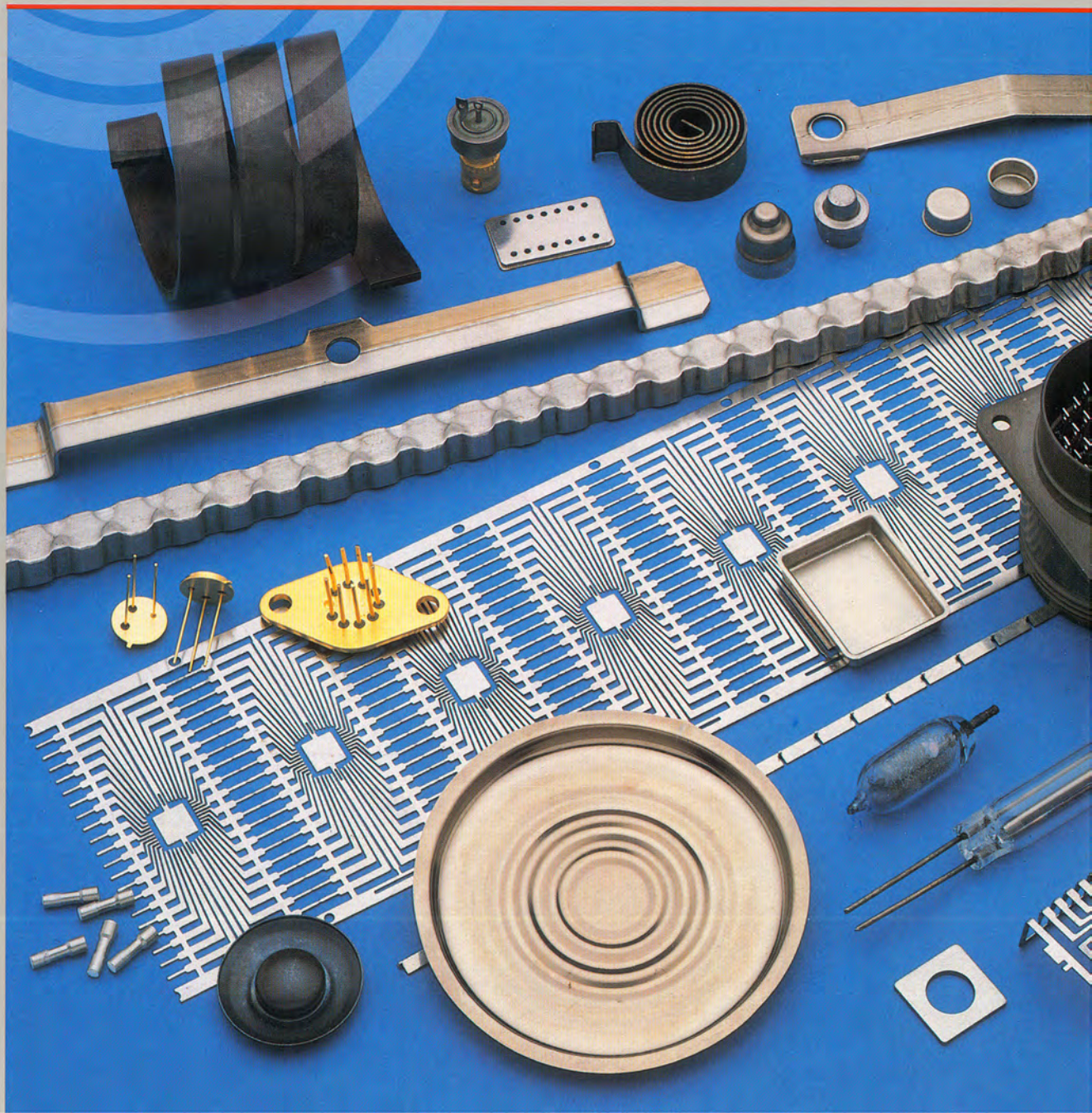


## Controlled-Expansion Alloys



## Carpenter...

Whether you are designing or fabricating a product for applications where thermal size change is critical, there are many good reasons to call on Carpenter. Our broad selection of controlled expansion alloys includes these major groups:

**Low thermal expansion alloys**, which provide either minimum, or precisely predictable, size change over variations in temperature;

**High thermal expansion alloys**, which respond more dramatically to temperature changes;

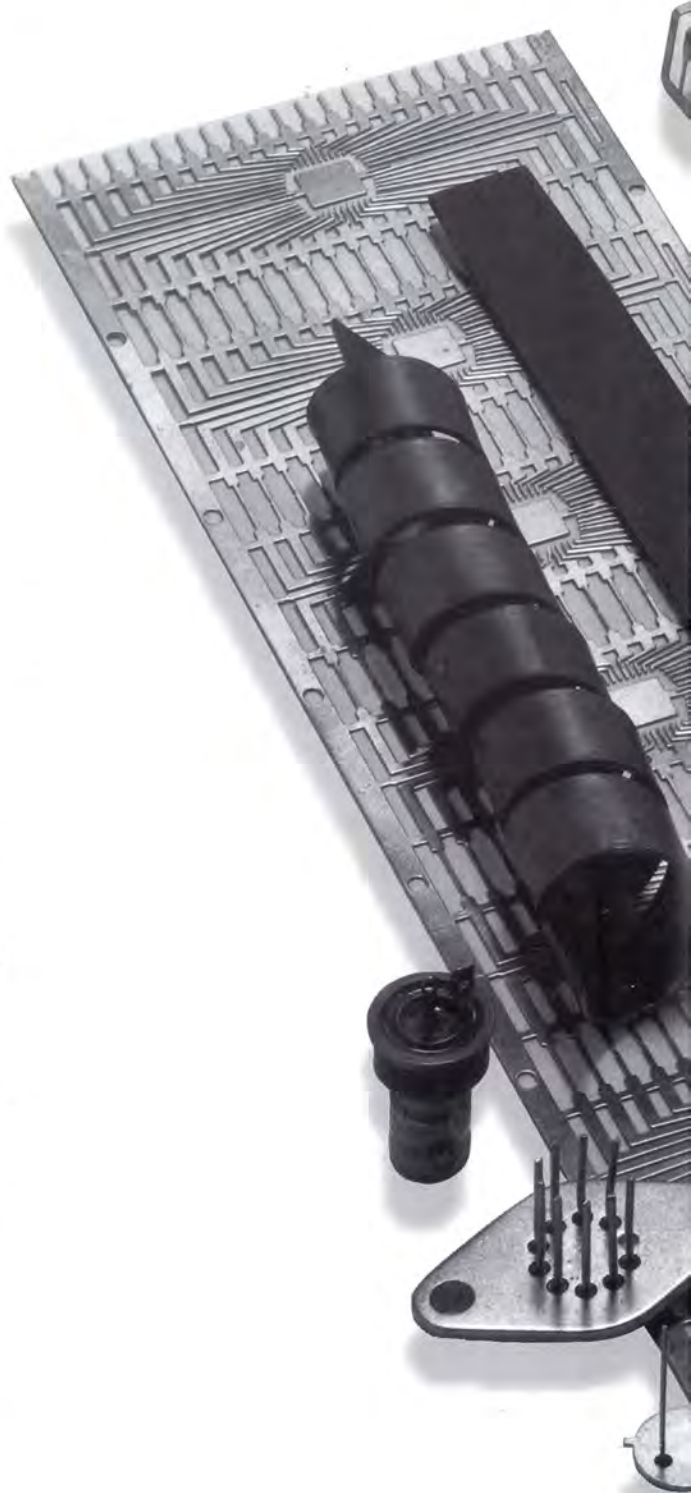
**Glass and ceramic sealing alloys**, with expansion characteristics matching those of glass and ceramic materials.

...in product forms including bar, wire, fine wire, strip and billet. Other forms may be available by special arrangement.

Carpenter controlled expansion alloys have established a reputation for providing fabrication and performance properties that enable users to achieve predictable results in their applications. That's because . . . from alloy composition through melting and finishing . . . we employ statistical process control methods and rigorous inspection procedures. In addition, our manufacturing equipment . . . among the most technically advanced in the specialty alloys production industry . . . enables us to produce materials to the most demanding specifications. And we assume single-source responsibility for our products, so that you can use them with confidence.

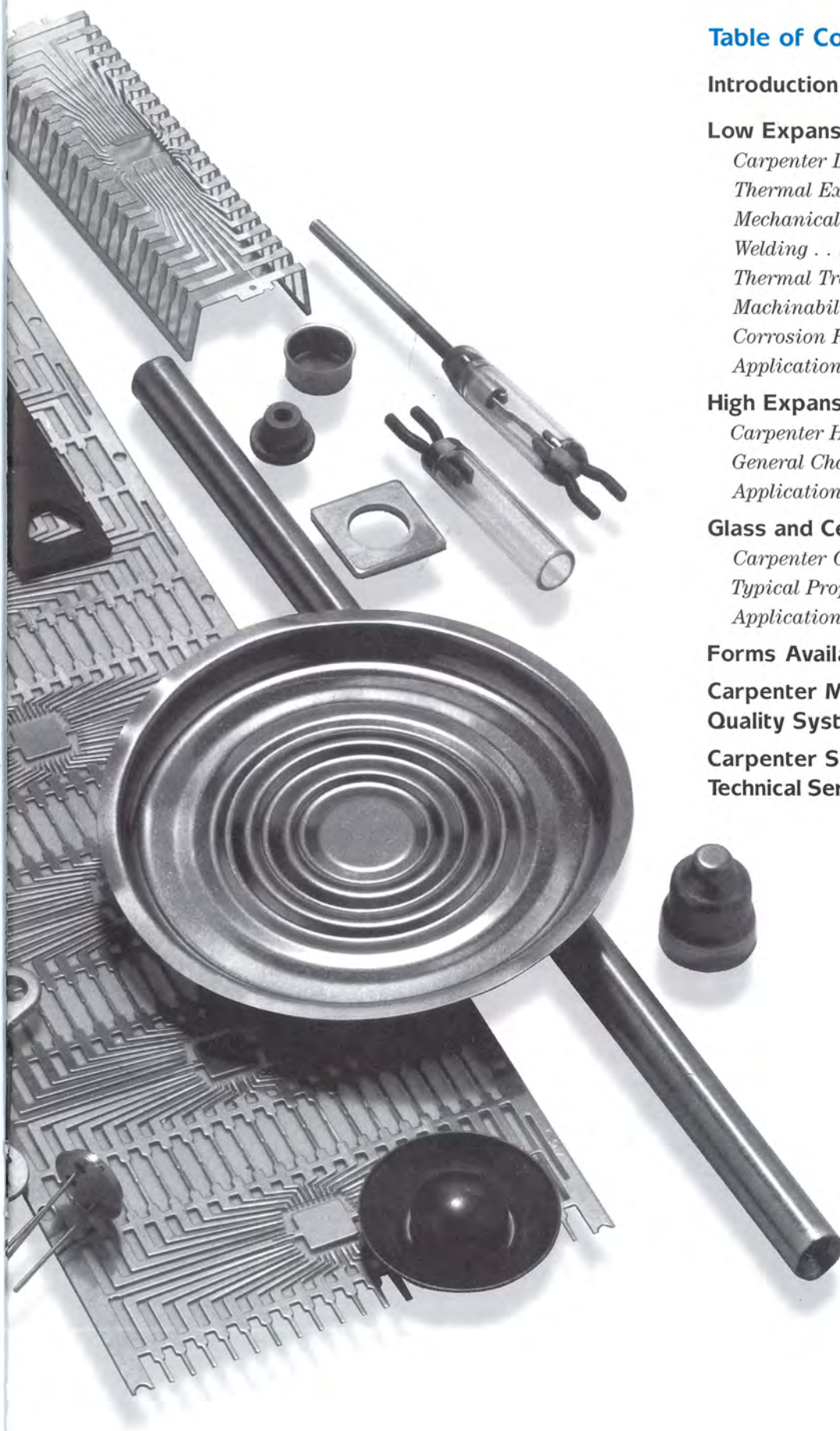
Many of Carpenter's controlled expansion alloys were originally developed in response to specific customer application requirements. That's why we urge you to do two things; first, review the technical information and product data in this book. Then, discuss your individual needs with us. We can help you to select the material that you require . . . or even "tailor" an existing alloy that will provide special characteristics needed to do the job.

