properties of hot-rolled carbon and alloy bars are considered individually. In practice, the effect of a particular element often depends on the presence and quantities of other elements in the steel. For example, the total effect of a combination of elements on the hardness of a steel is usually greater than the sum of their individual effects. This interrelation should be considered when a change in a specified analysis is being evaluated. (With the exception of sulfur and phosphorous, Table 12 details the chemical composition of pharmaceutical tool steels.)

**TABLE 12. CHEMICAL COMPOSITION OF TOOL STEELS**

| CHEMICAL ELEMENT | PERCENTAGE OF CHEMICAL ELEMENTS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 408[1] | S1 | S5 | S7 | A2 | D2 | D3 | 440C | O1[2] |
| CARBON | 0.45–0.55 | 0.40–0.55 | 0.50–0.65 | 0.45–0.55 | 0.95–1.05 | 1.40–1.60 | 2.00–2.35 | 0.95–1.20 | 0.85–1.00 |
| MANGANESE | 0.30–0.60 | 0.10–0.40 | 0.60–1.00 | 0.20–0.80 | 0.00–1.00 | 0.00–0.60 | 0.00–0.60 | 0.00–1.00 | 1.00–1.40 |
| SILICON | 0.15–0.30 | 0.15–1.20 | 1.75–2.25 | 0.20–1.00 | 0.00–0.50 | 0.00–0.60 | 0.00–0.60 | 0.00–1.00 | 0.10–0.40 |
| CHROMIUM | 0.90–1.25 | 1.00–1.80 | 0.00–0.35 | 3.00–3.50 | 4.75–5.50 | 11.0–13.0 | 11.0–13.5 | 16.0–18.0 | 0.40–0.60 |
| VANADIUM | | 0.15–0.30 | 0.00–0.35 | 0.00–0.35 | 0.15–0.50 | 0.00–1.10 | 0.00–1.00 | | 0.15–0.30 |
| TUNGSTEN | | 1.50–3.00 | | | | | 0.00–1.00 | | 0.40–0.60 |
| MOLYBDENUM | | 0.00–0.50 | 0.20–1.35 | 1.30–1.80 | 0.90–1.40 | 0.70–1.20 | | 0.00–0.75 | |
| NICKEL | 3.00–3.25 | | | | | | | 0.00–0.50 | |
| COBALT | | | | | | 0.00–1.00 | | | |

**NOTES:**

1. Source: *Tableting Specification Manual*, 3rd ed. Washington, DC: American Pharmaceutical Association; 1989.
2. Source: *Tool Steels*. 4th ed. Materials Park, OH: American Society for Metals; 1980.

### *Carbon*

Carbon is the principal hardening element in steel; each additional increment of carbon increases the hardness and tensile strength of steel in the as-rolled, or normalized, condition. As carbon content exceeds approximately 0.85%, the resultant increase in strength and hardness is proportionately less for each increment added. Upon quenching, the maximum attainable hardness also increases with increasing carbon; however, the rate of increase is very small for carbon contents above 0.60%.

Conversely, a steel's ductility and weldability decrease as its carbon content increases. Ductility is the ease with which metal flows during compression. Carbon also has a moderate tendency to segregate within the ingot. Because carbon has a significant effect on steel properties, its segregation is frequently more important than the segregation of other elements in the steel.

### *Manganese*

Manganese, which is present in all commercial steels, contributes significantly—but to a lesser degree than does carbon—to a steel's strength and hardness. The effectiveness of manganese depends largely on and is directly proportional to a steel's carbon content.

Manganese has a greater ability than any of the commonly used alloy elements to decrease the critical cooling rate during hardening, thereby increasing a steel's hardenability. This element is also an active deoxidizer and shows less tendency to segregate within the ingot than do most of the other elements. Manganese also improves a steel's surface quality because it tends to combine with sulfur, thereby minimizing the formation of iron sulfide. Iron sulfide can cause hot-shortness (i.e., the susceptibility of a steel to crack and tear when the ingot is rolled).

### *Silicon*

Silicon is one of the principal deoxidizers used in manufacturing carbon and alloy steels. Depending on the steel type, the amount of silicon can vary up to 0.35%; greater amounts are used in some steels