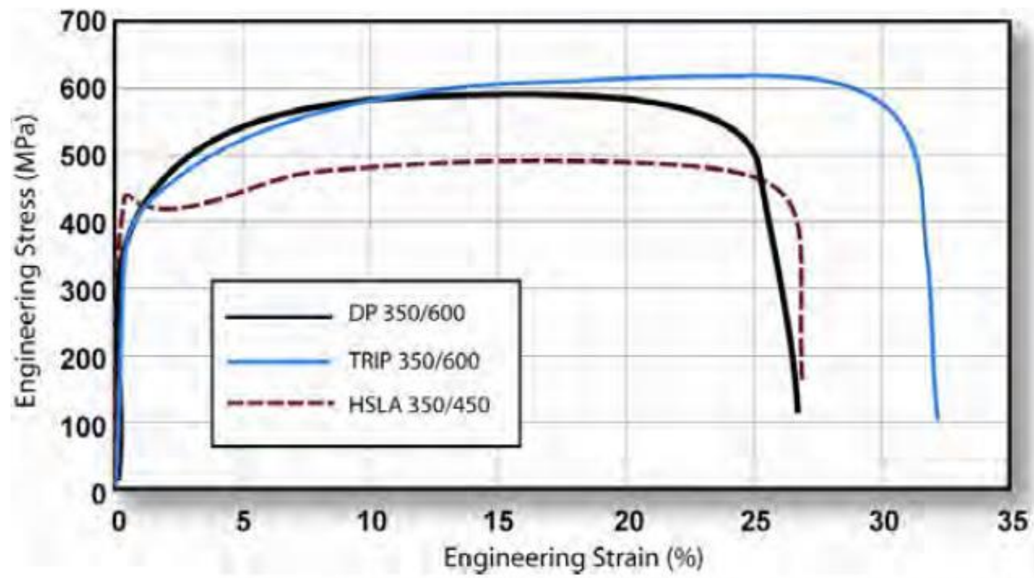
During deformation, the dispersion of hard second phases in soft ferrite creates a high work hardening rate, as observed in the DP steels. However, in TRIP steels **the retained austenite** also **progressively transforms to martensite** with increasing strain, thereby increasing the work hardening rate at higher strain levels.



TRIP 350/600 with a greater total elongation than DP 350/600 and HSLA 350/450

TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

The work **hardening rates of TRIP steels** are substantially **higher than for conventional HSS**, providing significant stretch forming. This is **particularly useful** when designers take advantage of the high work hardening rate (and increased bake hardening effect) to design a part utilizing the as-formed mechanical properties. The high work hardening rate persists to higher strains in TRIP steels, providing a slight advantage over DP in the most severe stretch forming applications.