Contact your nearby Carpenter Service Center. The professionals there will show you why and how Carpenter alloys can be the value choice for your controlled expansion applications.



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Metals, by their very nature, expand when heated and contract when cooled. Generally, the higher the temperature, the greater the expansion per degree of temperature rise.

An alloy's composition and crystal form determine its character and rate of thermal expansion. When plotting expansion versus temperature, most metals and alloys fit the shape of one of three common curves.

The measurement of thermal expansion is routinely accomplished by dilatometry methods. Measurements are expressed in unit expansion such as inch per inch, or cm per cm, over a specified temperature change. The most common expression of thermal expansion properties is the average coefficient of thermal expansion. This is expressed as unit expansion per degree temperature change (in/in/°F, cm/cm/°C) for a specified temperature change. The expansion behavior of certain materials is not linear; therefore it is important to specify the upper and lower temperature limits of interest when describing a material's expansion coefficient.

## General Expansion Characteristics

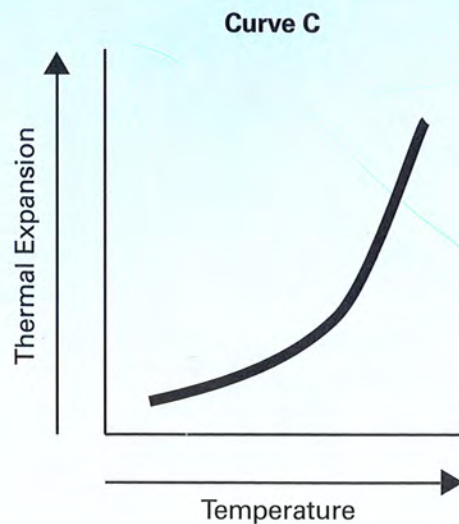
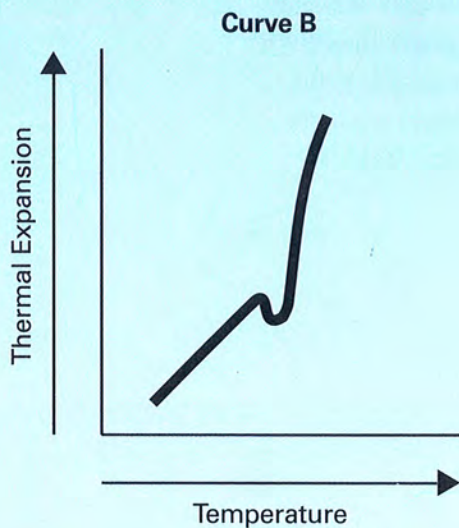
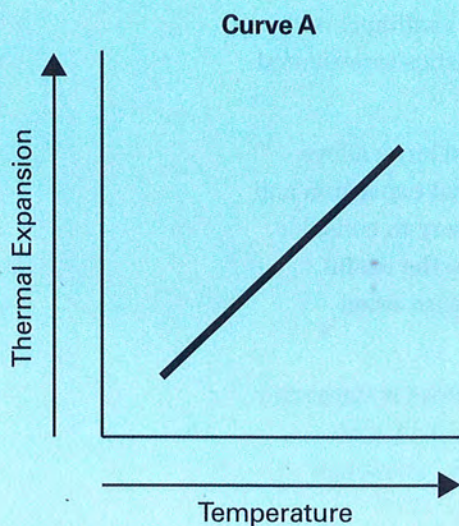
Curve "A" is characteristic of solid-solution alloys and metals that retain a single crystal structure over a given temperature range. Most austenitic stainless alloys (Types 304 and 316, for example), and many elemental metals exhibit this type of linear-expansion curve.

Curve "B" describes those alloys which undergo a phase transformation which is reversible during rising or falling temperatures. With these alloys there is an abrupt change in crystal structure (for example, martensite/austenite) that results in abrupt expansion or contraction of the metal. Carbon steels have type "B" expansion characteristics.

Curve "C" is characteristic of ferromagnetic alloys (like various nickel-iron alloys) that have an apparent anomalous thermal expansion. The atypical low thermal expansion results from the ferromagnetic character of the metal at temperatures below its Curie temperature. The Curie temperature defines the magnetic to non-magnetic transition for ferromagnetic materials. Above the Curie temperature, thermal expansion increases and is typical for the crystal form.

Alloys having type "B" expansion characteristics display the phase change at different temperatures upon heating or cooling and may be cooling rate dependent. In contrast, alloys displaying types "A" and "C" expansions are reversible in that they exhibit the same characteristic curve on heating and cooling.

In many applications the effects of thermal expansion usually can be ignored or accommodated by proper design of components and



assemblies. However, for some applications, dimensional change of the metal as a result of temperature change is a critical design consideration. Fortunately, metals can be produced with compositions controlled to provide thermal expansion characteristics suitable for the intended application. Over the years, many alloys have been developed with "controlled" thermal expansion characteristics.

The three general types of controlled expansion alloys are:

#### **Low Thermal Expansion**

Alloys which exhibit very low expansion coefficients within certain temperature ranges.

#### **High Thermal Expansion**

Alloys which exhibit expansion coefficients higher than those of carbon steel.

#### **Glass and Ceramic Sealing**

Alloys which possess approximately the same expansion coefficients as a given non-metallic material to which they will be matched.

Carpenter offers the most diversified range of electronic and electrical alloys available from any American manufacturer. Producing alloys with controlled expansion characteristics is a Carpenter specialty. So whether your application requires low expansion, high expansion or glass or ceramic to metal sealing material, there is a Carpenter alloy for you.



Low expansion alloys exhibit very low coefficients of thermal expansion (less than 1 to approximately  $6 \times 10^{-6}/^{\circ}\text{F}$ ) within certain temperature ranges and have expansion characteristics represented by curve "C".

The most important commercial alloys are the nickel-iron alloys. As nickel content increases from 36 percent, thermal expansion and Curie temperature also increase. Thus, it is necessary to consider not only the thermal expansion coefficient, but also the useful temperature range as limited by the Curie temperature when selecting alloys for low expansion applications.

One of the best known Carpenter low expansion alloys is Carpenter Invar "36" alloy; so named because its size change is almost "invariable" during ordinary changes in temperature, and it has "36" percent nickel content.

Where the expansion curve for ordinary steel is compared to other alloys, the expansion of Carpenter Invar "36" alloy is only one sixth that of carbon steel at ordinary temperatures. At greater than  $400^{\circ}\text{F}$  ( $204^{\circ}\text{C}$ ), Carpenter Invar "36" alloy expands at approximately the same rate as carbon steel. If higher temperature ranges are to be encountered in applications, a more suitable alloy may be Low

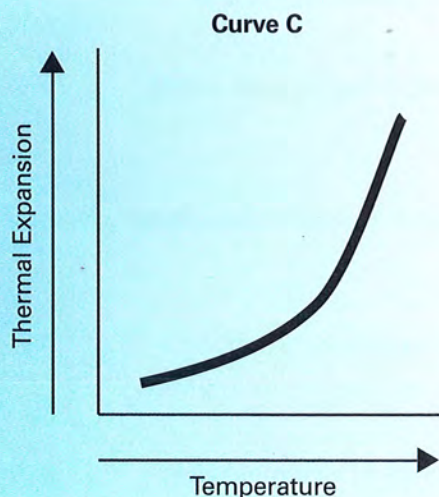
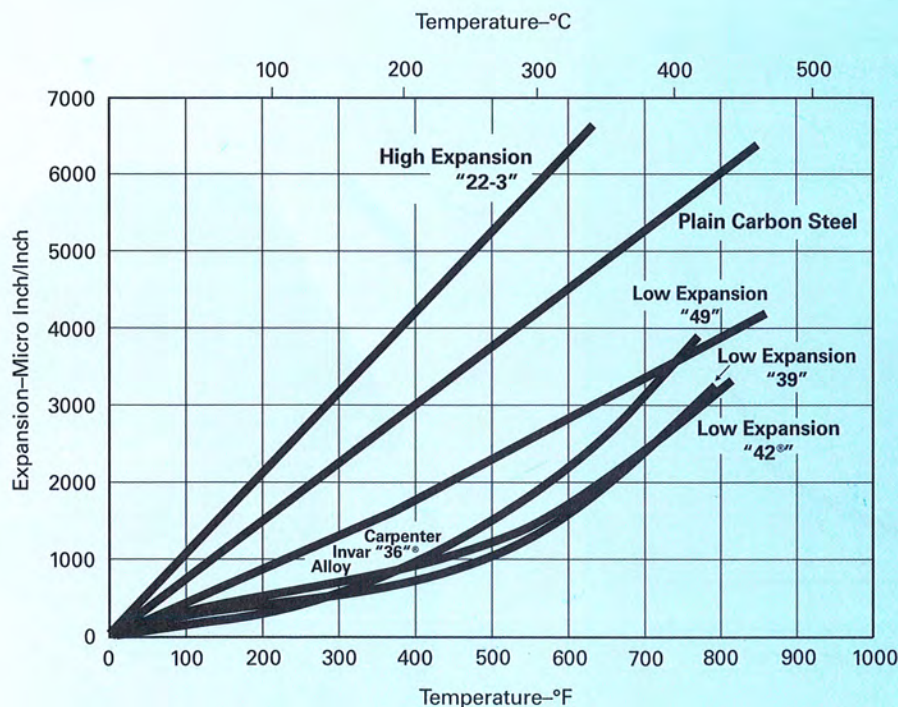


Figure 1



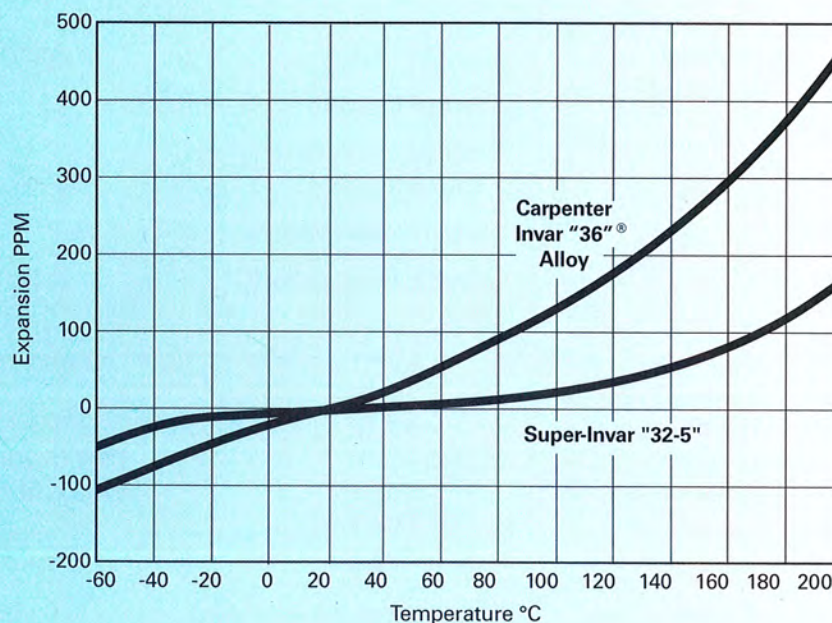
Expansion "39" alloy. While its expansion rate is marginally higher than Carpenter Invar "36" alloy, Low Expansion "39" alloy's useful temperature range extends to approximately 600°F (316°C). These relationships are illustrated in Figure 1.

