Austenitic Manganese Steels

Abstract:

The original austenitic manganese steel, containing about 1.2% C and 12% Mn, was invented by Sir Robert Hadfield in 1882. Hadfield`s steel was unique in that it combined high toughness and ductility with high work-hardening capacity and, usually, good resistance to wear. Many variations of the original austenitic manganese steel have been proposed, often in unexploited patents, but only a few have been adopted as significant improvements. These usually involve variations of carbon and manganese, with or without additional alloys such as chromium, nickel, molybdenum, vanadium, titanium, and bismuth.

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Consequently, it rapidly gained acceptance as a very useful engineering material. Hadfield`s austenitic manganese steel is still used extensively, with minor modifications in composition and heat treatment, primarily in the fields of earthmoving, mining, quarrying, oil well drilling, steelmaking, railroading, dredging, lumbering, and in the manufacture of cement and clay products. Austenitic manganese steel is used in equipment for handling and processing earthen materials (such as rock crushers, grinding mills, dredge buckets, power shovel buckets and teeth, and pumps for handling gravel and rocks). Other applications include fragmentizer hammers and grates for automobile recycling and military applications such as tank track pads.

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The available assortment of wrought grades is smaller and usually approximates ASTM composition B-3. Some wrought grades contain about 0.8% **C** and either 3% **Ni** or 1% **Mo**. Large heat orders are usually required for the production of wrought grades, while cast grades and their modifications are more easily obtained in small lots. A manganese steel foundry may have several dozen modified grades on its production list. Modified grades are usually produced to meet the requirements of application, section size, casting size, cost, and weldability considerations.

The mechanical properties of austenitic manganese steel vary with both carbon and manganese content. As carbon is increased it becomes increasingly difficult to retain all of the carbon in solid solution, which may account for reductions in tensile strength and ductility.

Nevertheless, because abrasion resistance tends to increase with carbon, carbon content higher than the 1.2% midrange of grade A may be preferred even when ductility is lowered. Carbon content above 1.4% is seldom used because of the difficulty of obtaining an austenitic structure sufficiently free of grain, boundary carbides, which are detrimental to strength and ductility. The effect can also be observed in 13% **Mn** steels containing less than 1.4% **C** because segregation may result in local variations of ±17% (±0.2%C) from the average carbon level determined by chemical analysis.

The low carbon content (0.7% **C** minimum) of grades D and E-1 may be used to minimize carbide precipitation in heavy castings or in weldments, and similar low carbon contents are specified for welding filler metal.

Carbides form in castings that are cooled slowly in the molds. In fact, carbides form in practically all as cast grades containing more than 1.0% **C**, regardless of mold cooling rates. They form in heavy-section castings during heat treatment if quenching is ineffective in producing rapid cooling throughout the entire section thickness. Carbides can form during welding or during service at temperatures above about 275°C. If carbon and manganese are lowered together, for instance to 0.53% **C** with 8.3% **Mn** or 0.62% **C** with 8.1% **Mn**, the work-hardening rate is increased because of the formation of strain-induced α (body-centered-cubic, or bcc) martensite. However, this does not provide enhanced abrasion resistance (at least to high-stress grinding abrasion) as is often hoped.

Titanium can reduce carbon in austenite by forming very stable carbides. The resulting properties may simulate those of lower-carbon grade. Titanium may also somewhat neutralize the effect of excessive phosphorus; some European practice is apparently based on this idea. Microalloying additions (<0.1%) of titanium, vanadium, boron, zirconium and nitrogen have been reported to promote grain refinement in manganese steels. The effect, however, is inconsistent. Higher level of these elements can result in serious losses in ductility. Nitrogen in amounts greater than 0.20% can cause gas porosity in castings. An overall reduction in grain size lowers the susceptibility of the steel to hot tearing.

Sulfur. The sulfur content in manganese steels seldom influences its properties, because the scavenging effect of manganese operates to eliminate sulfur by fixing it in the form of innocuous, rounded, sulfide inclusions. The elongation of these inclusions in wrought steels may contribute in directional properties; in cast steels such inclusions are harmless. However, it is best to keep sulfur as low as is practically possible to minimize the number of inclusions in the microstructure that would be potential sites for the nucleation of fatigue cracks in service.