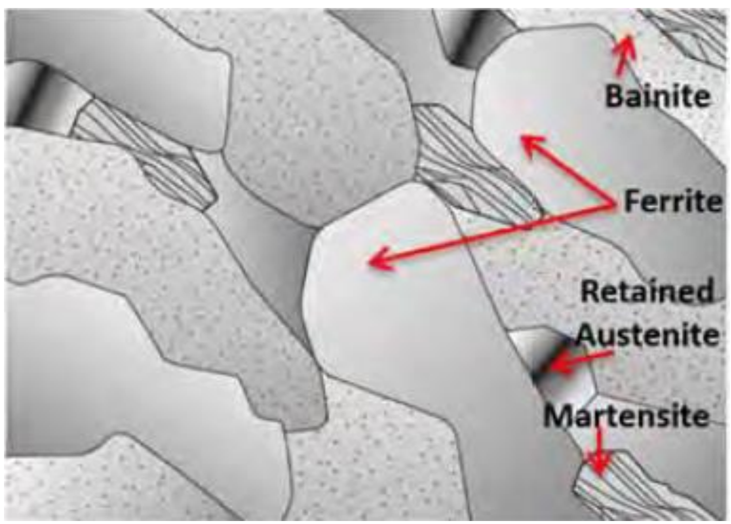


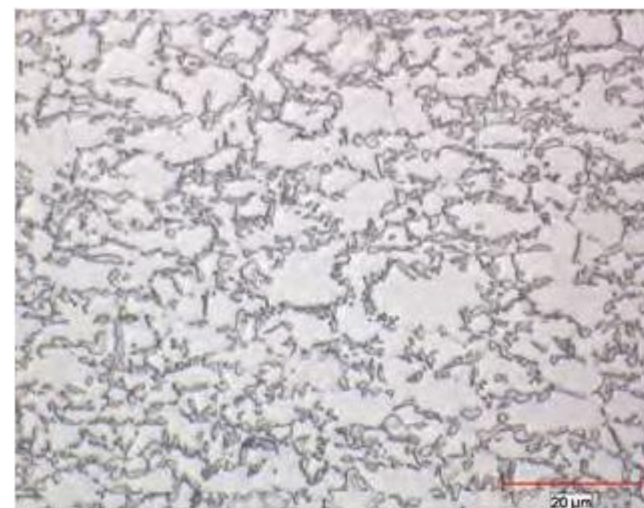
TRIP 350/600 with a greater total elongation than DP 350/600 and HSLA 350/450

TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

TRIP steels use **higher quantities of carbon** than DP steels to obtain sufficient carbon content for **stabilizing the retained austenite phase** to below ambient temperature.

Higher contents of silicon and/or aluminium accelerate the ferrite/bainite formation. These elements assist in maintaining the necessary carbon content within the retained austenite. Suppressing the carbide precipitation during bainitic transformation appears to be crucial for TRIP steels. **Silicon and aluminium are used to avoid carbide precipitation in the bainite region**.





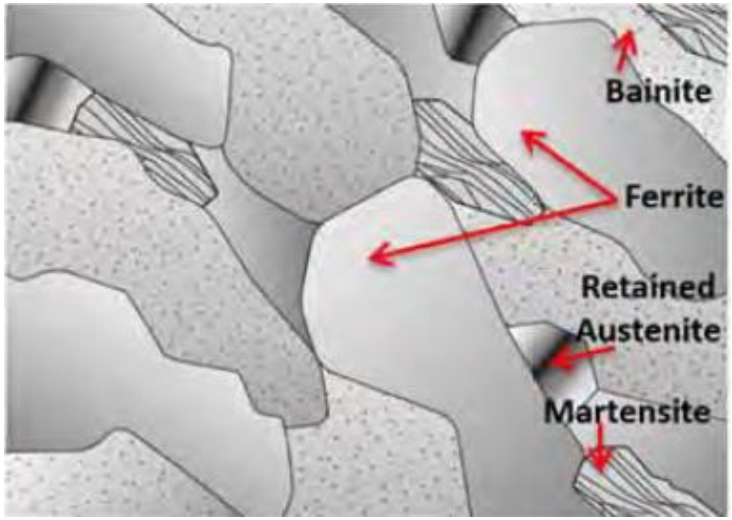
Micrograph of TRIP 690 steel

TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

The **strain level at which retained austenite begins to transform to martensite is controlled by adjusting the carbon content**.

At lower carbon levels, the retained austenite begins to transform **almost immediately** upon deformation, increasing the work hardening rate and formability during the stamping process.

At higher carbon contents, the retained austenite is **more stable** and begins to transform only at strain levels beyond those produced during forming.
At these carbon levels, the **retained austenite persists into the final part**.
It transforms to martensite during subsequent deformation, such as a **crash event**.

