# High-strength low-alloy steel

**High-strength low-alloy steel** (**HSLA**) is a type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. HSLA steels vary from other steels in that they are not made to meet a specific chemical composition but rather to specific mechanical properties. They have a carbon content between 0.05 - 0.25% to retain formability and weldability. Other alloying elements include up to 2.0% manganese and small quantities of copper, nickel, niobium, nitrogen, vanadium, chromium, molybdenum, titanium, calcium, rare earth elements, or zirconium.[1][2] Copper, titanium, vanadium, and niobium are added for strengthening purposes.[2] These elements are intended to alter the microstructure of carbon steels, which is usually a ferrite-pearlite aggregate, to produce a very fine dispersion of alloy carbides in an almost pure ferrite matrix. This eliminates the toughness-reducing effect of a pearlitic volume fraction yet maintains and increases the material's strength by refining the grain size, which in the case of ferrite increases yield strength by 50% for every halving of the mean grain diameter. Precipitation strengthening plays a minor role, too. Their yield strengths can be anywhere between 250 - 590 megapascals (36,000 - 86,000 psi). Because of their higher strength and toughness HSLA steels usually require 25 to 30% more power to form, as compared to carbon steels.[2]

Copper, silicon, nickel, chromium, and phosphorus are added to increase corrosion resistance. Zirconium, calcium, and rare earth elements are added for sulfide-inclusion shape control which increases formability. These are needed because most HSLA steels have directionally sensitive properties. Formability and impact strength can vary significantly when tested longitudinally and transversely to the grain. Bends that are parallel to the longitudinal grain are more likely to crack around the outer edge because it experiences tensile loads. This directional characteristic is substantially reduced in HSLA steels that have been treated for sulfide shape control.[2]

They are used in cars, trucks, cranes, bridges, roller coasters and other structures that are designed to handle large amounts of stress or need a good strength-to-weight ratio.[2] HSLA steels are usually 20 to 30% lighter than a carbon steel with the same strength.[3][4]

HSLA steels are also more resistant to rust than most carbon steels because of their lack of pearlite - the fine layers of ferrite (almost pure iron) and cementite in pearlite.[*citation needed*] HSLA steels usually have densities of around 7800 kg/m³.[5]

## Classifications

- **Weathering steels**: steels which have better corrosion resistance. A common example is COR-TEN.
- **Control-rolled steels**: hot rolled steels which have a highly deformed austenite structure that will transform to a very fine equiaxed ferrite structure upon cooling.

- **Pearlite-reduced steels**: low carbon content steels which lead to little or no pearlite, but rather a very fine grain ferrite matrix. It is strengthened by precipitation hardening.
- **Acicular ferrite steels**: These steels are characterized by a very fine high strength acicular ferrite structure, a very low carbon content, and good hardenability.
- **Dual-phase steels**: These steels have a ferrite microstruture that contain small, uniformly distributed sections of martensite. This microstructure gives the steels a low yield strength, high rate of work hardening, and good formability.[1]
- **Microalloyed steels**: steels which contain very small additions of niobium, vanadium, and/or titanium to obtain a refined grain size and/or precipitation hardening.

A common type of micro-alloyed steel is improved-formability HSLA. It has a yield strength up to 80,000 psi (550 MPa) but only costs 24% more than A36 steel (36,000 psi (250 MPa)). One of the disadvantages of this steel is that it is 30 to 40% less ductile. In the U.S., these steels are dictated by the ASTM standards A1008/A1008M and A1011/A1011M for sheet metal and A656/A656M for plates. These steels were developed for the automotive industry to reduce weight without losing strength. Examples of uses include door-intrusion beams, chassis members, reinforcing and mounting brackets, steering and suspension parts, bumpers, and wheels.[2][6]

## SAE grades

The Society of Automotive Engineers (SAE) maintains standards for HSLA steel grades because they are often used in automotive applications.

