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. Carbon also strengthens the martensite as a ferrite solute strengthener, as do silicon and phosphorus. 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 highest strength grade (DP 700/1000) to itself, the spot weldability may require adjustments to the welding practice.

Transformation-Induced Plasticity (TRIP) Steel

The microstructure of TRIP steels is retained austenite embedded in a primary matrix of ferrite. In addition to a minimum of 5 volume percent of retained austenite, hard phases such as martensite and bainite are present in varying amounts. A schematic TRIP steel microstructure is shown in Figure 1-4.

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. This is illustrated in Figure 1-5, where the stress-strain behaviour of HSLA, DP and TRIP steels of approximately similar yield strengths are compared. The TRIP steel has a lower initial work hardening rate than the DP steel, but the hardening rate persists at higher strains where work hardening of the DP begins to diminish.

The work hardening rates of TRIP steels are substantially higher than for conventional HSS, providing significant stretch forming and unique cup drawing advantages. 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 steels use higher quantities of carbon than DP steels to lower the martensite start temperature to below ambient temperature to form the retained austenite phase. 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.
The strain level at which retained austenite begins to transform to martensite can be designed 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 can therefore be engineered or tailored to provide excellent formability for manufacturing complex AHSS parts or to exhibit high work hardening during crash deformation to provide excellent crash energy absorption. The additional alloying requirements of TRIP steels degrade their resistance spot-welding behaviour. This can be addressed somewhat by modification of the welding cycles used (for example, pulsating welding or dilution welding).

Complex Phase (CP) Steel

Complex phase steels typify the transition to steel with very high ultimate tensile strengths. CP steels consist of a very fine microstructure of ferrite and a higher volume fraction of hard phases that are further strengthened by fine precipitates. They use many of the same alloy elements found in DP and TRIP steels, but also often have small quantities of niobium, titanium, and/or vanadium to form fine strengthening precipitates. CP steels display higher yield strengths for equal tensile strength levels of 800 MPa and greater. CP steels are characterized by high deformability, high energy absorption, and high residual deformation capacity.

Martensitic (Mart) Steel

To create martensitic steels, the austenite that exists during hot-rolling or annealing is transformed almost entirely to martensite during quenching on the run-out table or in the cooling section of the continuous annealing line. This structure can also be developed with post-forming heat treatment. Martensitic steels provide the highest strengths, up to 1700 MPa ultimate tensile strength. Martensitic steels are often subjected to post-quench tempering to improve ductility, and can provide substantial formability even at extremely high strengths.

Carbon is added to martensitic steels to increase hardenability and for strengthening the martensite. The data in Figure 1-6 illustrates the relationship between carbon content and tensile strength in untempered martensite. Manganese, silicon, chromium, molybdenum, boron, vanadium, and nickel are also used in various combinations to increase hardenability.

![Figure 1-6 - Relation of carbon content and tensile strength in untempered martensite.](image)