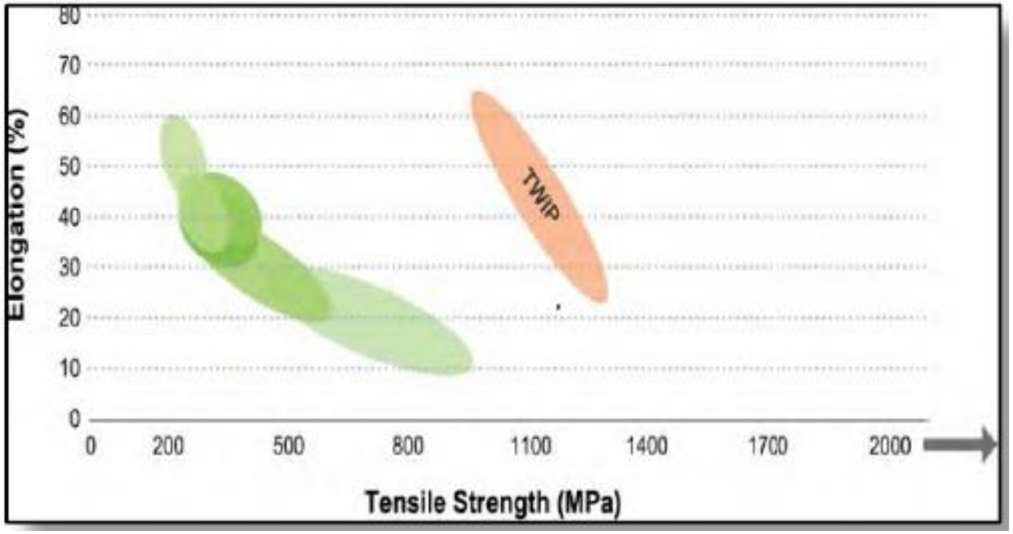


TRIP STEELS (TRANSFORMATION INDUCED PLASTICITY)

Current production grades of TRIP steels
and example automotive applications:

TRIP 350/600	**Frame rails, rail reinforcements**
TRIP 400/700	**Side rail, crash box**
TRIP 450/800	**Dash panel, roof rails**
TRIP 600/980	**B-pillar upper, roof rail, engine cradle, front and rear rails, seat frame**

TWIP STEELS (TWINNING INDUCED PLASTICITY)



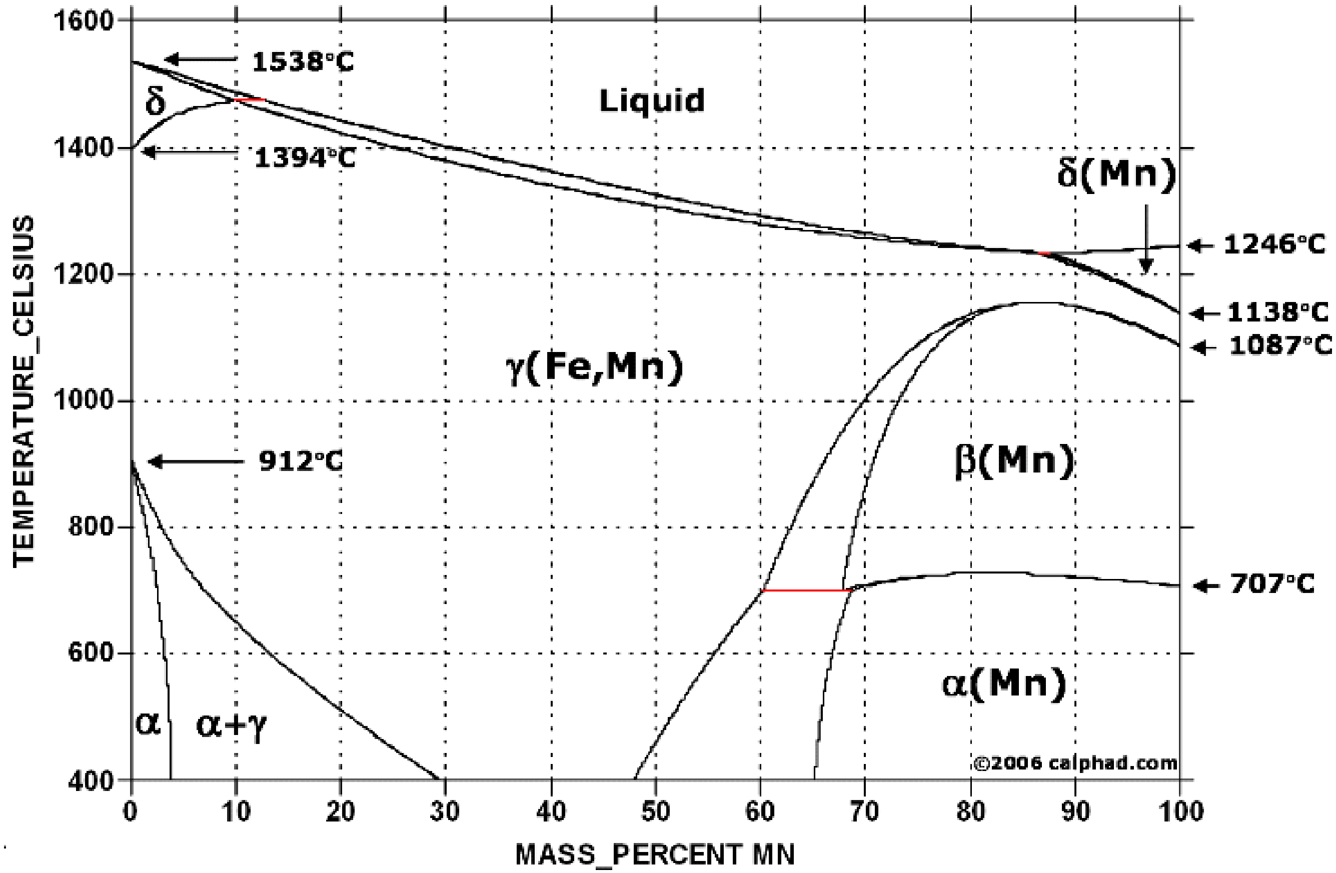
TWIP steels have a **high manganese content** (17-24%) that causes the steel to be **fully austenitic at room temperatures**.

