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The Influence of Manganese in Steel

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They say that everyone and everything gets 15 minutes of fame somewhere, sometime, somehow. Well, for manganese, its time is now. The effect of a particular alloying element on both the steelmaking process and the steel's response to heat treatment depends on the individual element and on its (complex) interactions with other elements, either individually or collectively. Manganese is considered, next to carbon, the most important elemental addition to steel. Let's learn more.

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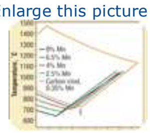

Fig. 1. Effect of manganese on the shape of the austenite field[2]

Strictly from a heat treater's perspective, the purpose of adding alloying elements to steel is to enhance the material's response to heat treatment, which in turn results in improvement of the mechanical and physical properties of the steel. Alloying additions can be made for one or more of the following reasons:

- To increase hardenability
- To help reduce part distortion
- To produce a finer grain size
- To improve tensile strength without appreciably lowering ductility
- To avoid quench cracking
- To gain toughness
- To achieve better wear resistance
- To improve hot hardness
- To achieve better corrosion resistance

Beside the role manganese plays in deoxidation of steel and modification of sulfides present, it is a major alloying element, has complex interactions with carbon and is used to control inclusions. Manganese is beneficial to surface quality in all carbon ranges with the exception of rimmed steels (<0.15%C) and is particularly beneficial in high-sulfur steels. Manganese contributes to strength and hardness but to a lesser degree than carbon. The increase depends on the carbon content – higher-carbon steels being affected more by manganese. Higher-manganese steels decrease ductility and weldability (but to a lesser extent than carbon). Manganese also increases the rate of carbon penetration during carburizing.

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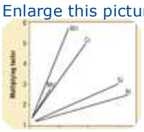

Fig. 2. Effect of alloying elements on hardenability - Grossman multiplying factors[2]

The effects of manganese can be summarized as:[2]

1. Lowers the temperature at which austenite begins to decompose

2. Extends the metastable austenitic region and delays the commencement of all the austenite decomposition reactions

3. Favors the formation of lower bainite and suppresses the upper bainite reaction on isothermal transformation

4. Is the most effective alloying addition for lowering the martensite-start (M_S) temperature

5. Favors the formation of e-martensite

6. Has little effect on the strength of martensite and on the volume change from austenite to martensite

7. Has little or no solution-hardening effect in austenite and between 30–40 MN/m^2 per wt. % in ferrite (by lowering the stacking-fault energy of austenite, manganese increases the work-hardening rate)

8. By lowering the M_S temperature, manganese prevents the deleterious effects of autotempering

9. Lowers the transformation temperature, causing substantial grain refinement

10. In general, lowers the tough-to-brittle impact transition temperature (due to its grain-refinement action)

11. Increases the propensity for weld cracking due to the effect on hardenability. The severity of its influence depends to a great extent on the type of steel and the welding techniques.

12. Does not increase the susceptibility of the steel to delayed fracture due to hydrogen absorption

13. Improves the fatigue limit

14. Reduces the number of cycles to failure under high strain conditions

15. Forms five carbides ($Mn_{23}C_5$, $Mn_{15}C_4$, Mn_3C, Mn_5C_2 and Mn_7C_3), the dominant one being Mn_3C, which forms a continuous range of solid solutions with Fe_3C, thus reducing the solubility of carbon in a-iron

16. Prevents the formation of an embrittling grain-boundary cementite

17. Suppresses the yield extension in deep-drawing steels by virtue of its grain-refinement effect

18. Suppresses strain aging

19. In combination with nitrogen, has a solid-solution hardening effect and improves high-temperature properties

20. Extends the range of use of low-carbon steels

21. Has a strong influence on the pearlite morphology of high-carbon steels

22. Extends the range of use of high-carbon steels through its grain-refining and pearlite-refining actions

23. Raises strength values in bainitic steels by reducing grain size and increasing dispersion hardening

24. Allows bainitic steels to be produced by air hardening

25. Increases hardenability

26. Slows down the temper reactions in martensite

27. Assists interphase precipitation

28. Improves austemper and martemper properties

29. Increases temper embrittlement unless the carbon content is very low and trace element impurities are minimal

30. In spring steels, promotes ductility and fracture toughness without undue loss in tensile strength

31. Removes the risk of hot shortness and hot cracking when the ratio of manganese to sulfur is greater than 20:1 by forming a higher melting-point eutectic with sulfur than iron sulphide

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Fig. 3. Isothermal sections from the iron-manganese-carbon ternary diagram 600°C (1110°F), 800°C (1475°F) and 1000°C (1825°F)

32. Has a major influence on the anisotropy of toughness in wrought steels due to the ability to deform manganese sulfides during hot working

33. Forms three manganese sulfide morphologies (Type I, II and III) dependent upon the state of oxidation of the steel

34. Enhances free-cutting steels

35. Increases the stability of austenite

36. Has similar atomic size as iron (Mn = 3.58Å, Fe = 3.44 Å)

37. Lowers the stacking-fault energy of austenite (in contrast to alloying element additions such as chromium or nickel)

38. Allows lower solution temperatures for precipitation-hardening treatments in highly alloyed austenite due to increased carbon solubility

39. Forms intermetallic compounds suitable for precipitation-hardened austenitic steels

40. Plays a major role in controlling the precipitation process that occurs during isothermal transformation to austenite

41. Increases the rate of carbon penetration during carburizing

42. Contributes, in combination with nitrogen, to the performance of work-hardenable austenitic stainless steels

43. Improves hot corrosion resistance in sulfurous atmospheres

44. Enhances wear-resistance in carbon-containing austenitic steels where the manganese content is between 12-14%

45. Improves response of low-alloy steels to thermomechanical treatments

46. Strengthens certain steels by maraging by producing an austenitic structure using manganese-containing compounds

47. Enhances the performance of TRIP steels

48. Promotes ferro-elastic behavior in appropriate steels

49. Less tendency to segregate within the ingot

50. In general, improves surface quality

Summing Up

Manganese is the type of addition that is easily overlooked but can play a significant role in helping steels achieve their mechanical and metallurgical properties (e.g., hardness when austempering of medium-to-high-carbon steels).

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