For unique low expansion requirements, a number of alloy modifications have been developed by Carpenter to provide certain specific characteristics. One example is Free-Cut Invar "36"® alloy, developed by adding small additions of selenium to the Carpenter Invar "36" alloy composition. Free-Cut Invar "36" alloy offers improved machining characteristics over the original alloy.

Another example of an alloy modification is Carpenter's Super Invar "32-5", an iron-nickel-cobalt alloy having thermal expansion rates less than half that of Carpenter Invar "36" alloy, but with a slightly narrower application temperature range due to a lower Curie temperature.

Figure 2 shows the characteristic thermal expansion of Super Invar "32-5" over the temperature range of -60 to +200°C (-76 to +392°F), and also a comparison to Carpenter Invar "36" alloy at similar temperatures.

**Figure 2**  
Comparison of Thermal Expansion for Super Invar "32-5"  
and Carpenter Invar "36"® Alloy



### Super Invar "32-5"

Super Invar "32-5" is an iron-nickel-cobalt alloy which exhibits approximately one-half of the thermal expansion of Carpenter Invar "36" alloy in the vicinity of room temperature. This alloy has been used as structural components or bases and supports for optical and laser instruments.

### Carpenter Invar "36"® Alloy

A 36 percent nickel-iron alloy with a rate of thermal expansion approximately one-tenth that of carbon steel at temperatures up to 400°F (204°C). Has been used in applications such as radio and electronic devices where dimensional changes due to temperature must be minimal as well as in support and structural members in precision optical laser mechanical measuring and positioning devices and for thermostats metals.

### Free-Cut Invar "36"® Alloy

Free-machining alloy used for machined parts in which dimensional changes due to temperature variations must be minimized. It has been used in radio and electronic devices and aircraft controls.

Typical Properties of Carpenter Low Expansion Alloys

| Properties                                                                                                      |                                                                                                                                              | Super Invar<br>"32-5"<br>(ASTM F1684)                                                      | Carpenter Invar<br>"36"® Alloy<br>(ASTM F1684)       |
|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------|
| Type Analysis:                                                                                                  | Carbon<br>Manganese<br>Silicon<br>Nickel<br>Other Elements                                                                                   | .05<br>.35<br>.30<br>32<br>Co 5.25<br>Fe Bal.                                              | .05<br>.35<br>.30<br>36<br>Fe Bal.                   |
| Physical Constants:                                                                                             | Specific Gravity<br>Thermal Conductivity W/m-°C<br>Electrical Resistivity:<br>Microhm-cm<br>Curie Temperature, °C<br>Specific Heat, cal/g-°C | 8.10<br>10<br>80<br>260<br>0.12                                                            | 8.05<br>10<br>82<br>280<br>0.12                      |
| Typical Coefficients of Thermal Expansion (As Annealed)<br>(x 10 <sup>-6</sup> /°C)<br>(x 10 <sup>-6</sup> /°F) | 25°C to 93°C<br>149°C<br>260°C<br>371°C<br>75°F to 200°F<br>300°F<br>500°F<br>700°F                                                          | 25°C to 93°C<br>.72 x 10 <sup>-6</sup> /°C<br>75°F to 200°F<br><.40 x 10 <sup>-6</sup> /°F | 1.6<br>2.0<br>4.1<br>7.2<br>0.9<br>1.1<br>2.3<br>4.0 |
| Typical Mechanical Properties:<br>(As Annealed)                                                                 | Tensile Strength, ksi (MPa)<br>Yield Strength, ksi (MPa)<br>Elongation in 2"<br>Hardness, Rockwell<br>Elastic Modulus, Mpsi (kMPa)           | 70.0 (483)<br>40.0 (276)<br>30<br>B80<br>21.0 (144)                                        | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>20.5 (141)  |

### Low Expansion "39" Alloy

A special controlled-expansion alloy designed originally to match the thermal expansion of certain hard glasses up to 392°F (200°C). Has been used for tunable capacitors and as low expansion element in thermostat bimetal products.

### Carpenter Low Expansion "42"® Alloy

This nickel-iron alloy has a virtually constant low rate of thermal expansion at temperatures up to about 650°F (343°C). Has been used in thermostats and thermostwitches, as well as in thermostat bimetal applications as the low expansion element.

### Low Expansion "45" Alloy

This alloy has a relatively constant rate of thermal expansion to about 800°F (538°C). It has been used in thermostats, and its thermal expansion approximates that of some alumina ceramics.

### Low Expansion "49" Alloy

Has been used for glass sealing of fiber optics.

| Free-Cut Invar<br>"36"® Alloy<br>(ASTM F1684)        | Low Expansion<br>"39"<br>(ASTM B-753)                | Carpenter<br>Low Expansion<br>"42"® Alloy<br>(ASTM B-753) | Low Expansion<br>"45"<br>(ASTM B-753)                | Low Expansion<br>"49"                                |
|------------------------------------------------------|------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|
| .10<br>.90<br>.35<br>36<br>Se .20<br>Fe Bal.         | .05<br>.40<br>.25<br>39<br>Fe Bal.                   | .05<br>.10<br>.20<br>42<br>Fe Bal.                        | .05<br>.50<br>.25<br>45<br>Fe Bal.                   | .05<br>.50<br>.40<br>47.5<br>Fe Bal.                 |
| 8.05<br>10<br>82<br>280<br>0.12                      | 8.08<br>11<br>71<br>340<br>0.12                      | 8.12<br>11<br>67<br>380<br>0.12                           | 8.20<br>16<br>55<br>440<br>0.12                      | 8.25<br>17<br>48<br>500<br>0.12                      |
| 1.8<br>2.3<br>4.5<br>7.9<br>1.0<br>1.3<br>2.5<br>4.4 | 2.3<br>2.7<br>3.2<br>5.8<br>1.3<br>1.5<br>1.8<br>3.2 | 5.8<br>5.6<br>5.4<br>5.8<br>3.2<br>3.1<br>3.0<br>3.2      | 7.9<br>7.7<br>7.4<br>7.2<br>4.4<br>4.3<br>4.1<br>4.0 | 8.5<br>8.5<br>8.5<br>8.5<br>4.7<br>4.7<br>4.7<br>4.7 |
| 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>20.5 (141)  | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>21.0 (144)  | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>21.5 (148)       | 82.0 (565)<br>40.0 (276)<br>30<br>B80<br>21.0 (144)  | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>24.0 (166)  |

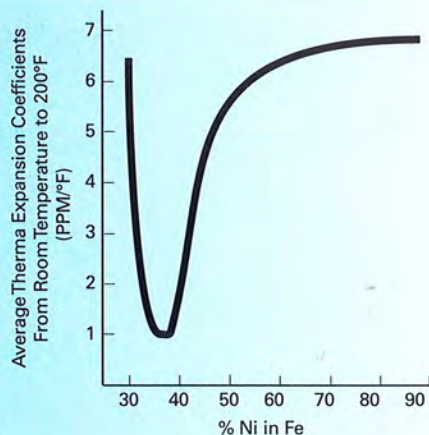


**Figure 3**  
Change in Apparent Average  
Thermal Expansion Coefficient  
With Nickel Content in Iron

### Thermal Expansion of Low Expansion Alloys

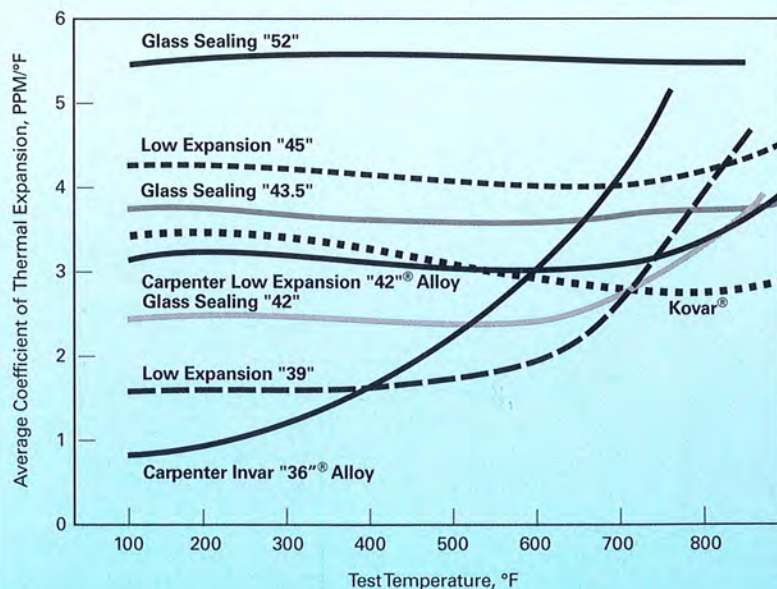
Thermal expansion changes significantly as nickel content is varied between approximately 30 to 50 percent nickel-iron. Around room temperature thermal expansion is less than 1 ppm/°F with 36 percent nickel in iron. However, thermal expansion increases as nickel is increased from 36 to 50 percent nickel-iron. In addition, as nickel increases from approximately 28 percent, the Curie temperature (magnetic transition) increases from room temperature to greater than 950°F (510°C) for 50 percent nickel-iron. Table I and Figure 3 show the relationship of nickel content to thermal expansion. Above 52 percent nickel in iron, thermal expansions are greater than 6 ppm/°F.

Alloys having 60 to 80 percent nickel in iron are used primarily for their soft magnetic properties rather than low thermal expansion. In Figure 4, thermal expansion is shown as temperature increases for a number of nickel-iron alloys. This illustrates how the thermal expansion and Curie temperatures increase with nickel. For those alloys having nickel greater than 36 percent, higher Curie temperatures extend the useful application range to higher temperatures. Also shown is thermal expansion for Kovar® alloy, a nickel-iron containing cobalt, illustrating how cobalt additions extend the Curie point to higher temperatures.

