Chemical Composition and Alloying Elements of Steel

Chemical Composition

The chemical composition of steel is of great importance since it determines the potential mechanical properties of the finished steel product and controls the degree of corrosion resistance and weld- ability of the material For this reason structural steel specifications always pro- vide a table of chemical composition limits within which the steel producer must develop his own particular recipe. The purpose of the specified chemical composition is not to provide the detailed chemical formula necessary to produce a certain type of steel but to provide safeguards. The steel producer is informed that he must keep within the limits which are deemed to be acceptable for the type of steel considered. Within these limits, which may be broad or narrow, the steel producer has complete freedom to use his skill and knowledge to make steel with the required mechanical properties. Each producer selects a combination of quantities of elements, which fall within the requirements of the applicable specification, provide the required mechanical and other properties, and are most suitable from the point of view of his particular material supply and steel- making facilities. For this reason actual heats of steel seldom, if ever, will contain the elements in the exact combination of quantities called for in the applicable specification.

Obviously the steel producer has more latitude, and is in a better position to keep production costs down if the requirements as to chemical composition are kept to a minimum. Thus the aim of the specification is to impose only the chemistry which is deemed essential and to provide the broadest possible limits. The limits placed on the various elements are therefore usually specified as either a maximum or minimum percentage and, only where considered to be essential, as a range between minimum and maximum. In some cases, the permissible range of a particular element is specified because it tells the steel producer that he must produce the steel in a certain way. For instance a specification which states that the percentage of silicon is to be within the range 0.15/0.30 tells the steel producer that killed steel is required, whereas if the percentage of silicon is specified to be 0.30 maximum, the steel producer is informed that the steel may be semi-killed or killed at his option.

Generally, a maximum limit is placed on elements which the steel producer has to reduce in the refining process (i.e. carbon, sulphur, phosphorus) and a minimum limit is placed on elements which the steel producer has to add (i.e. metallic alloying elements).

Effects of Alloying Elements

About twenty different elements are used in various proportions and combinations in the manufacture of both carbon and low alloy structural steels. Some are used because they impart specific properties to the steel when they alloy with it (i.e. dissolve in the iron), or when they com- bine with carbon, wholly or in part, to form compounds known as carbides. Others are used because they are beneficial in ridding the steel of impurities or rendering the impurities harmless. Still another group is used to counteract harmful oxides or gases in the steel. The elements of this last group act only as fluxes or scavengers and do not remain in the steel to any extent after solidification occurs. Some elements fall into more than one of the above groups.

The effects of some of the more common alloying elements are as follows:

Aluminum is often used to promote nitriding but its major use in steel making is as a deoxidizer. It may be used alone, as in low carbon steels where exceptional drawability is desired, or more commonly in conjunction with other deoxidizers. It effectively restricts grain growth and its use as a deoxidizer to control grain size is widely practiced in the steel industry.

Carbon, although not generally considered an alloying element, is by far the most important element in steel. As carbon is added to steel up to about .90 per cent, its response to heat treatment and its depth of hardening increase. In the "as- rolled" condition, increasing the carbon content increases the hardness, strength and abrasion resistance of steel but ductility, toughness, impact properties and machinability decrease.

Chromium contributes to the heat treatment of steel by increasing its strength and hardness. Its carbides are very stable and chromium may be added to high carbon steels subject to prolong anneals to prevent graphitization. Chromium increases resistance to both corrosion and abrasion. Chromium steels maintain strength at elevated temperatures.

Columbium is used in carbon steels to develop higher tensile properties. It also combines with carbon to provide improved corrosion resistance, and is often used for this purpose in stainless steels.

Iron is the principal element and makes up the body of steel. In commercial production iron always contains quantities of other elements. Production of pure iron is accomplished with difficulty and generally in small quantities. Iron does not have great strength, is soft, ductile and can be appreciably hardened only by cold work. Manganese by its chemical interaction with sulphur and oxygen makes it possible to roll hot steel. It is next in importance to carbon as an alloying element. It has a strengthening effect upon iron and also a beneficial effect upon steel by increasing its response to heat treatment. It increases the machinability of free machining steels but tends to decrease the ductility of low carbon drawing steels.

Molybdenum has a pronounced effect in promotion of hardenability. It raises the coarsening temperature of steel, increases the high temperature strength, improves the resistance to creep and enhances the corrosion resistance of stainless steels.

Nickel is soluble in iron and, in combination with other elements, improves the hardenability of steel and toughness after tempering. It is especially effective in strengthening unhardened steels and improving impact strength at low temperatures. It is used in conjunction with chromium in stainless steels.

Phosphorus strengthens steel but reduces its ductility. It improves the machinability of high sulphur steels and under some conditions may confer some increase in corrosion resistance. Silicon is one of the principal steel deoxidizers and is commonly added to steel for this purpose. In amounts up to about 2.5% it increases the hardenability of steels. Specified coarse grain steels are silicon killed. In lower carbon electrical steels, silicon is used to promote the crystal structure desired in annealed sheets.

Sulphur added to steel increases machinability. Because of its tendency to segregate, sulphur may decrease the ductility of low carbon drawing steel. Its detrimental effect in hot rolling is offset by manganese.

Titanium is an extremely effective carbide former and is used in stainless steels to stabilize the steel by holding carbon in combination. Titanium is used for special single coat enameling steels. In low alloy structural steels its use in combination with other alloys promotes fine grain structure and improves the strength of the steel in the "as-rolled" condition.

Vanadium is a mild deoxidizer and its addition to steel results in a fine grain structure which is maintained at high temperature. It has very strong carbide forming tendencies and very effectively promotes strength at high Temperatures, Vanadium steels have improved fatigue values and excellent response to heat treatment. In unhardened steels it is particularly beneficial in strengthening the metal