

# APPLICATION DATA SHEET

COPPER • BRASS • BRONZE

## LOW-TEMPERATURE PROPERTIES OF COPPER AND COPPER ALLOYS

Copper and copper alloys were the first metals used in the fabrication of low-temperature equipment for liquefaction and storage of cryogenic fluids. Copper and many copper alloys retain excellent ductility at low temperatures. This plus their good thermal conductivity makes an unusual combination of properties for heat exchangers and other components in cryogenic plants and in low-temperature processing and storage equipment. Low-temperature property data are

available for two coppers and twelve copper alloys as listed in Table 1.

The data in Table 2 indicate that the yield strength, tensile strength, and elongation increase as the testing temperature is reduced from room temperature to liquid-hydrogen temperature (-423 F). Selected tensile data are shown graphically in Figures 1 and 2. The elastic modulus and notched strength ( $K_t = 5.0$ ) also increase as the temperature is reduced. The impact energy for the fracturing of

TABLE 1. STANDARD DESIGNATIONS FOR COPPER AND COPPER ALLOYS FOR WHICH LOW-TEMPERATURE PROPERTY DATA ARE AVAILABLE <sup>(1)</sup>

| Copper or<br>Copper Alloy<br>Number | Common Name   | Composition, Per Cent Maximum <sup>(a)</sup> |      |         |         |      |                              |                   |
|-------------------------------------|---|--|------|---------|---------|------|------------------------------|-------------------|
|                                     |   | Copper                                       | Lead | Iron    | Tin     | Zinc | Additional Named<br>Elements | Other<br>Elements |
| 102                                 | Oxygen Free Copper  | 99.95 <sup>(b)</sup>                         |      |         |         |      |                              |                   |
| 122                                 | Phosphorus Deoxidized Copper,<br>High Residual Phosphorus | 99.90 <sup>(b)</sup>                         |      |         |         |      | 0.015-0.040P                 |                   |
| 172                                 | Beryllium Copper  | 99.5 <sup>(c)</sup>                          |      | (d)     |         |      | 1.8-2.0Be                    |                   |
| 175                                 | Beryllium Copper  | 99.5 <sup>(c)</sup>                          |      | 0.10    |         |      | 2.2-3.0Co, 0.40-0.8Be        |                   |
| 230                                 | Red Brass 85%   | 84.0-86.0                                    | 0.05 | 0.05    |         | Rem  |                              | 0.15              |
| 260                                 | Cartridge Brass 70%<br>(70-30 Brass)                      | 68.5-71.5                                    | 0.07 | 0.05    |         | Rem  |                              | 0.15              |
| 443                                 | Admiralty Arsenical                                       | 70.0-73.0                                    | 0.07 | 0.06    | 0.8-1.2 | Rem  | 0.02-0.10As                  | 0.15              |
| 464                                 | Naval Brass   | 59.0-62.0                                    | 0.20 | 0.10    | 0.5-1.0 | Rem  |                              | 0.10              |
| 510                                 | Phosphor Bronze 5% A                                      | 99.5 <sup>(e)</sup>                          | 0.05 | 0.10    | 3.5-5.8 | 0.30 | 0.03-0.35P                   |                   |
| 521                                 | Phosphor Bronze 8% C                                      | 99.5 <sup>(e)</sup>                          | 0.05 | 0.10    | 7.0-9.0 | 0.20 | 0.03-0.35P                   |                   |
| 614                                 | Aluminum Bronze D   | 99.5 <sup>(c)</sup>                          |      | 1.5-3.5 |         |      | 6.0-8.0Al, 1.0Mn             |                   |
| 647                                 | Copper Nickel Silicon                                     | 99.5 <sup>(c)</sup>                          | 0.10 | 0.10    |         | 0.50 | 1.6-2.2Ni, 0.4-0.8Si         |                   |
| 655                                 | High Silicon Bronze A                                     | 99.5 <sup>(c)</sup>                          | 0.05 | 0.8     |         | 1.5  | 0.6Ni, 1.5Mn, 2.8-3.8Si      |                   |
| 715                                 | Copper Nickel 30%   | 99.5 <sup>(c)</sup>                          | 0.05 | 0.4-0.7 |         | 1.0  | 29.0-33.0Ni, 1.0Mn           |                   |

(a) Maximum unless shown as range or minimum.