A large amount of deformation is driven by the formation of crystal twins.

Face centred cubic (like austenite) and close packed hexagonal **crystal structures tend to crystal twinning**.

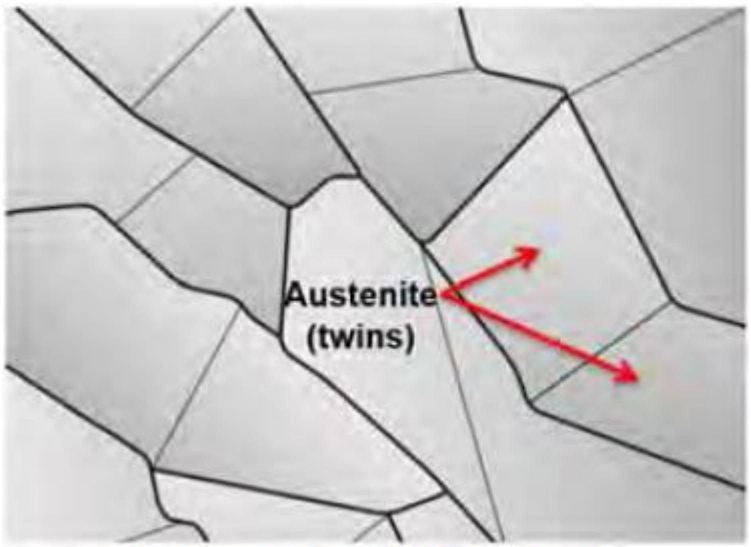
The resultant **twin boundaries act like grain boundaries and strengthen the steel**.

TWIP STEELS (TWINNING INDUCED PLASTICITY)

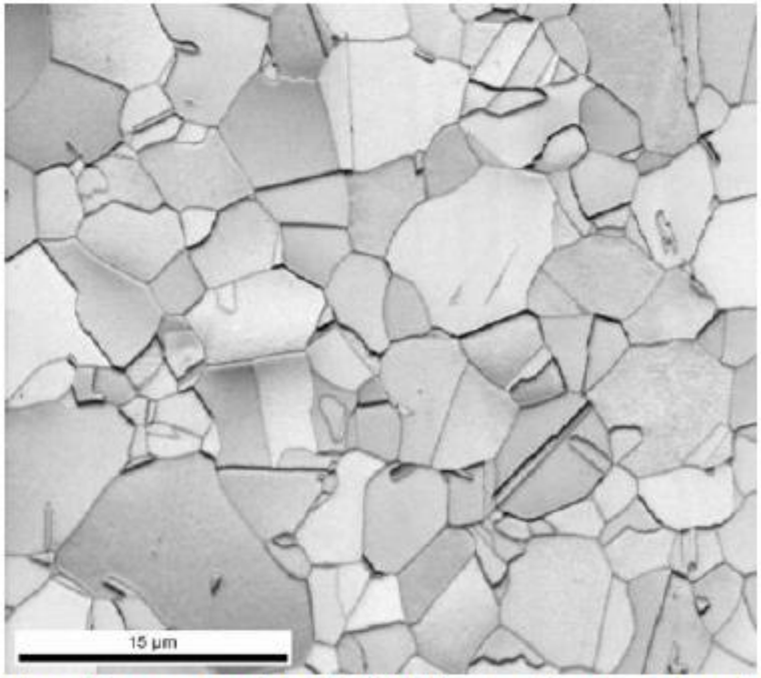


TWIP steels have a **high manganese content** (17-24%) that causes the steel to be **fully austenitic at room temperatures**.