**Table I**  
Average Thermal Expansion  
Coefficients for Low Expansion Alloys  
(PPM/°F) Room Temperature  
to Temperature Indicated

| Alloy                            | 200°F<br>(93°C) | 300°F<br>(149°C) | 500°F<br>(260°C) | 700°F<br>(371°C) |
|----------------------------------|-----------------|------------------|------------------|------------------|
| Carpenter Invar "36"®            | 0.72            | 1.20             | 2.45             | 4.33             |
| Low Expansion "39"               | 1.56            | 1.62             | 1.87             | 3.20             |
| Low Expansion "40"               | 2.30            | 2.20             | 2.20             | 2.80             |
| Glass Sealing "42"               | 2.55            | 2.45             | 2.50             | 3.00             |
| Carpenter<br>Low Expansion "42"® | 3.19            | 3.11             | 2.98             | 3.16             |
| Low Expansion "45"               | 4.35            | 4.27             | 4.06             | 3.96             |

**Figure 4**  
Comparison of Average Expansion Coefficients  
for Various Carpenter Controlled Expansion Alloys



## Mechanical Properties

The Carpenter nickel-iron alloys of commercial interest for their low thermal expansion are austenitic solid solutions that exhibit moderate strength levels and are not hardenable by heat treatment. They exhibit excellent ductility which contributes to ease of fabrication in parts requiring bending, forming, deep drawing, etc. For nickel-irons having approximately 30 to 50 percent nickel, the tensile strengths for annealed alloys will be typically 65 to 85 ksi with tensile elongations greater than 25 percent. For some product forms, the tensile strengths can be increased by cold working to greater than 120 ksi with subsequent reductions in tensile elongations to less than 5 percent. Some typical data is shown in Table II.

At higher temperatures, the tensile and yield strength of these alloys decreases rapidly, with tensile strengths dropping to less than 50 ksi at temperatures of approximately 900°F (482°C). Data for several low expansion alloys are shown in Table III. The higher nickel containing alloys show marginally higher tensile properties for test temperatures up to 900°F (482°C).

For nickel contents between 30 and 60 percent in iron, elastic modulus varies from a low of  $20 \times 10^6$  psi at 36 percent nickel to  $26 \times 10^6$  psi with 60 percent nickel in iron. Variations of elastic modulus with nickel content are shown in Figure 5. For 36 to 42 percent nickel contents, the modulus will increase 5 percent as temperature is increased to 700°F (371°C) and decrease thereafter.

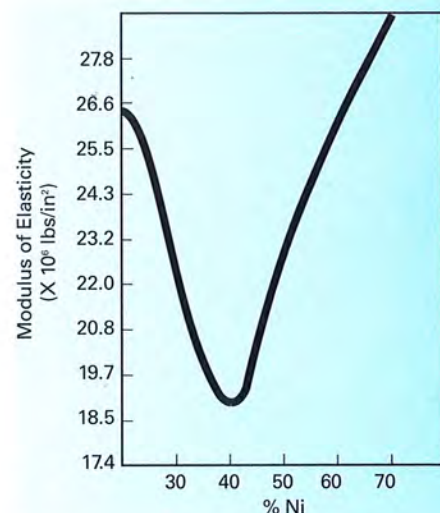


**Figure 5**  
Apparent Variation for Modulus of Elasticity with Varying Nickel in Iron

| Alloy                  |                   | .2% Yield (ksi) | Ultimate Tensile (ksi) | % Elong. | Approx. Equivalent Hardness |
|------------------------|-------------------|-----------------|------------------------|----------|-----------------------------|
| Carpenter Invar "36" ® | As annealed       | 38              | 68                     | 37       | 75 Rb                       |
|                        | % Cold worked, 10 | 54              | 82                     | 23       | 86 Rb                       |
|                        | 30                | 80              | 98                     | 10       | 95 Rb                       |
|                        | 50                | 93              | 105                    | 5        | 96 Rb                       |
|                        | 70                | 102             | 106                    | 3        | 97 Rb                       |
| Glass Sealing "52"     | As annealed       | 34              | 78                     | 32       | 83 Rb                       |
|                        | % cold worked, 10 | 76              | 93                     | 19       | 92 Rb                       |
|                        | 30                | 104             | 109                    | 6        | 99 Rb                       |
|                        | 50                | 112             | 118                    | 3        | 100 Rb                      |
|                        | 70                | 116             | 121                    | 2        | 26 Rb                       |

**Table II**  
Mechanical Properties of Several Nickel-Iron Alloys

| Alloy                          | Test Temperature |      | .2% Yield Strength | Ultimate Tensile Strength | % Elongation | % Reduction of Area |
|--------------------------------|------------------|------|--------------------|---------------------------|--------------|---------------------|
|                                | °F               | °C   |                    |                           |              |                     |
| Carpenter Invar "36" ®         | 75               | 23.9 | 38.5               | 70.0                      | 44.0         | 81.5                |
|                                | 300              | 149  | 20.2               | 59.0                      | 44.5         | 77.5                |
|                                | 600              | 316  | 14.0               | 61.0                      | 50.0         | 73.0                |
|                                | 900              | 482  | 13.0               | 40.0                      | 63.0         | 73.0                |
| Carpenter Low Expansion "42" ® | 75               | 23.9 | 43.0               | 80.0                      | 43.7         | 73.5                |
|                                | 300              | 149  | 32.5               | 74.0                      | 45.6         | 67.1                |
|                                | 600              | 316  | 27.3               | 71.8                      | 52.8         | 67.1                |
|                                | 900              | 482  | 22.8               | 54.0                      | 43.0         | 58.4                |
| Low Expansion "39"             | 75               | 23.9 | 43.3               | 78.0                      | 46.2         | 79.3                |
|                                | 300              | 149  | 35.3               | 70.3                      | 43.2         | 75.6                |
|                                | 600              | 316  | 32.3               | 67.0                      | 42.0         | 73.5                |
|                                | 900              | 482  | 31.5               | 55.8                      | 35.5         | 51.9                |

**Table III**  
Typical Tensile Properties at Elevated Temperatures for Several Low Expansion Alloys

## Welding

The Invar alloys can be successfully welded using most standard arc welding processes. In general, preparation for welding should be similar to stainless steels and should include proper cleaning and handling. Joint designs should allow easy access to the weld because of poor weld pool fluidity. Designs should also limit total weld volume to reduce shrinkage problems. Pre-heating and post-heating are not required and should be avoided. A low interpass temperature (300°F max.) should be maintained.

Welding is most commonly performed using the gas tungsten arc or gas metal arc process. Gas tungsten arc welding can be accomplished with Ar and/or He shielding gases. Welding is best performed with a freshly ground thoriated tungsten electrode. Gas metal arc welding can be successfully performed in all metal transfer modes depending primarily on base metal thickness. Shielding gases should be Ar or Ar/He mixtures. Other non-arc welding processes (ex. resistance) may also be used.

When a filler metal is needed, a matching composition like Carpenter Invarod alloy will provide the best match in thermal expansion properties. If a matching composition is not available, a high-nickel filler metal conforming to AWS A5.14 ERNi-1 or ERNiCrFe-5 can be used. These materials will result in a weld with different thermal expansion properties.

## Thermal Treatments

Although the nickel-iron low expansion alloys are not hardenable, annealing and stress relief thermal treatments are at times necessary to promote structure uniformity and dimensional stability. The relief of stresses introduced by severe forming, bending, or machining, can be accomplished by annealing at temperatures of approximately 1400 to 1800°F (760 to 982°C) for a time sufficient to thoroughly heat through the section. However, the nickel-irons will oxidize readily at these high temperatures. When annealing cannot be done in a non-oxidizing environment (vacuum, dry hydrogen, dissociated ammonia, etc.), sufficient material must be allowed on work pieces to clean-up by light grinding, pickling, etc., after annealing. Stress relief for sections having light finishing cuts or grinding performed after annealing is accomplished by heating to 600 to 800°F (316 to 427°C), for a time to uniformly heat through the work piece.

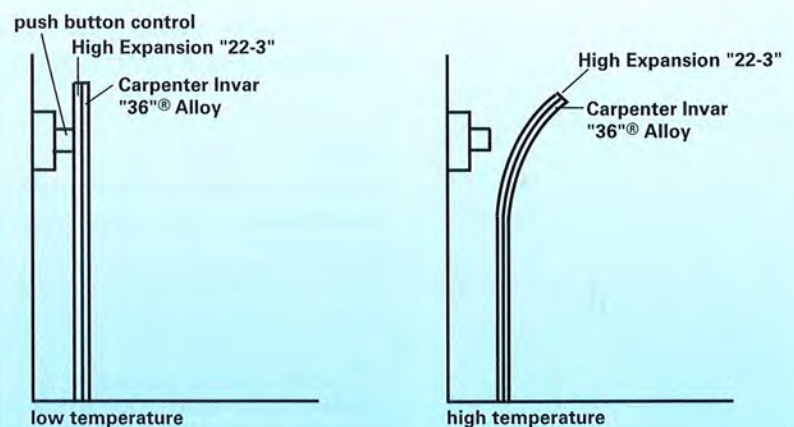
All of the nickel-iron controlled expansion alloys can be hot forged, upset, formed, etc., at temperatures between 1800 to 2100°F (982 to 1149°C). However, heating for hot working must be done uniformly at slow rates from relatively cold furnaces (black) to minimize the potential for cracking through large sections as a result of differential thermal expansion stresses. Large forgings should be annealed to promote uniformity after hot working.

## Machinability

Typically, Carpenter low expansion alloys machine similar to, but not as good as a Type 316 austenite stainless steel; or, around 25 percent as good as AISI B1112. They develop somewhat gummier and stringy chips and higher forces, but do not work harden as rapidly as Type 316. Work hardened bars can result in some improvement of the inherent machinability in some instances. If machining is a major concern, free-machining versions of some of the basic grades are available. Generally speaking, the free-machining versions can be turned at around 50 to 95 surface feet per minute higher at the same or slightly higher feed rates (inches per revolution) than their non-free-machining counterparts.

Tool geometries normally used for austenitic stainless steels are applicable to these alloys. All tools should be kept sharp with a fine finish, be as large as possible and rigidly supported.

Cutting fluid selection is an important consideration in the machining of low expansion alloys. For best machinability, a 1 to 1 blend of a sulfachlorinated petroleum oil containing 8 to 10 percent fatty oil and a paraffin blending oil would be used, or a water emulsifiable cutting fluid with polar and extreme pressure additives. However, the presence of any residual sulfur from the cutting fluid on the machined part, followed by heat treating, could result in serious degradation of magnetic properties. Meticulous degreasing and cleaning of machined parts can remove sulfur residues resulting from the sulfur-bearing cutting compounds. Animal lard is also used as a cutting lubricant. In any event, the parts should be degreased and cleaned as soon after machining as possible. Residual sulfur can also cause grain boundary embrittlement.



A temperature control designed with bimetallic strip.