(b) Copper plus silver, minimum amount.

(c) Copper plus silver plus elements with specific limits, minimum amount.

(d) Nickel and/or cobalt 0.20 minimum; nickel plus cobalt plus iron 0.60 maximum.

(e) Copper plus tin plus phosphorus, minimum amount.

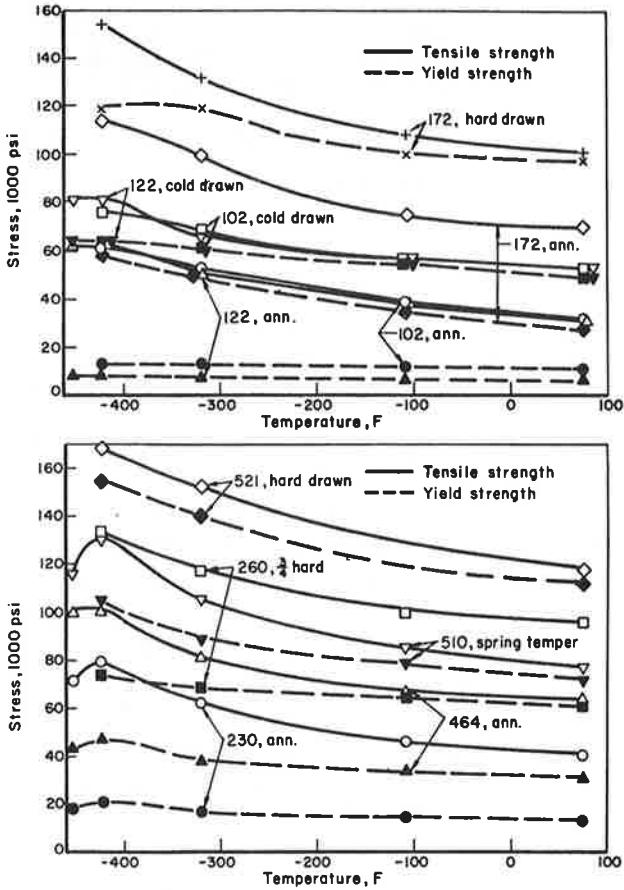


FIGURE 1. TENSILE AND YIELD STRENGTHS OF COPPER AND COPPER ALLOY BAR STOCK AT LOW TEMPERATURES (See Table 2)

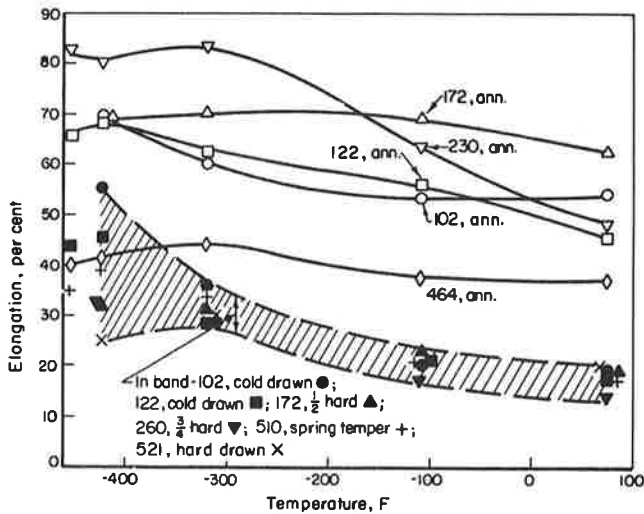


FIGURE 2. ELONGATION FOR TENSILE SPECIMENS OF BAR STOCK (See Table 2)

notched specimens (Table 3) also remains at high levels for many of the alloys at temperatures as low as -418 F. These data represent average values from two or more tests on longitudinal specimens of the wrought product. Selected impact data are plotted in Figure 3.

