EFFECTS OF ALLOYING ELEMENTS ON STEEL

Element & Symbol	Solid solubility		Influence upon ferrite	Influence upon austenite (hardenenability)	Influence exerted through carbide.		Principal function of the element.
	In gamma Fe	In alpha Fe			Carbide-forming tendency	Action during temperature	
Aluminum(Al)	1.1% (increase by carbon)	36%±	Hardens considerably by solid solution	If dissolved in austenite increases hardenability mildly	Graphitizes	—	a. Used as deoxidizer. b. Restricts grain growth. c. Alloying element in nitriding steels.
Chromium(Cr)	12.8% (in 0.5%C steels 20%)	Unlimited	Hardens slightly; increased corrosion resistance	Increases hardenability moderately, similar to manganese	Greater than Mn less than W	Mildly resists softening	a. Increases corrosion and oxidation resistance. b. Increases hardenabability. c. Increases strength at high temperature. d. With high C resists wear and abrasion.
Cobalt(Co)	Unlimited	75%	Hardens considerably by solid solution	Decreases hardenability as dissolved	Similar to Fe	Sustains hardness by solid solutions	a. Contributes to red hardness by hardening ferrite. b. Alloying element is certain high-speed steels.
Manganese (Mn)	Unlimited	3%	Hardens, ductility somewhat reduced	Similar to Ni	Greater than Fe, less than Cr	Very little in usual percentage	a. Counteracts effect of brittleness from sulphur. b. Increases hardenability inexpensively. c. High Mn. high C produces steels resistant to wear and abrasion.
Molybdenum (Mo)	3% (with 0.5% C steels 8%)	37.5% (less with lowered temp)	Age-hardening system in high Mo-Fe alloys.	Increases hardenability strongly	Strong, greater than Cr	Opposes softening by secondary hardening	a. Raises grain coarsening temperature of austenite. b. Increases depth of hardening. c. Raises hot and creep strength promotes red hardness. d. Enhances corrosion resistance in stainless steels. e. Forms abrasion resistant particles.
Nickel (N)	Unlimited	10% independent of C content	Strengthens and toughens by solid solution	Increases hardenability slightly, austenite retention with higher carbon	Graphitizes less than Fe	Very little in small percentages	a. Strengthens unquenched or annealed steels. b. Toughens pearlitic-ferritic steels (especially low temperatures). c. Renders high Cr/Fe alloys austenitic.
Phosphorous (P)	0.5%	2.8% independent of C content	Hardens strongly by solid solution. Lowers ductility inducing Brittleness.	Increases hardenability similar to Mn	Nil	—	a. Strengthens low C steels. b. Increases resistance to atmospheric corrosion. c. Improves machinability in free cutting steel

EFFECTS OF ALLOYING ELEMENTS ON STEEL

Element & Symbol	Solid solubility		Influence upon ferrite	Influence upon austenite (hardenenability).	Influence exerted through carbide.		Principal function of the element.
	In gamma Fe	In alpha Fe			Carbide-forming tendency	Action during temperature	
Silicon (Si)	Approx. 2% (with 0.35% C approx 9%)	18.5% (carbon has little effect)	Hardens with loss in ductility.	Increases hardenability more than Ni	Negative graphitizes	Sustains hardness by solid solution	a. Used as deoxidizer. b. Alloy for electrical and magnetic sheet metals. c. Improves oxidation resistance. d. Strengthens low alloy steels.
Titanium (Ti)	0.75% (with 0.2% C steels approx 1%)	Approx. 0.6% (less with lowered temperatures)	Gives age-hardening in high Fe-Ti alloy.	Probably increases hardenability very strongly dissolved; its carbide effects reduce hardenability	Greatest known (2% Ti renders, 0.5% C steel unhardenable)	Some secondary hardening	a Fixes carbon in inert particles. b Reduces martensitic hardness and ardenability in medium Cr steels. c. Prevents formation of austenite in high Cr steels. d. Prevents localized depletion of Cr in stainless steels during long heating periods.
Tungsten (W)	6% (with 0.25% C 11%)	33% (less with lowered temperature)	Age-hardening system in W-Fe alloys.	Increases hardenability strongly in small quantities	Strong	Opposes softening by secondary hardening	a. Forms hard, abrasion resistant particles in tool steels, high-speed steels. b. Promotes red hardness and hot strength
Vanadium (V)	Approx. 1% (with 0.2% C steels 4%)	Unlimited	Hardens moderately in solid solutions.	Increases hardenability very strongly as dissolved	Very strong	Maximum for secondary hardening	a. Promotes fine grain-elevates coarsening temperature of austenite. b. Increases hardenability when dissolved. c. Resists tempering and causes marked secondary hardening.