Chapter 9

Controlled-Expansion and Controlled-Modulus Alloys

LOW-EXPANSION ALLOYS

In the late 19th century, discovery of deviations from the expected values of the coefficients of expansion in the nickel–iron system led to a study of the system by Guillaume. He found that the minimum coefficient of expansion occurred in the alloy containing approximately 36\% nickel and called the alloy “Invar.” He found also that the addition of 12\% chromium produced an alloy having an invariable modulus of elasticity over a considerable temperature range and called this alloy “Elinvar.” Both of these alloys are still in use. Elinvar will be discussed later.

In a sense, Invar is a misnomer because the low value of coefficient of expansion occurs only over a limited temperature range. It is often regarded as resulting from a combination of a normal dilatational effect and an increase in volume on cooling caused by magnetic effects (magnetostriction). In the nonmagnetic state above the Curie point, the alloy has a normal coefficient of expansion, similar to that of iron or nickel. As the alloy cools, and passes the Curie point, a range is entered where the coefficient is low, but on additional reduction of temperature the coefficient again increases. These phenomena are characteristic also of iron–nickel alloys ranging from about 30 to 70\% nickel, although the abnormality becomes less marked with increasing nickel content.\(^1\)

The coefficient of expansion of Invar is influenced by a number of factors. Impurities generally increase the minimum. Annealing tends to increase the expansion coefficient and quenching has the opposite effect. Cold work also has a tendency to lower the value and, in a pure 36\% nickel alloy, can cause the alloy to have a negative expansion coefficient.

The 36% nickel-iron alloy has a coefficient of expansion approximately one-tenth that of carbon steel at temperatures up to 400 F. It is used where dimensional changes resulting from variations in temperature must be minimized and also as the low-expansion side of bimetallic thermoelements. Because of its excellent low-temperature characteristics it is used also as a structural material in cryogenic applications. A free-machining modification, containing about 0.2% selenium, is used for parts requiring extensive machining. The properties of this alloy approximate those of the normal 36% alloy.

Sands reported that cobalt may be substituted for nickel in the 36% nickel alloy with no effect on the inflection temperature but a beneficial effect on both the minimum and mean coefficients of expansion. For an inflection temperature of 932 F, for example, he noted that the substitution of 28% cobalt for a like percentage of nickel will lower the minimum coefficient of expansion from \(5.2 \times 10^{-6}\) to \(2.9 \times 10^{-6}\) per °F; the mean coefficient will be lowered from \(5.5 \times 10^{-6}\) to \(3.5 \times 10^{-6}\) per °F.

Increasing the temperature above room temperature shifts the minimum coefficient toward higher nickel contents. This is advantageous in selecting a low-expansion alloy for service at temperatures above those at which the 36% alloy is effective. For example, the 42% nickel-iron alloy has a virtually constant low rate of thermal expansion at temperatures up to about 650 F and the 49% nickel-iron alloy has a low rate, much lower than that of carbon steel, up to temperatures of about 1100 F.

The wide range of expansion coefficients available in the nickel-iron alloys and in modified alloys based on the nickel-iron system leads to their use as glass-sealing materials. Rosenberg notes that alloys containing 42% nickel, 5.5% chromium, balance iron are suitable for seals in many soft glasses. Alloys containing 29% nickel, 17% cobalt, balance iron and 52% nickel, balance iron are suitable for sealing hard, heat resistant glasses.

The 36% nickel alloy is the most widely used material for applications requiring low expansivity at temperatures up to about 400 F; the 42% alloy for applications from 400 to 650 F; and the 49% alloy for applications at temperatures from 650 to 1000 F. There are a number of other low-expansion alloys which are modifications of the simple nickel-iron alloys, including some which are age hardenable. However, the 36%, 42%, and 49% nickel-iron alloys will be used to indicate the properties to be expected of low-expansion alloys.

**Physical Properties**

Typical physical properties of the three alloys are given in Table 9-1. As indicated in the table, a number of the properties show a progressive