## THE EFFECT OF ALLOYING ELEMENTS ON THE PROPERTIES OF STEELS

| Alloying element | Mechanical properties | | | | | | | | | | | | | | | | Magnetic properties | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hardness | Strength | Yield Point | Elongation | Reduction of area | Impact value | Elasticity | High temperature stability | Cooling rate | Carbide formation | Resistance to wear | Forgeability | Machinability | Scaling | Nittrability | Resistance to corrosion | hysteresis | Permeability | Coercive force | Remanence | Loss of Watt |
| Silicon | ↑ | ↑ | ↑↑ | ↓ | ~ | ↓ | ↑↑↑ | ↑ | ↓ | ↓ | ↓↓↓ | ↓ | ↓ | ↓ | ↓ | - | ↓↓ | ↑↑ | ↓↓ | - | ↓↓ |
| Manganese inperlit. steels | ↑ | ↑ | ↑ | ~ | ~ | ~ | ↑ | ~ | ↓ | ~ | ↓↓ | ↑ | ↓ | ~ | ~ | - | | | | | |
| Manganese in austenlt. steels | ↓↓↓ | ↑ | ↓ | ↑↑↑ | - | - | - | - | ↓↓ | - | - | ↓↓↓ | ↓↓↓ | ↓↓ | - | - | not magnetic | | | | |
| Chromium | ↑↑ | ↑↑ | ↑↑ | ↓ | ↓ | ↓ | ↑ | ↑ | ↓↓↓ | ↑↑ | ↑ | ↓ | - | ↓↓↓ | ↑↑ | ↑↑↑ | | | ↑ | ↑↑ | |
| Nickel in perlit, steels | ↑ | ↑ | ↑ | ~ | ~ | ~ | - | ↑ | ↓↓ | - | ↓↓ | ↓ | ↓ | ↓ | - | - | | | ↑↑ | ↑↑ | |
| Nickel in austenit- steels | ↓↓ | ↑ | ↓ | ↑↑↑ | ↑↑ | ↑↑↑ | - | ↑↑↑ | ↓↓ | - | - | ↓↓↓ | ↓↓↓ | ↓↓ | - | ↑↑ | not magnetic | | | | |
| Aluminium | - | - | - | - | ↓ | ↓ | - | - | - | - | - | ↓↓ | - | ↓↓ | ↑↑↑ | - | | | ↑↑ | ↑↑ | |
| Tungsten | ↑ | ↑ | ↑ | ↓ | ↓ | ~ | - | ↑↑↑ | ↓↓ | ↑↑ | ↑↑↑ | ↓↓ | ↓↓ | ↓↓ | ↑ | - | | | ↑↑↑ | ↑↑↑ | |
| Vanadium | ↑ | ↑ | ↑ | ~ | ~ | ↑ | ↑ | ↑↑ | ↓↓ | ↑↑↑↑ | ↑↑ | ↑ | - | ↓ | ↑ | ↑ | | | | | |
| Cobalt | ↑ | ↑ | ↑ | ↓ | ↓ | ↓ | - | ↑↑ | ↑↑ | - | ↑↑↑ | ↓ | ~ | ↓ | - | - | | ↑↑ | ↑↑↑ | ↑↑↑ | |
| Molybdenum | ↑ | ↑ | ↑ | ↓ | ↓ | ↑ | - | ↑↑ | ↓↓ | ↑↑↑ | ↑↑ | ↓ | ↓ | ↑↑ | ↑↑ | - | | | ↑ | | |
| Copper | ↑ | ↑ | ↑↑ | ~ | ~ | ~ | - | ↑ | - | - | - | ↓↓↓ | ~ | ~ | - | ↑ | | | | | |
| Sulphur | - | - | - | ↓ | ↓ | ↓ | - | - | - | - | - | ↓↓↓ | ↑↑↑ | - | - | ↓ | | | | | |
| Phosphorous | ↑ | ↑ | ↑ | ↓ | ↓ | ↓↓↓ | - | - | - | - | - | ↓ | ↑↑ | - | - | - | | | | | |

↑ = Increase ↓=Reduction ~ = constant - = not characteristic or unknown  Several arrows = more intensive effect