Table IV shows the cutting parameters for turning, drilling, tapping and milling. Machining operations generally involve so many variables that it is difficult to list specific parameters which would apply to all conditions. The cutting parameters listed should be considered as a starting point for specific applications.

| Turning Parmeters—Single Point and Box Tools |                  |                            |                |              |               |              |          |              |          |
|----------------------------------------------|------------------|----------------------------|----------------|--------------|---------------|--------------|----------|--------------|----------|
| <u>Depth of Cut-in.</u>                      | <u>Speed-fpm</u> | <u>Feed-ipr</u>            |                |              |               |              |          |              |          |
| .100                                         | 30               | .010 (Roughing)            |                |              |               |              |          |              |          |
| .020                                         | 20               | .002 (Finishing)           |                |              |               |              |          |              |          |
| Turning Parmeters—Cutoff and Form Tools      |                  |                            |                |              |               |              |          |              |          |
|                                              |                  | <u>Feed-ipr</u>            |                |              |               |              |          |              |          |
|                                              |                  | <u>Tool Width</u>          |                |              |               |              |          |              |          |
|                                              |                  | <u>.125"</u>               | <u>.250"</u>   | <u>.500"</u> | <u>1.00"</u>  | <u>2.00"</u> |          |              |          |
| Speed—fpm                                    | 20               | .001                       | .001           | .0015        | .001          | .0007        |          |              |          |
| Drilling Parmeters                           |                  |                            |                |              |               |              |          |              |          |
|                                              |                  | <u>Feed-ipr</u>            |                |              |               |              |          |              |          |
|                                              |                  | <u>Drill Diameter—in.</u>  |                |              |               |              |          |              |          |
|                                              |                  | <u>1/16</u>                | <u>1/8</u>     | <u>1/4</u>   | <u>1/2</u>    | <u>3/4</u>   | <u>1</u> | <u>1 1/2</u> | <u>2</u> |
| Speed—fpm                                    | 35               | .001                       | .003           | .004         | .008          | .010         | .012     | .015         | .018     |
| Tapping Parmeters                            |                  |                            |                |              |               |              |          |              |          |
|                                              |                  | <u>Speed-fpm</u>           |                |              |               |              |          |              |          |
|                                              |                  | <u>Threads/inch</u>        |                |              |               |              |          |              |          |
| <u>7 or less</u>                             | <u>8-15</u>      | <u>16-24</u>               | <u>Over 24</u> |              |               |              |          |              |          |
| 6                                            | 8                | 12                         | 15             |              |               |              |          |              |          |
| End Milling Parameters                       |                  |                            |                |              |               |              |          |              |          |
| <u>Radial Depth of Cut-in.</u>               | <u>Speed ppm</u> | <u>Feed-in./tooth</u>      |                |              |               |              |          |              |          |
|                                              |                  | <u>Cutter Diameter—in.</u> |                |              |               |              |          |              |          |
|                                              |                  | <u>3/8</u>                 | <u>1/2</u>     | <u>3/4</u>   | <u>1 to 2</u> |              |          |              |          |
| .020                                         | 65               | .002                       | .002           | .003         | .004          |              |          |              |          |
| .060                                         | 50               | .002                       | .003           | .004         | .005          |              |          |              |          |

**Table IV**  
Machining Parameters for Low Expansion Alloys

## Corrosion Resistance

The low expansion alloys are not considered corrosion resistant and will "rust" in relatively mild industrial environments. They will exhibit more resistance to "rusting" than iron, however, the lower nickel containing alloys (less than 40 percent) show rust initiation times of approximately 24 hours when exposed to 95 percent humidity at 95°F (35°C). This is illustrated by Table V.

**Table V**  
Effects of Relative Humidity on Low Expansion Alloys  
as Compared to Other Nickel-Iron Alloys<sup>(1)</sup>

| Alloy                                   | Annealed                                   |                     | Cold Rolled                 |                     |
|-----------------------------------------|--------------------------------------------|---------------------|-----------------------------|---------------------|
|                                         | % of Surface Rusted <sup>(2)</sup><br>Avg. | First Rust<br>(hrs) | % of Surface Rusted<br>Avg. | First Rust<br>(hrs) |
| Electrical Iron                         | 70, 70, 70                                 | 70                  | 1, 1, 1                     | 1, 1, 2             |
| Carpenter Temperature Compensator "30"® | 5, 5, 5                                    | 5                   | 24, 24, 24                  | 24, 24, 24          |
| Carpenter Invar "36"®                   | Few Rust Spots                             | —                   | 48, 48, 96                  | 96, 96, 96          |
| Carpenter Low Expansion "42"®           | 0                                          | —                   | —                           | —                   |
| Low Expansion "49"                      | 0                                          | —                   | —                           | —                   |
| Glass Sealing "52"                      | 0                                          | —                   | —                           | —                   |
| Carpenter HyMu "80"® <sup>(3)</sup>     | 0                                          | —                   | —                           | —                   |

(1) 95% relative humidity for 200 hrs @ 95°F

(2) % Rust - Visual estimate of the % of surface rust

(3) This alloy contains approximately 80% nickel and has a molybdenum content of approx. 4.5%

More severe environments (salt spray per ASTM B-117) show rust initiation times as short as 1 hour. Some test results are shown in Figures 6A and 6B. In addition, tests show the 36 to 50 percent nickel-irons are susceptible to stress corrosion cracking when exposed to chloride solutions. Crack depths up to .015" have occurred in bend samples after 90 days' exposure to 20 percent salt spray environments. Salt spray results for 36 percent nickel-iron alloys are shown in Figure 7.

**Figure 6A**

Effect of exposure to salt spray on low expansion alloys as compared to other nickel-iron alloys

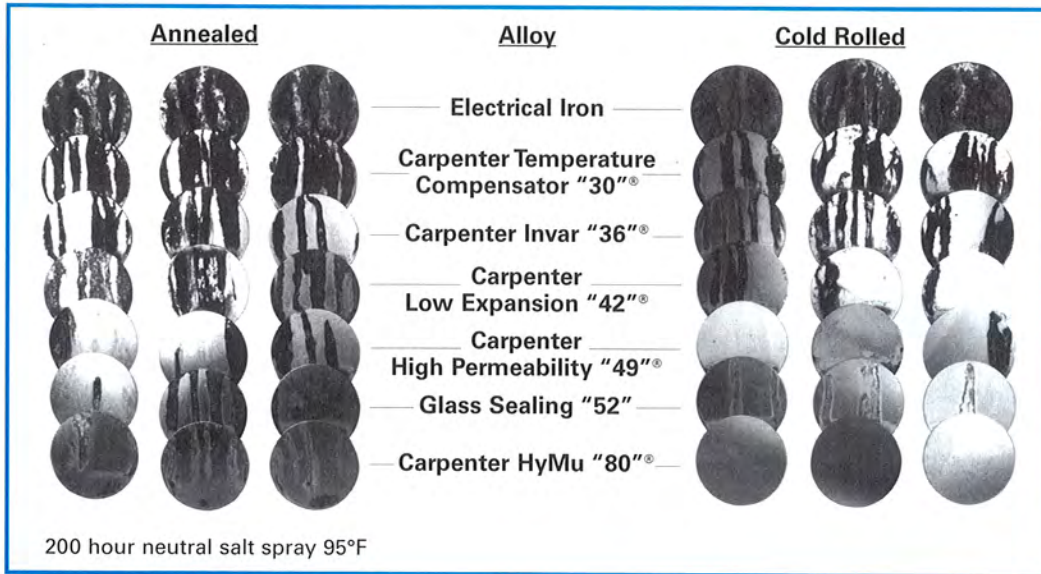


**Figure 6B**

% Rust vs. Nickel Content  
200 Hour Neutral Salt Spray @ 95°F

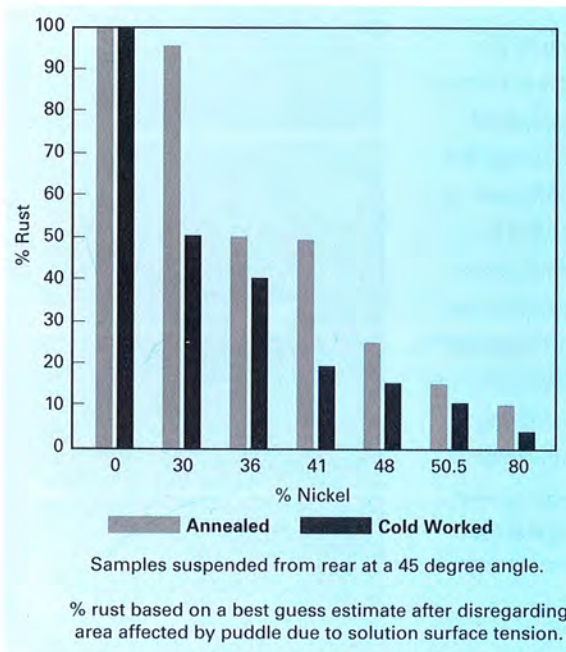
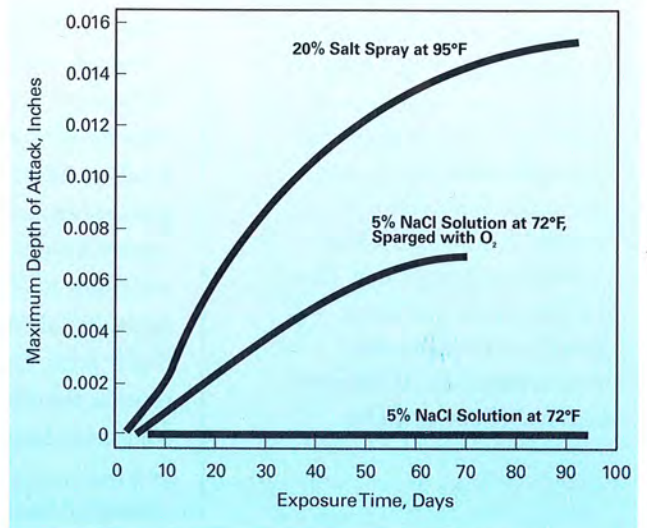


**Figure 7**

Stress Corrosion of U-Bend Specimen  
Carpenter Invar "36" Alloy



## **Carpenter Invar "36"® and Carpenter Low Expansion "42"® Alloys Make Possible High Temperature Curing of Aircraft Thermoset Composites**

In recent years, increasing numbers of military and civilian aircraft structural components have been made of composite epoxy/fibers with thermoplastic and thermoset resins. They provide high strength, light weight and exceptional resistance to fatigue failure in wing and stabilizer sections, and fuselage parts. They require fewer fasteners and less internal reinforcement than aluminum components.

The tooling needed for these parts must be designed and made to mirror the contours and dimensions of each part. Each "tool" is used to "lay up" successive layers of epoxy-impregnated carbon fiber cloth.

The tool is autoclaved-cured with the assembly, so it must have a low thermal expansion closely matching that of the composite. Alloys such as Carpenter Invar "36" alloy and Carpenter Low Expansion "42" alloy provide excellent expansion matches at, and below, the temperatures needed to solidify the composite resin parts. Also, they are less costly and more durable than such other tooling materials as ceramic and monolithic graphite.