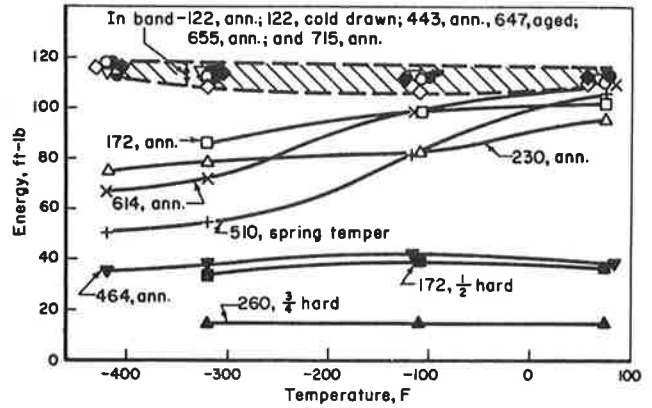


FIGURE 3. IMPACT ENERGY FOR CHARPY SPECIMENS FROM BAR STOCK

(All specimens were V-notch, except for Alloy No. 172, which was U-notch)  
(See Table 3)

The fatigue properties of copper and copper alloys also increase as the testing temperature is reduced to -423 F or -452 F. Data for small axial-loaded round-bar specimens are plotted in Figure 4. Data for fatigue tests on flexure specimens of sheet of Copper Alloy Numbers 172 and 260 are presented in Figure 5.

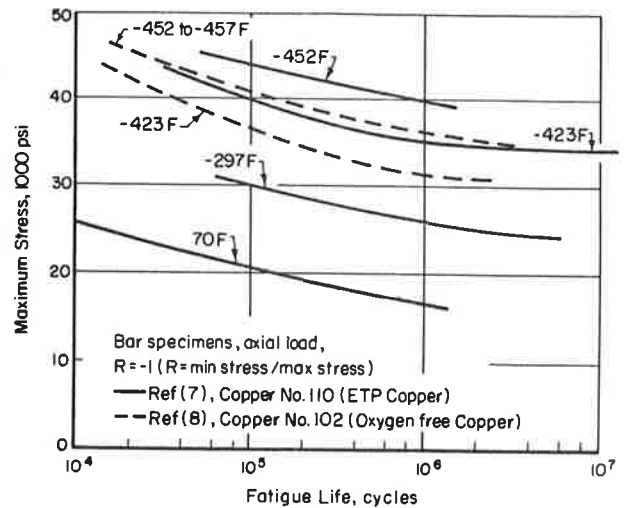


FIGURE 4. FATIGUE PROPERTIES OF ANNEALED COPPER AT LOW TEMPERATURES (6)