Higher Manganese Content Steel

Austenitic steels with higher manganese contents (>15%) have recently been developed for applications requiring low magnetic permeability, low temperature (cryogenic) strength and low temperature toughness. This applications stem from the development of superconducting technologies used in transportation systems and nuclear fusion research and to meet the need for structural materials to store and transport liquefied gases.
For low magnetic permeability, these alloys have lower carbon content than the regular Hadfield steels. The corresponding loss in yield strength is compensated by alloying with vanadium, nitrogen, chromium, molybdenum, and titanium. Chromium also imparts corrosion resistance, as required in some cryogenic applications.

The alloys are used in the heat-treated (solution-annealed and quenched) condition except for those that are age-hardenable. Wrought alloys are available in the hot-rolled condition. The microstructure is usually a mixture of γ (face-centered cubic or fcc) austenite and ε (hexagonal close-packed, or hcp) martensite.

These alloys are characterized by good ductility and toughness, both especially desirable attributes in cryogenic applications. Further, the ductile-brittle transition is gradual, not abrupt. Because the stability of the austenite is composition dependent, a deformation-induced transformation can occur in service under certain conditions. This is usually undesirable because it is accompanied by a corresponding increase in magnetic permeability.

Additions of sulfur, calcium, and aluminum are made to enhance the machinability of these alloys where required. Because of their lower carbon content, most of these alloys are readily weldable by the shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and electron beam welding (EBW) processes. The composition of the weld metal is similar to that of the base metal and tailored for low magnetic permeability. The phosphorus content is generally maintained below 0.02% to minimize the tendency for hot cracking.

Another class of austenitic steels with high manganese additions has been developed for cryogenic and for marine applications with resistance to cavitation corrosion. These alloys have been viewed as economical substitutes for conventional austenitic stainless steels because they contain aluminum and manganese instead of chromium and nickel. Consequently, these alloys are generally of higher strength but lower ductility than conventional stainless steels such as type 304. The microstructure of these alloys is a mixture of γ (fcc) austenite and ε (hcp) martensite, and in some cases (especially when the aluminum content exceeds about 5%) α (bcc) ferrite. There is a tendency for an embrittling β-Mn phase to form in the high manganese compositions during aging at elevated temperatures. The result is a significant decrease in ductility. The addition of aluminum to some extent suppresses the precipitation of this compound.

Heat Treatment

Heat treatment strengthens austenitic manganese steel so that it can be used safely and reliably in a wide variety of engineering applications. Solution annealing and quenching, the standard treatment that produces normal tensile properties and the desired toughness, involves austenitizing followed quickly by water quenching. Variations of this treatment can be used to enhance specific desired properties such as yield strength and abrasion resistance.
Usually, a fully austenitic structure, essentially free of carbides and reasonably homogeneous with respect to carbon and manganese, is desired in the as-quenched condition, although this is not always attainable in heavy sections or in steels containing carbide-forming elements such as chromium, molybdenum, vanadium and titanium. If carbides exist in the as-quenched structure, it is desirable for them to be present as relatively innocuous particles or nodules within the austenite grains rather than as continuous envelopes at grain boundaries.

Mechanical Properties After Heat Treatment

As the section size of manganese steel increases, tensile strength and ductility decrease substantially in specimens cut from heat-treated castings. This occurs because, except under specially controlled conditions, heavy sections do not solidify in the mold fast enough to prevent coarse grain size, a condition that is not altered by heat treatment.
Fine grain specimens may exhibit tensile strength and elongation as much as 30% greater than those of coarse-grain specimens. Grain size is also the main reason for the differences between cast and wrought manganese steels -- the latter are usually on fine grain size.

Mechanical properties vary with section size. Tensile strength, tensile elongation, reduction in area and impact strength are substantially lower in 102 mm (4 inches) thick sections than in 25 mm (1 inch) thick sections. Because section thicknesses of production castings are often from 102 to 152 mm (4 to 6 inches), this factor is an important consideration for proper grade specification.

Austenitic manganese steel remains tough at subzero temperatures above the Ms temperature. The steel is apparently immune to hydrogen embrittlement. There is gradual decrease in impact strength with decreasing temperature. The transition temperature is not well defined because there is no sharp inflection in the impact strength-temperature curve down to temperatures as low as -85^{o}C. At a given temperature and section size, nickel and manganese additions are usually beneficial for enhancing impact strength, while higher carbon and chromium levels are not.

Resistance to crack propagation is high and is associated with very sluggish progressive failures. Because of this, any fatigue cracks that develop might be detected, and the affected part or parts removed from service before complete failure occurs.

Yield strength and hardness vary only slightly with section size. The hardness of most grades is about 200 HB after solution annealing and quenching, but this value has little significance for estimating machinability or wear resistance.

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