## **Applications**

Practical uses of low expansion alloys are divided into two general categories. First are those in which size change due to temperature variation must be minimized. These applications have included structural components for measurement and control instruments in which excessive expansion and contraction due to temperature changes would seriously impair accuracy such as aircraft and missile control components, laser and optical systems, wave guide tubes, and frequency resonators.

The second category includes temperature controls that use a bimetallic strip. This simple type of control consists of a low expansion alloy metallurgically bonded to a high expansion alloy to produce a composite. When the strip is heated, the difference in thermal expansion rates between the two alloys causes the bimetal to flex or bend. The extent of this flexure is related to the differential expansion of the bonded alloys.

While many design variations exist, all bimetallic temperature controls are based on the fact that the strip will bend a fixed amount at a specific temperature, and at that temperature a control circuit will either open or close. A unique advantage for this type of device is its ability to act both as the sensing element and the active control (relay) component. A primary advantage is its simplicity and reliability at relatively low cost.

### **Temperature Stability of Super Invar "32-5" Alloy Provides Ideal Support for Unique SST Telescope**

Atop 14,000-foot Mauna Kea in Hawaii, a 33-ton glass mirror in the world's largest optical-infrared telescope requires the smallest possible coefficient of thermal expansion (CTE) to minimize deformations under variations in ambient temperatures. 261 sleeves of Carpenter's Super Invar "32-5" alloy provide precise, thermally-matching support between the mirror and the telescope's computer-controlled tracking systems.





In solid solution ferrous based alloys, thermal expansion is significantly higher for alloys that have austenite crystal structures (face-centered cube structures), when compositions are such that the magnetic transition (Curie temperature) is below room temperature. These “non” magnetic compositions, like austenitic stainless steels, will exhibit thermal expansion coefficients of roughly  $9 \times 10^{-6}/^{\circ}\text{F}$  compared to carbon iron which has a thermal coefficient of greater than or equal to  $6 \times 10^{-6}/^{\circ}\text{F}$ .

The most common high expansion alloys have compositions that promote marginally stable austenite structures, by having “lean” nickel and chrome additions in iron. Carpenter’s High Expansion “22-3” alloy has nominally 22 percent nickel, 3 percent chrome, 0.1 percent carbon, balance iron and exhibits thermal coefficient of expansion greater than or equal to  $10 \times 10^{-6}/^{\circ}\text{F}$ . Our High Expansion “19-2” alloy has 19 percent nickel, 2 percent chrome, and .50 percent carbon, balance iron with a thermal coefficient of expansion greater than or equal to  $11.0 \times 10^{-6}/^{\circ}\text{F}$ .

The iron-nickel-chrome high expansion alloys find wide application in thermostats because they have good fabricability, are compatible with low expansion iron-nickel alloys when heat treating, welding, or bonding, and they exhibit similar mechanical behavior.

There are instances when non-ferrous alloys, because of their lower melting points (having “weaker” crystal lattice bonds) have a significantly higher thermal expansion than ferrous alloys. These alloys provide an advantage when combined with very low expansion alloys as they promote greater flexing due to the greater differential of thermal expansion. A common non-ferrous alloy is Carpenter’s High Expansion “72”, which is nominally 72 percent manganese, 18 percent copper, and 10 percent nickel alloy having a thermal coefficient of expansion greater than  $14 \times 10^{-6}/^{\circ}\text{F}$ .

### Carpenter High Expansion Alloys

#### High Expansion “19-2” Alloy

Has been used as the high expansion component in thermostat bimetal applications.

#### High Expansion “22-3” Alloy

A high expansion alloy which has been used as the high expansion component in thermostat bimetal applications.

#### High Expansion “72” Alloy

A non-ferrous alloy which has been used as the high expansion component in thermostat bimetal applications.

Typical Properties of Carpenter High Expansion Alloys

| Properties                                              |                                       | High Expansion<br>"19-2"<br>(ASTM B-753) | High Expansion<br>"22-3"<br>(ASTM B-753) | High Expansion<br>"72"<br>(ASTM B-753) |
|---------------------------------------------------------|---------------------------------------|------------------------------------------|------------------------------------------|----------------------------------------|
| Type Analysis:                                          | Carbon                                | .50                                      | .10                                      | .05                                    |
|                                                         | Manganese                             | 1.00                                     | .50                                      | .72                                    |
|                                                         | Silicon                               | .25                                      | .25                                      | .20                                    |
|                                                         | Chromium                              | 2.2                                      | 3.1                                      | —                                      |
|                                                         | Nickel                                | 19                                       | 22                                       | 10                                     |
|                                                         | Other Elements                        | Fe Bal.                                  | Fe Bal.                                  | Cu 18<br>Fe Bal.                       |
| Physical Constants:                                     | Specific Gravity                      | 8.10                                     | 8.18                                     | 7.21                                   |
|                                                         | Thermal Conductivity W/m-°C           | —                                        | —                                        | 8                                      |
|                                                         | Electrical Resistivity:<br>Microhm-cm | 79                                       | 77                                       | 175                                    |
|                                                         | Curie Temperature, °C                 | None                                     | None                                     | None                                   |
|                                                         | Specific Heat, cal/g-°C               | —                                        | —                                        | 0.13                                   |
| Typical Coefficients of Thermal Expansion (As Annealed) | 25°C to 93°C                          | 20.0                                     | 19.6                                     | 27.0                                   |
|                                                         | 149°C                                 | 20.2                                     | 19.6                                     | 27.7                                   |
|                                                         | 260°C                                 | 20.2                                     | 19.8                                     | 29.0                                   |
|                                                         | 371°C                                 | 20.3                                     | 19.8                                     | 29.9                                   |
| (x 10 <sup>-6</sup> /°C)                                | 75°F to 200°F                         | 11.1                                     | 10.9                                     | 15.0                                   |
| (x 10 <sup>-6</sup> /°F)                                | 300°F                                 | 11.2                                     | 10.9                                     | 15.4                                   |
|                                                         | 500°F                                 | 11.2                                     | 11.0                                     | 16.1                                   |
|                                                         | 700°F                                 | 11.3                                     | 11.0                                     | 16.6                                   |
| Typical Mechanical Properties: (As Annealed)            | Tensile Strength, ksi (MPa)           | 80.0 (552)                               | 75.0 (518)                               | 60.0 (414)                             |
|                                                         | Yield Strength, ksi (MPa)             | 45.0 (310)                               | 40.0 (276)                               | 30.0 (207)                             |
|                                                         | Elongation in 2"                      | 25                                       | 30                                       | >30                                    |
|                                                         | Hardness, Rockwell                    | B80                                      | B80                                      | B85                                    |
|                                                         | Elastic Modulus, Mpsi (kMPa)          | —                                        | 27.0 (186)                               | 18.0 (124)                             |

## General Characteristics of Carpenter High Expansion Alloys

The high expansion alloys are not hardenable by heat treatment. With cold work, High Expansion "22-3" alloy can exhibit yield strengths greater than 125 ksi, while High Expansion "19-2" alloy will strengthen to greater than 175 ksi yield. Annealing, to soften, can be accomplished by heating to approximately 1832°F (1000°C), and stress relieving is generally done at temperatures between 572 to 932°F (650 and 800°C). These alloys oxidize readily at high temperatures and are usually annealed in protective atmospheres or vacuums.

High Expansion "72" alloy, because of its low melting point, will anneal fully at temperatures between 1202 and 1472°F (650 and 800°C). Due to the high manganese content, oxidation at high temperatures is severe and care must be taken to protect the metal. Surface oxides are not readily removed by usual acid cleaning practices. Mechanical cleaning is required.

## Applications

High expansion alloys have been used primarily in the production of differential expansion thermostats. There are two major classifications. **Metallurgically Bonded Bimetal Thermostats** operate according to the differential expansion principle. There are two major types, with several variations of each. However, the most common are the bimetal strip and bimetal disc.

In the bimetal strip thermostat, two strips of dissimilar metals are bonded together. The unequal expansion rates of the two metals during temperature changes causes the strip to bend into an arc. This mechanical bending is used to control movement as in the making and breaking of electrical contacts.

Snap-action bimetal disc thermostats also operate around the principle of unequal expansion of two dissimilar, bonded metals. In this application, though, the metals are formed into a concave shape rather than a flat strip. As the temperature changes, expansion of the metal on one side is much greater than on the opposite side. If the temperature change is sufficient, the stress created overcomes the biasing stress formed in the disc, causing it to invert with a snap. When the temperature returns to normal, the process is reversed.

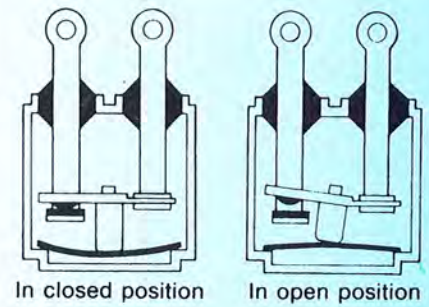
Cost is the primary advantage of both the bimetal strip and bimetal disc thermostats. They also have small mass, and respond rapidly when in heat contact with a circulating gas or liquid.

Typical applications for metallurgically bonded bimetal controllers include furnace controls, room thermostats and home appliances. Their maximum service temperature is about 800°F (427°C); and because bimetal elements are subject to corrosion they are generally provided with a protective housing.

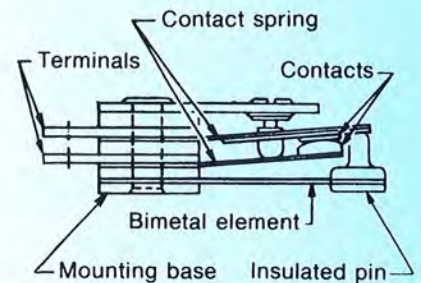
The other major category of thermostats is the **Mechanically Linked** type which has only one metal directly exposed to the temperature medium, with the expansion or contraction converted to a switching action.

The most typical mechanically linked thermostat is the strut-and-shell design. The high-expansion outer shell is linked mechanically to a pair of low-expansion internal struts.

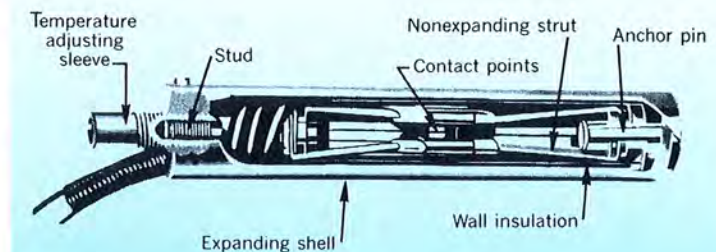
Mechanically linked differential expansion thermostats are used in presses, platens, ovens, baths, dryers, humidifiers and water jackets. Because their rapid response minimizes the effects of poor heat transfer they are commonly used as high and low temperature limit switches for protecting equipment and materials against damage.



A typical bimetal strip thermostat.



A snap action, bimetal-disc thermostat.



A strut-and-shell thermostat.

These alloys have thermal expansion characteristics compatible with certain glass and ceramic materials.