TABLE 2 TENSILE PROPERTIES OF COPPER AND COPPER ALLOYS AT LOW TEMPERATURES

| Copper or<br>Copper<br>Alloy<br>Number | Common Name  | Condition   | Test<br>Temperature,<br>F | Yield<br>Strength, <sup>(a)</sup><br>1000 psi | Tensile<br>Strength,<br>1000 psi | Elongation,<br>per cent | Reduction<br>in Area,<br>per cent | Elastic<br>Modulus,<br>1,000,000<br>psi | Notch<br>Strength<br>(K <sub>t</sub> = 5.0),<br>1000 psi | Reference |
|--|--|---|---------------------------|---|----------------------------------|-------------------------|-----------------------------------|---|--|-----------|
| 102                                    | Oxygen Free Copper   | Ann. bar, 0.75-<br>in. diam<br>(Rockwell H86)             | 75                        | 10.9  | 32.2                             | 53.8                    | 86.2                              |   |  | 2         |
|  |  |   | -108                      | 11.6  | 39.1                             | 53.2                    | 84.5                              |   |  |           |
|  |  |   | -320                      | 12.8  | 52.2                             | 60.1                    | 84.1                              |   |  |           |
|  |  |   | -423                      | 13.1  | 60.7                             | 68.9                    | 83.0                              |   |  |           |
| 102                                    | Oxygen Free Copper   | Ann. sheet,<br>0.010 in.                                  | 75                        | 10  | 32                               | 40                      | --                                |   |  | 3         |
|  |  |   | -320                      | 16  | 57                               | 52                      | --                                |   |  |           |
|  |  |   | -423                      | 20  | 65                               | 57                      | --                                |   |  |           |
| 102                                    | Oxygen Free Copper   | Cold-drawn bar,<br>0.75-in. diam.<br>(Rockwell B57)       | 75                        | 49  | 52                               | 19                      | 75                                | 18.6                                    |  | 3         |
|  |  |   | -108                      | 55  | 57                               | 20                      | 79                                | 19.9                                    |  |           |
|  |  |   | -320                      | 61  | 69                               | 36                      | 79                                | 20.2                                    |  |           |
|  |  |   | -423                      | 63  | 76                               | 55                      | 81                                | 21.2                                    |  |           |
| 122                                    | Phosphorus Deoxidized<br>Copper, High Re-<br>sidual Phosphorus | Ann. bar, 0.75-<br>in. diam                               | 75                        | 6.7   | 31.3                             | 45.3                    | 76.2                              | 15.1                                    | 43.3   | 4         |
|  |  |   | -108                      | 6.6   | 38.3                             | 56.0                    | 87.3                              | 16.0                                    | 50.4   |           |
|  |  |   | -320                      | 7.4   | 50.6                             | 62.4                    | 84.4                              | 16.2                                    | 62.3   |           |
|  |  |   | -423                      | 8.4   | 63.8                             | 68.2                    | 83.0                              | 16.3                                    | 72.0   |           |
|  |  |   | -452                      | 7.9   | 60.4                             | 65.3                    | 80.8                              | 16.4                                    | 74.7   |           |
| 122                                    | Phosphorus Deoxidized<br>Copper, High Re-<br>sidual Phosphorus | Cold-drawn bar,<br>0.75-in. diam                          | 75                        | 49.4  | 51.8                             | 17.0                    | 75.6                              | 18.9                                    | 81.0   | 4         |
|  |  |   | -108                      | 53.6  | 56.8                             | 20.8                    | 78.6                              | 19.9                                    | 86.8   |           |
|  |  |   | -320                      | 59.9  | 68.4                             | 28.3                    | 75.8                              | 20.3                                    | 99.8   |           |
|  |  |   | -423                      | 64.1  | 81.4                             | 45.5                    | 77.6                              | 20.8                                    | 108.6  |           |
|  |  |   | -452                      | 63.6  | 81.0                             | 43.6                    | 72.5                              | 21.1                                    | 109.3  |           |
| 172                                    | Beryllium Copper   | Ann. bar, 0.75-<br>in. diam<br>(Rockwell B55)             | 75                        | 27.4  | 69.9                             | 62.6                    | 79.6                              |   |  | 2         |
|  |  |   | -108                      | 34.7  | 74.9                             | 69.0                    | 79.0                              |   |  |           |
|  |  |   | -320                      | 49.4  | 99.0                             | 69.8                    | 72.8                              |   |  |           |
|  |  |   | -423                      | 58.2  | 117.2                            | 69.0                    | 69.8                              |   |  |           |
| 172                                    | Beryllium Copper   | 1/2-hard-drawn<br>bar, 0.75-in.<br>diam (Rockwell<br>B95) | 75                        | 96.7  | 101.8                            | 19.2                    | 68.0                              |   |  | 2         |
|  |  |   | -108                      | 100.1   | 108.4                            | 22.9                    | 69.8                              |   |  |           |
|  |  |   | -320                      | 118.8   | 131.9                            | 31.0                    | 66.0                              |   |  |           |
|  |  |   | -423                      | 119.0   | 153.8                            | 31.4                    | 60.0                              |   |  |           |
| 172                                    | Beryllium Copper   | 1/2 hard sheet,<br>0.125 in.<br>(Rockwell B98)            | 75                        | 80  | 90                               | 15                      | --                                | 17.5                                    |  | 3         |
|  |  |   | -108                      | 87  | 95                               | 20                      | --                                | 17.7                                    |  |           |
|  |  |   | -320                      | 100   | 117                              | 36                      | --                                | 18.8                                    |  |           |