TWIP STEELS (TWINNING INDUCED PLASTICITY)



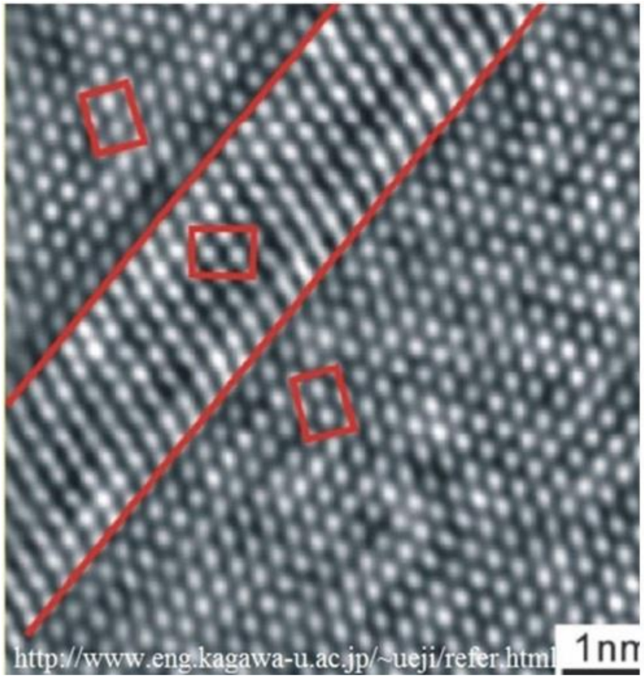
Schematic of TWIP steel.

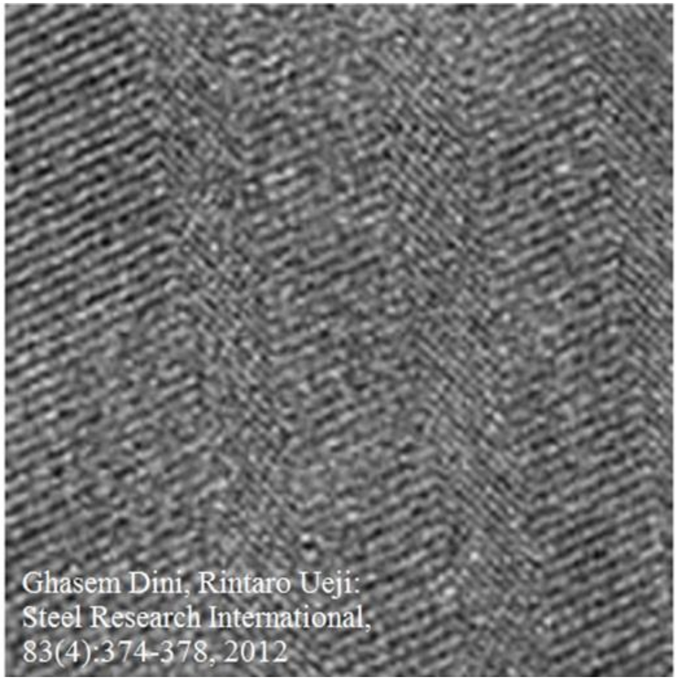


Photomicrograph of TWIP steel as annealed.

TWIP STEELS (TWINNING INDUCED PLASTICITY)