## THE EFFECTS OF ALLOYING ELEMENTS IN STEEL

| ELEMENT & SYMBOL | SOLID SOLUBILITY | | INFLUENCE UPON FERRITE | INFLUENCE UPON AUSTENITE (HARDEN-ABILITY) | INFLUENCE EXERTED THROUGH CARBIDE | | PRINCIPAL FUNCTION OF ELEMENT |
|---|---|---|---|---|---|---|---|
| | In Gamma Fe | In Alpha Fe | | | Carbide forming Tendency | Action during Tempering | |
| Aluminium **Al** | 1.1% (in creased by carbon) | 36% ± | Hardens considerably by solid solution. | If dissolved in Austenite increases hardenability mildly. | Graphitizes | - | 1. Used as deoxidiser,<br>2. Restricts grain growth.<br>3. Alloying element in nitriding steels. |
| Chromium Cr | 12:8% (in 0-5% C steels 20%)- | Unlimited | Hardens slightly, increases corrosion resistance | Increases hardenability moderately. similar to manganese. | Greater than Mn. Less than W. | Mildly resists softening | 1. Increases corrosion and oxidation resistance.<br>2. Increases hardenability.<br>3. Increases strength at high temperature.<br>4. With added 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 solution. | 1. Contributes to red hardness by hardening ferrite.<br>2. Alloying element in high-grade, high-speed steels. |
| Manganese Mn | Unlimited | 3% | Hardens, plasticity somewhat reduced. | Similar to Cr. | Greater than Fe.Less than Cr. | Very little in usual per centages, | 1. Counteracts effect of brittleness from sulphur.<br>2. Increases hardenabliity inexpensively.<br>3. High Mn high C produces steels resistant to wear and abrasion, |

*Continued.*

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|---|---|---|---|---|---|---|---|
| | In Gamma Fe | In Alpha F6 | | | Carbide forming Tendency | Action during Tempering | |
| Molybdenum Mo | 3% (in 0.05% C . steels 8%) | 37.5% (less with lowered temp.) | Age-hardening effect in high Mo-Fe alloys. | Increases hardenability strongly. | Strong. Greater than Cr. | Opposes softening by secondary hardening, | 1. Raises coarsening temperature of austenite.<br>2. Increases depth of hardening.<br>3. Raises hot and creep strength, red hardness<br>4. Enhances corrosion resis-tance in stainless steels.<br>5. Forms abrasion resistant particules. |
| Nickel Ni | Unlimited | 10% indepen-dent of C content, | Strengthens & toughens by solid solution, | Increases hardenability slightly, austenite retention with higher carbon, | Graphitizes less than Fe, | Very little in small per-centages. | 1. Strengthens unauenched or annealed steels.<br>2. Toughens pearlitic, ferritic steels (especially at low temperatures)<br>3. Renders high Cr/Fe alloys austeniiic- |
| Phosphorous P | 0.5% | 2.8% inde pendent of C content | Hardens strongly by solid solution. | Increases hardenability sirnilar to Mn. | Nil | - | 1. Strengthens low C steels.<br>2. Increases resistance to corrosion.<br>3. Improves machinability in free cutting steels. |
| Silicon Si | 2%± (in 0.35% C steels 9%) | 18.5% (Carbon has little effect) | Hardens with loss in ductility. | Increases hardenability more than Ni | Negative, graphitizes. | Sustains hardness by solid solution. | 1. Used as deoxidiser,<br>2. Alloy for electrical and magnetic sheet steels,<br>3. Improves oxidation resistance.<br>4. Strengthens low alloy steels, |
| Titanium Ti | 0:75% (in 0.2% C steels 1%±) | 6%± (less with lowered tempe-ratures) | Gives age-hardening in high Fe-Ti alloys. | Probably increases hardenability very strongly as | Greatest known (2% Ti renders 0.5% C stee! unhardenable) dissolved. Its carbide effects reduce hardenability. | Some secondary hardening. | 1. Fixes carbon in inert particles.<br>2. Reduces martensitic hardness and hardenability in medium Cr steels.<br>3. Prevents formation of austenite in high Cr steels.<br>4. Prevents localised deple tion of Cr in stainless steels during long heating periods. |
| Tungsten W | 6% (in 0.25% C steels 11%) | 33% (less with lowered tempe-ratures) | Age-harden ing system in high W-Fe Alloys. | Increases hardenability strongly in small quantities, | Strong | Opposes softening by secondary hardening. | 1. Forms hard, abrasion resistant particles in too) steels, high speed steels.<br>2. Promotes red hardness and hot strength. |
| Vanadium V | 1.0%± (in 0.2% C steels 4%) | Unlimited | Hardens moderately in solid solution, | Increases hardenability very strongly as dissolved. | Very strong | Maximum for secondary hardening, | 1. Promotes fine grain, elevates coarsening temperature of austenite.<br>2. Increases hardenability when dissolved,<br>3. Resists tempering and causes marked secondary hardening. |