|  |  |   | -423                      | 108   | 137                              | 45                      | --                                | 19.5                                    |  |           |
| 172                                    | Beryllium Copper   | A.T. sheet,<br>0.040 in.                                  | 75                        | 133   | 160                              | 4.5                     | --                                |   |  | 5         |
|  |  |   | -423                      | 191   | 218                              | 9.8                     | --                                |   |  |           |
| 175                                    | Beryllium Copper<br>(2.6Co)                                    | 1/2 hard sheet<br>0.125 in.<br>(Rockwell B73)             | 75                        | 51  | 60                               | 10                      | --                                | 19.5                                    |  | 3         |
|  |  |   | -108                      | 58  | 67                               | 19                      | --                                | 19.5                                    |  |           |
|  |  |   | -320                      | 64  | 82                               | 32                      | --                                | 20.0                                    |  |           |
|  |  |   | -423                      | 70  | 95                               | 49                      | --                                | 22.7                                    |  |           |
| 230                                    | Red Brass 85%  | Ann. bar, 0.75-<br>in. diam                               | 75                        | 13.0  | 40.4                             | 47.8                    | 73.8                              | 14.9                                    | 53.9   | 4         |
|  |  |   | -108                      | 14.0  | 46.5                             | 63.3                    | 78.9                              | 15.8                                    | 58.5   |           |
|  |  |   | -320                      | 16.4  | 62.0                             | 83.0                    | 76.7                              | 17.6                                    | 71.2   |           |
|  |  |   | -423                      | 20.9  | 79.2                             | 80.1                    | 75.2                              | 18.1                                    | 72.0   |           |
|  |  |   | -452                      | 18.3  | 71.0                             | 82.4                    | 70.8                              | 18.2                                    | 74.9   |           |
| 260                                    | Cartridge Brass 70%<br>(70-30 Brass)                           | 3/4 hard bar,<br>0.75-in. diam<br>(Rockwell B88)          | 75                        | 60.9  | 95.2                             | 14.2                    | 58.3                              |   |  | 2         |
|  |  |   | -108                      | 64.3  | 100.8                            | 17.3                    | 62.3                              |   |  |           |
|  |  |   | -320                      | 68.6  | 117.0                            | 28.4                    | 63.4                              |   |  |           |
|  |  |   | -423                      | 73.4  | 132.5                            | 32.2                    | 58.2                              |   |  |           |
| 464                                    | Naval Brass  | Ann. bar, 0.75-<br>in. diam                               | 75                        | 31.0  | 63.3                             | 36.8                    | 52.3                              | 14.0                                    | 74.7   | 4         |
|  |  |   | -108                      | 33.8  | 67.4                             | 37.4                    | 54.4                              | 14.5                                    | 84.8   |           |
|  |  |   | -320                      | 38.0  | 80.4                             | 44.2                    | 48.0                              | 14.8                                    | 100.7  |           |
|  |  |   | -423                      | 47.6  | 105.2                            | 41.4                    | 41.9                              | 15.0                                    | 113.9  |           |
|  |  |   | -452                      | 43.7  | 99.6                             | 40.0                    | 47.6                              | 15.1                                    | 115.4  |           |
| 510                                    | Phosphor Bronze<br>5% A  | Spring temper<br>bar, 0.75-in.<br>diam                    | 75                        | 72.0  | 77.4                             | 17.6                    | 77.6                              | 15.6                                    | 136  | 4         |
|  |  |   | -108                      | 78.7  | 85.6                             | 20.4                    | 78.2                              | 16.5                                    | 147  |           |
|  |  |   | -320                      | 89.2  | 105.2                            | 33.5                    | 67.4                              | 16.7                                    | 167  |           |
|  |  |   | -423                      | 104.8   | 131                              | 38.8                    | 61.5                              | 16.5                                    | 185  |           |
|  |  |   | -452                      | --  | 116                              | 34.3                    | 58.2                              | 16.4                                    | 185  |           |
| 521                                    | Phosphor Bronze<br>8% C  | Hard drawn bar,<br>0.75-in. diam<br>(Rockwell B100)       | 75                        | 112   | 118                              | 20                      | --                                | 16.0                                    |  | 3         |
|  |  |   | -320                      | 140   | 152                              | 30                      | --                                | 17.8                                    |  |           |
|  |  |   | -423                      | 154   | 168                              | 25                      | --                                | 18.0                                    |  |           |
| 655                                    | High Silicon Bronze A  | 1/4 hard sheet,<br>0.125 in.<br>(Rockwell B78)            | 75                        | 40  | 65                               | 50                      | --                                | 17                                      |  | 3         |
|  |  |   | -108                      | 42  | 72                               | 58                      | --                                | 17                                      |  |           |
|  |  |   | -320                      | 50  | 92                               | 64                      | --                                | 21                                      |  |           |
|  |  |   | -423                      | 54  | 107                              | 64                      | --                                | 19                                      |  |           |