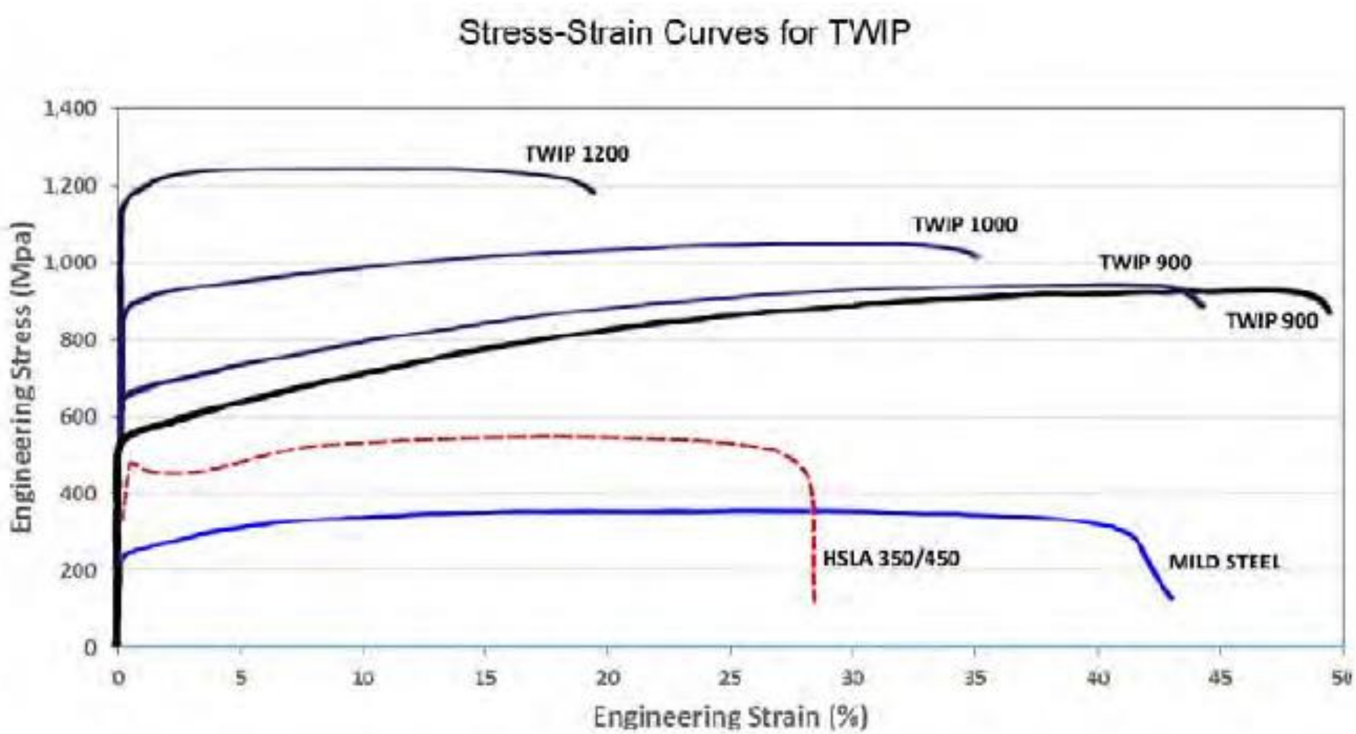
TEM images





The **symmetry planes of the twins behave like grain boundaries** (**NANOGRAIN STRUCTURE**), so they **inhibit the movement of the dislocations** strongly, **therefor the strength is high**. Beside this, **the structure remains a close packed face centred cubic crystal structure which is most favourable regarding the formability**.

TWIP STEELS (TWINNING INDUCED PLASTICITY)



TWIP steels combine **extremely high strength with extremely high stretchability**. The n-value increases to a value of 0.4 at an approximate engineering strain of 30% and then remains constant until both uniform and total elongation reach 50%. The **tensile strength is higher than 1000 MPa**.

TWIP STEELS (TWINNING INDUCED PLASTICITY)

In TWIP steels **the austenite** also **progressively transforms to martensite** with increasing strain, thereby increasing the work hardening rate at higher strain levels. This strengthening process is about twice effective than for TRIP steels.

The TWIP steels contain additional alloying elements of 3% Al+Si, so the total amount of the alloying ingredients is large. Therefor **the specific weight of the TWIP steels is smaller than for traditional steels**. This means mass reduction for vehicles.

TWIP STEELS (TWINNING INDUCED PLASTICITY)

Current production grades of TWIP steels and example automotive applications:

TWIP 500/900	A-Pillar, wheelhouse, front side member
TWIP 500/980	Wheel, lower control arm, front and rear bumper beams, B-pillar, wheel rim
TWIP 600/900	Floor cross-member, wheelhouse
TWIP 750/1000	Door impact beam
TWIP 950/1200	Door impact beam