Glass and ceramics are a lot like steel . . . their physical and mechanical properties depend on their composition which can be modified to make the material soft or hard, tough or brittle depending on the application. As a matter of fact, glass and ceramics are often annealed or stress-relieved by heat treatment just as steel is, to increase toughness.

Glass also expands when heated and shrinks as it is cooled. The amount of expansion depends on the composition of the glass. However, it is usually less than the amount that conventional metals expand over the same temperature range. To make a glass-seal with an alloy, you must select a grade whose thermal expansion is about the same as the glass.

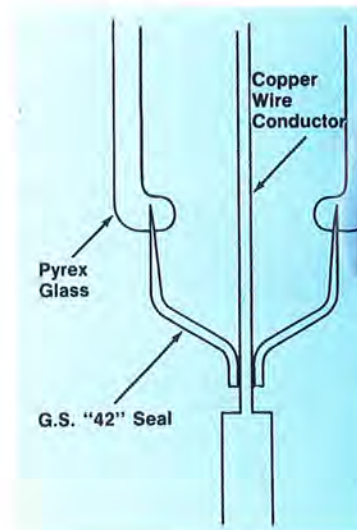
This expansion characteristic allows metal-to-glass fusion in hermetically sealed envelopes. The glass/metal interface is heated until the glass becomes molten. Upon cooling, the glass sets. As cooling continues, the glass reaches its strain point which is defined as the highest temperature from which stress-free glass can be cooled without introducing permanent strain. It is particularly important that the glass and metal expansion/contraction characteristics are similar below the strain point temperature. Where there are excessive differences between the materials being sealed, the stresses generated below the strain point will result in glass breakage.

Some selection criteria to consider for glass and ceramic sealing applications are:

**1. Glass Expansion:** "Soft" glasses (like potash soda lime glass) have expansion coefficients in the range of  $4$  to  $6 \times 10^{-6}/^{\circ}\text{F}$ , while "hard" (borosilicate) glasses have lower thermal expansion coefficients of approximately  $1.5$  to  $3.0 \times 10^{-6}/^{\circ}\text{F}$ . Kovar alloy has been used for sealing to many "hard" (borosilicate) glass types, while Glass Sealing "52" alloy has been used for many "soft" (potash soda lime) glasses.

**2. Design of the Seal:** Some mismatch between metal and glass can be accommodated by use of thin metal sections so that the stress developed by the expansion mismatch is absorbed by the ductility of the metal component.

**3. Package Requirements:** Seals that contain high-vacuum, or pressured envelopes, may require selection of a metal that not only matches glass expansion but promotes a suitable surface oxide to enhance the bond strength between metal and glass. Iron-chrome

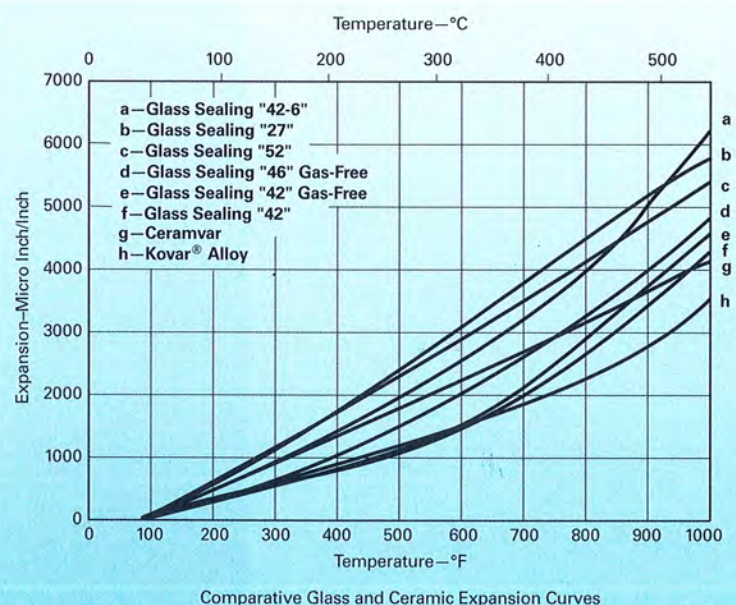
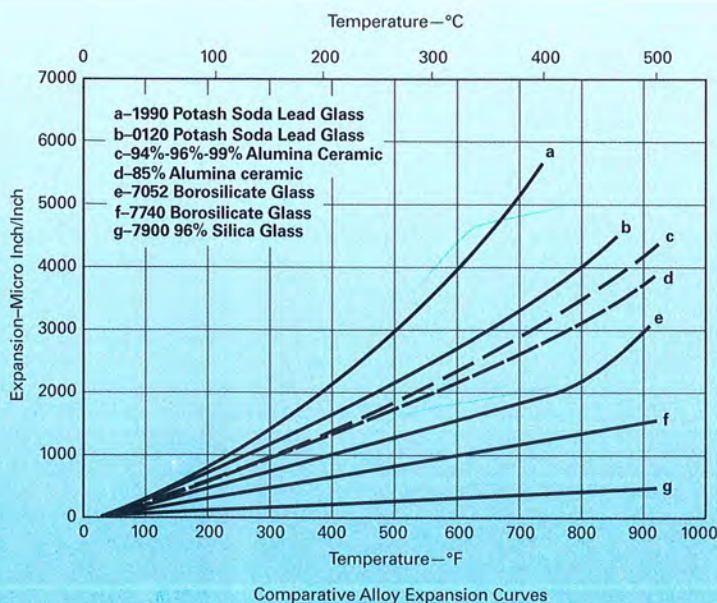


alloys such as Glass Sealing "27" and Glass Sealing "42-6" (iron-nickel-chrome) alloys provide this characteristic. The general practice is to pre-oxidize the metal parts by thermal treating prior to the glass sealing.

Even after an alloy is selected which most closely matches the expansion rate of the glass to be used, the seal must be carefully designed so that it remains air tight. In addition, component part preparation is important. Glass and metal surfaces must be clean and free of contamination. Surface irregularity in metal components could result in leak paths. Gas bubbles formed by contamination at the metal-glass interface could also cause "leakers".

**4. Ceramic Sealing:** As operating temperature, power dissipation requirements and mechanical environments have become more severe, the use of ceramic-to-metal seals for all types of electronic devices has increased substantially. These seals have often consisted of a metallized and plated alumina (nominal 96%  $\text{Al}_2\text{O}_3$ ) or beryllia (nominal 99%  $\text{BeO}$ ) brazed to a Kovar alloy member.

Ceramic parts are often produced by their manufacturer with a metallized surface. In the case of alumina, the "moly-manganese" process is the most widely used. The metallized-ceramic/metal assemblies are brazed in continuous, or batch-type furnace equipment with a controlled reducing atmosphere. Consistently well-brazed joints are obtainable by proper adjustment of temperature, time, atmosphere and fixturing.



## Carpenter Glass and Ceramic Sealing Alloys

### Glass Sealing "42" Alloy

Has been used for integrated circuit lead frames and some selected glass-metal sealing applications.

### Glass Sealing "42" Gas-Free Alloy

Has been used for automotive and industrial lamps and terminals for enameled resistors and without prior thermal treatment, in making bubble-free glass-metal seals.

### Glass Sealing "42-6" Alloy

Has been used for sealing to Corning 0120 glass. A special thermal treatment develops a tightly adherent oxide beneficial to obtaining hermetic seals.

### Glass Sealing "46" Gas-Free Alloy

Has been used for terminal bands in enameled resistors and for enameling without degasification.

### Glass Sealing "51" Gas-Free Alloy

Has been used for contact blades in dry reed switches.

### Glass Sealing "52" Alloy

Has been used for sealing to soft glasses such as in the lead wire for mercury switches and semiconductor devices.



Typical Properties of Carpenter Glass & Ceramic Sealing Alloys

| Properties                                                                                                |                                                                                                                                              | Glass Sealing<br>"42"<br>(ASTM F-30)                               | Glass Sealing<br>"42"<br>Gas Free                                  | Glass Sealing<br>"46"<br>Gas Free<br>(ASTM F-30)                   |
|-----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|
| Type Analysis:                                                                                            | Carbon<br>Manganese<br>Silicon<br>Chromium<br>Nickel<br>Other Elements                                                                       | <.02<br>.50<br>.25<br>—<br>40.5<br>Fe Bal.                         | <.02<br>.50<br>.25<br>—<br>41<br>Ti .40<br>Fe Bal.                 | <.05<br>.50<br>.25<br>—<br>46<br>Ti .20<br>Cb .20<br>Fe Bal.       |
| Physical Constants:                                                                                       | Specific Gravity<br>Thermal Conductivity W/m-°C<br>Electrical Resistivity:<br>Microhm-cm<br>Curie Temperature, °C<br>Specific Heat, cal/g-°C | 8.12<br>15<br>72<br>380<br>0.12                                    | 8.12<br>15<br>72<br>380<br>0.12                                    | 8.17<br>16<br>46<br>460<br>0.12                                    |
| Typical Coefficients of Thermal Expansion (As Annealed) (x 10 <sup>-6</sup> /°C) (x 10 <sup>-6</sup> /°F) | 25°C to 200°C<br>300°C<br>400°C<br>450°C<br>500°C<br>75°F to 392°F<br>572°F<br>752°F<br>842°F<br>932°F                                       | 4.2<br>4.4<br>6.2<br>7.1<br>8.1<br>2.3<br>2.4<br>3.4<br>3.9<br>4.5 | 4.4<br>4.6<br>6.6<br>7.7<br>8.5<br>2.4<br>2.6<br>3.7<br>4.3<br>4.7 | 7.4<br>7.9<br>7.8<br>8.1<br>8.5<br>4.1<br>4.4<br>4.3<br>4.5<br>4.7 |
| Typical Mechanical Properties: (As Annealed)                                                              | Tensile Strength, ksi (MPa)<br>Yield Strength, ksi (MPa)<br>Elongation in 2"<br>Hardness, Rockwell<br>Elastic Modulus, Mpsi (kMPa)           | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>21.5 (148)                | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>21.0 (144)                | 75.0 (517)<br>40.0 (276)<br>27<br>B80<br>23.0 (159)                |

### Kovar® Alloy

(also known as Rodar® alloy)

A low expansion alloy which has been widely used for making hermetic seals with the harder Pyrex glass and ceramic materials such as in power tubes, microwave tubes, transistors, and diodes, as well as integrated circuits.

### Glass Sealing "18" Alloy

Ductile iron-chromium alloy which has been used in high volume glass-to-metal sealing applications such as stud pins, fluorescent feed-throughs and monitor support members.

### Glass Sealing "27" Alloy

Ductile chromium-iron alloy which has been used for strong glass-to-metal seals in electronic and vacuum tubes, incandescent and fluorescent lamps. It exhibits no phase transformation up to 2100°F (1150°C).

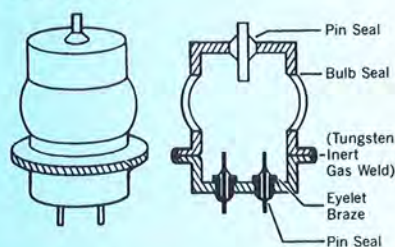
### Ceramvar® Alloy

An iron, nickel, cobalt alloy specially designed and suited for ceramic-to-metal sealing. It has expansion characteristics closely matching those of high temperature alumina ceramics.