SAE HSLA steel grade compositions[7]

| Grade | % Carbon (max) | % Manganese (max) | % Phosphorus (max) | % Sulfur (max) | % Silicon (max) | Notes |
|---|---|---|---|---|---|---|
| 942X | 0.21 | 1.35 | 0.04 | 0.05 | 0.90 | Niobium or vanadium treated |
| 945A | 0.15 | 1.00 | 0.04 | 0.05 | 0.90 | |
| 945C | 0.23 | 1.40 | 0.04 | 0.05 | 0.90 | |
| 945X | 0.22 | 1.35 | 0.04 | 0.05 | 0.90 | Niobium or vanadium treated |
| 950A | 0.15 | 1.30 | 0.04 | 0.05 | 0.90 | |
| 950B | 0.22 | 1.30 | 0.04 | 0.05 | 0.90 | |
| 950C | 0.25 | 1.60 | 0.04 | 0.05 | 0.90 | |
| 950D | 0.15 | 1.00 | 0.15 | 0.05 | 0.90 | |
| 950X | 0.23 | 1.35 | 0.04 | 0.05 | 0.90 | Niobium or vanadium treated |

| | | | | | | |
|---|---|---|---|---|---|---|
| 955X | 0.25 | 1.35 | 0.04 | 0.05 | 0.90 | Niobium, vanadium, or nitrogen treated |
| 960X | 0.26 | 1.45 | 0.04 | 0.05 | 0.90 | Niobium, vanadium, or nitrogen treated |
| 965X | 0.26 | 1.45 | 0.04 | 0.05 | 0.90 | Niobium, vanadium, or nitrogen treated |
| 970X | 0.26 | 1.65 | 0.04 | 0.05 | 0.90 | Niobium, vanadium, or nitrogen treated |
| 980X | 0.26 | 1.65 | 0.04 | 0.05 | 0.90 | Niobium, vanadium, or nitrogen treated |

SAE HSLA steel grade mechanical properties[8]

| Grade | Form | Yield strength (min) [psi (MPa)] | Ultimate tensile strength (min) [psi (MPa)] |
|---|---|---|---|
| 942X | Plates, shapes & bars up to 4 in. | 42,000 (290) | 60,000 (414) |
| 945A, C | Sheet & strip | 45,000 (310) | 60,000 (414) |
| | Plates, shapes & bars: | | |
| | 0 - 0.5 in. | 45,000 (310) | 65,000 (448) |
| | 0.5 - 1.5 in. | 42,000 (290) | 62,000 (427) |
| | 1.5 - 3 in. | 40,000 (276) | 62,000 (427) |
| 945X | Sheet, strip, plates, shapes & bars up to 1.5 in. | 45,000 (310) | 60,000 (414) |
| 950A, B, C, D | Sheet & strip | 50,000 (345) | 70,000 (483) |
| | Plates, shapes & bars: | | |
| | 0 - 0.5 in. | 50,000 (345) | 70,000 (483) |
| | 0.5 - 1.5 in. | 45,000 (310) | 67,000 (462) |
| | 1.5 - 3 in. | 42,000 (290) | 63,000 (434) |
| 950X | Sheet, strip, plates, shapes & bars up to 1.5 in. | 50,000 (345) | 65,000 (448) |
| 955X | Sheet, strip, plates, shapes & bars up to 1.5 in. | 55,000 (379) | 70,000 (483) |
| 960X | Sheet, strip, plates, shapes & bars up to 1.5 in. | 60,000 (414) | 75,000 (517) |
| 965X | Sheet, strip, plates, shapes & bars up to 0.75 in. | 65,000 (448) | 80,000 (552) |
| 970X | Sheet, strip, plates, shapes & bars up to 0.75 in. | 70,000 (483) | 85,000 (586) |
| 980X | Sheet, strip & plates up to 0.375 in. | 80,000 (552) | 95,000 (655) |

| Ranking of various properties for SAE HSLA steel grades[9] | | | |
|---|---|---|---|
| Rank | Weldability | Formability | Toughness |
| Worst | 980X | 980X | 980X |
| | 970X | 970X | 970X |
| | 965X | 965X | 965X |
| | 960X | 960X | 960X |
| | 955X, 950C, 942X | 955X | 955X |
| | 945C | 950C | 945C, 950C, 942X |
| | 950B, 950X | 950D | 945X, 950X |
| | 945X | 950B, 950X, 942X | 950D |
| | 950D | 945C, 945X | 950B |
| | 950A | 950A | 950A |
| Best | 945A | 945A | 945A |

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