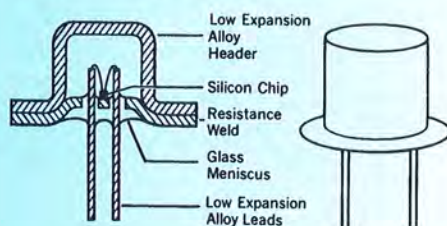
| Vacumet<br>Glass Sealing<br>"51"<br>Gas Free<br>(ASTM F-30)             | Glass Sealing<br>"52"<br>(ASTM F-30)                                  | Glass Sealing<br>"42-6"<br>(ASTM F-31)                               | Kovar® Alloy<br>(ASTM F-15)                                        | Ceramvar®<br>Alloy<br>(ASTM F-1466)                                | Glass Sealing<br>"18"<br>(ASTM F-256)                                  | Glass Sealing<br>"27"<br>(ASTM F-256)                                   |
|-------------------------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------------------|
| <.01<br>.50<br>.25<br>—<br>51<br>Fe Bal.                                | <.01<br>.50<br>.25<br>—<br>50.5<br>Fe Bal.                            | <.07<br>.50<br>.25<br>5.5<br>42<br>Fe Bal.                           | <.02<br>.30<br>.20<br>—<br>29<br>Co 17<br>Fe Bal.                  | <.05<br>.30<br>.20<br>—<br>27<br>Co 25<br>Fe Bal.                  | <.10<br>.60<br>.40<br>18<br>.5<br>Ti .4<br>Fe Bal.                     | <.10<br>.60<br>.40<br>28<br>.5<br>Fe Bal.                               |
| 8.30<br>18<br>43<br>530<br>0.12                                         | 8.30<br>18<br>43<br>530<br>0.12                                       | 8.12<br>13<br>95<br>295<br>0.12                                      | 8.36<br>17<br>49<br>435<br>0.11                                    | 8.40<br>17<br>37<br>525<br>0.11                                    | 7.70<br>22<br>60<br>680<br>0.11                                        | 7.60<br>23<br>63<br>610<br>0.14                                         |
| 10.2<br>10.2<br>10.2<br>10.1<br>10.1<br>5.7<br>5.7<br>5.7<br>5.6<br>5.6 | 10.1<br>10.1<br>10.0<br>9.9<br>9.9<br>5.6<br>5.6<br>5.5<br>5.5<br>5.5 | 6.9<br>7.9<br>9.9<br>10.5<br>11.2<br>3.8<br>4.4<br>5.5<br>5.8<br>6.2 | 5.2<br>5.1<br>4.9<br>5.3<br>6.2<br>2.9<br>2.8<br>2.7<br>2.9<br>3.4 | 8.7<br>8.4<br>8.0<br>7.8<br>7.7<br>4.8<br>4.7<br>4.4<br>4.3<br>4.3 | 9.9<br>10.4<br>10.8<br>11.1<br>11.3<br>5.5<br>5.8<br>6.1<br>6.2<br>6.3 | 10.0<br>10.3<br>10.5<br>10.7<br>11.0<br>5.5<br>5.7<br>5.8<br>5.9<br>6.1 |
| 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>24.0 (166)                     | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>24.0 (166)                   | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>23.0 (159)                  | 75.0 (517)<br>40.0 (276)<br>30<br>B80<br>30.0 (207)                | 75.0 (517)<br>40.0 (276)<br>30<br>B82<br>19.0 (131)                | 80.0 (552)<br>45.0 (310)<br>25<br>B82<br>29.0 (200)                    | 80.0 (552)<br>50.0 (345)<br>25<br>B85<br>30.0 (207)                     |

Bulb Assembly



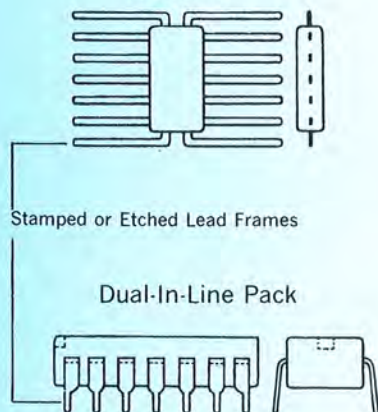
This typical "bulb assembly" illustrates the classical sealing concepts used in power tubes.

Hollow Base "TO" Package



A typical transistor or diode hermetic package—the so-called "TO" type, is illustrated here. This particular design is produced in high volume and at a low cost. A number of multi-pin versions of this package type are used for integrated circuits.

Flat Pack



Integrated circuit package types.

## Glass and Ceramic Sealing Alloy Applications

Glass and ceramic sealing alloys have been used in a wide range of applications where their unique physical properties make them the intelligent choice. Examples of applications in which they have been used are image converters, intensifiers, and visual displays. Devices capable of producing presentations from a variety of incident radiation (including infrared, x-ray, neutrons or low-level visual information) require ultra-high vacuum envelopes. These envelopes must be able to withstand extremes of shock, vibration and temperature.

"Frequency determining" crystals also require packaging which isolates them from their environment while maintaining dimensional stability over a wide range of temperatures.

Certain structural glass systems such as vacuum equipment, cryogenic pumps and flasks, as well as devices mounted to these systems, have also utilized Kovar alloy for flanges and junctions and other intermediate metal members.

**Power Tubes:** Most of today's power tube market uses sealing alloys in either glass- or ceramic-to-metal construction. They have been used as power amplifiers in such diverse applications as radio and television transmitters, induction heating equipment, and navigation aids. Applications also include other types of communication equipment, such as relay links and teletypes.

**Microwave Tubes:** These thermoionic electron devices include duplexers, klystrons, magnetrons and traveling wave tubes. With the exception of duplexers which function as microwave switches, these devices translate kinetic energy directly into electromagnetic energy at microwave frequencies and have served as oscillators, amplifiers and converters.

Radar, scatter propagation systems, electronic counter-measure equipment, planetary navigation systems, and satellite communication links are only possible because of the development of microwave tubes.

In addition to using the classical joining and sealing techniques, microwave tubes added design innovations of their own. The most significant innovation is the "window seal assembly," consisting of ceramics or specialized glasses framed into windows which serve as output parts on the tube. While in operation, severe thermal stresses frequently develop in the window due to the dissipation of transmission power. Thermally matched materials are mandatory in order to prevent tube failure.

**Transistors and Diodes:** A transistor is a non-thermoionic component with gain and band width capabilities comparable to those of the electron tube. A diode is a rectifier consisting of a

semi-conducting crystal with two terminals and is analogous in use to an electron tube diode.

**Integrated Circuits:** There are many package designs for these devices. Some, like flatpacks, hybrids and dual-in-line package utilize Carpenter Glass Sealing "42" alloy or Kovar alloy structure for access to, and isolation for, the semi-conducting chip and circuitry. Many of the metal components are fabricated by either chemically etching, multistage stamping thin strip, and forming or machining the enclosures or substrates.



## Forms Available

All the Carpenter controlled expansion alloys are available in various forms including bar, wire and strip.

### Strip Forms

Generally, controlled-expansion alloy strip is produced in the following conditions:

#### **Deep-Drawing-Quality**

**Strip:** A combination of non-directional mechanical properties and controlled grain size which promotes performance for deep drawing, and minimizes "orange peel".

#### **Stamping-Quality Strip:**

Produced as cold-rolled condition having a bright, clean surface and a rolled temper to promote efficiency in stamped parts having minimum burr.

The use of flat strip is necessary if a stamping process is to obtain the benefits of quantity production. Without the critical characteristics of flatness and minimum camber present in the strip, it is almost impossible to stamp quality electronic components.

**Coining-Quality Strip:** Strip with an intermediate temper to provide ease of coining and blanking "COINING-QUALITY" alloy strip has sufficient ductility for good metal flow in fabrication, which results in good tool life.

#### **Forming-Quality Strip:**

Annealed strip for forming and bending operations.

## Wire Forms

Controlled-expansion alloy wire is produced in all the standard size dimensions as well as cold-drawn fine and superfine diameters and some ribbon sizes. These alloys can also be produced as shaped wire in a variety of finished dimensions and shapes.

## Bar Forms

Cold-finished bars are produced in straight lengths, with cold drawn, centerless ground or precision ground surfaces; hot finished bars are available in rectangular, round or square configurations.

## Other Forms

Billets, which have usually been used for forging, and plates are available.



**Carpenter...**

## ***A Leader in Specialty Alloys Production and Distribution***

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### **Over a Century of Specialty Alloys Production**

For more than 110 years, high-performance specialty alloys from Carpenter have been meeting the difficult challenges of advancing technologies. That's why designers and fabricators have specified our alloys when they require the highest standards of quality and performance for their products.

### **A Commitment to Capital Expansion**

Carpenter consistently invests in the most advanced specialty alloys production technologies. Our production and systems technologies have significantly contributed to innovation in our industry.

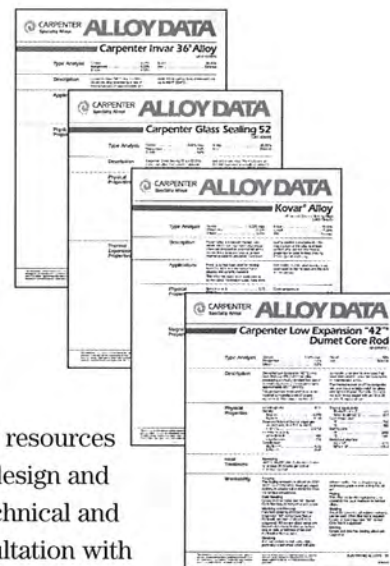
### **Advanced Manufacturing and Quality Systems**

Carpenter's manufacturing equipment is designed to minimize material handling operations and reduce manufacturing lead-times. Computerized in-line process controls automatically adjust for variations and verify product quality. Our continuing commitment to variation reduction involves teams which strive to improve operations throughout the company.

Our advanced manufacturing and quality systems enable us to meet... or exceed... a wide-range of customer requirements and industry specifications, including ASTM, AMS, DIN and TÜV.



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## Technical Support

Carpenter is prepared to provide the resources and staff to work closely with your design and manufacturing teams. Our broad technical and metallurgical support includes consultation with Regional Metallurgists in the field, plus Application Engineers and R&D specialists at the mill.

We also offer an extensive library of technical data covering the attributes and usage of our products.

Application engineering assistance for controlled expansion alloys is available by calling **610-208-2705**.

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Our unique international network of sales and service centers is staffed with skilled customer service professionals who can assist in alloy selection, arrange metallurgical field consultations, as well as provide availability, pricing and delivery information.

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In Canada: 800-268-4740  
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Metal Centres Ltd.  
Mundhwa, Pune-36  
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Carpenter Technology (Taiwan) Ltd.  
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FAX: 65.734.7983

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**CARPENTER**  
Specialty Alloys

Carpenter Technology Corporation  
Wyomissing, PA, 19610 U.S.A.

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