(a) 0.2 per cent offset except for Copper No. 102 which is 0.1 per cent offset.

TABLE 3. IMPACT PROPERTIES OF COPPER AND COPPER ALLOYS AT LOW TEMPERATURES

| Copper or<br>Copper<br>Alloy<br>Number | Common Name  | Condition   | Type of<br>Specimen                 | Test<br>Temperature,<br>F | Energy<br>Absorbed,<br>ft-lb | Fracture<br>Area <sup>(a)</sup> ,<br>per cent | Reference |
|--|--|---|-------------------------------------|---------------------------|------------------------------|---|-----------|
| 102                                    | Oxygen Free Copper   | Ann. bar, 0.75-in.<br>diam (Rockwell<br>H86)              | 1/2 thickness,<br>V-notch<br>Charpy | 75                        | 52.5                         | 25  | 2         |
|  |  |   |                                     | -108                      | 57.0                         | 25  |           |
|  |  |   |                                     | -320                      | 65.5                         | 25  |           |
|  |  |   |                                     | -423                      | 63.5                         | 25  |           |
| 122                                    | Phosphorus Deoxidized<br>Copper, High Re-<br>sidual Phosphorus | Ann. bar, 0.75-<br>in. diam                               | V-notch<br>Charpy                   | 75                        | 111                          | 20  | 4         |
|  |  |   |                                     | -108                      | 112                          | 20  |           |
|  |  |   |                                     | -320                      | 112                          | 20  |           |
|  |  |   |                                     | -418                      | 119                          | 50  |           |
| 122                                    | Phosphorus Deoxidized<br>Copper, High Re-<br>sidual Phosphorus | Cold-drawn bar,<br>0.75-in. diam                          | V-notch<br>Charpy                   | 75                        | 112                          | 10  | 4         |
|  |  |   |                                     | -108                      | 112                          | 10  |           |
|  |  |   |                                     | -320                      | 112                          | 10  |           |
|  |  |   |                                     | -418                      | 119                          | 40  |           |
| 172                                    | Beryllium Copper   | Ann. bar, 0.75-<br>in. diam<br>(Rockwell B55)             | U-notch<br>Charpy                   | 75                        | 102                          | 50  | 2         |
|  |  |   |                                     | -108                      | 98.5                         | 50  |           |
|  |  |   |                                     | -320                      | 86.5                         | 75  |           |
| 172                                    | Beryllium Copper   | 1/2 hard-drawn<br>bar, 0.75-in.<br>diam (Rockwell<br>B95) | U-notch<br>Charpy                   | 75                        | 37.5                         | 75  | 2         |
|  |  |   |                                     | -108                      | 40.0                         | 75  |           |
|  |  |   |                                     | -320                      | 34.5                         | 100   |           |
| 172                                    | Beryllium Copper   | AT bar, 0.50-in.<br>diam                                  | 1/2 thickness,<br>V-notch<br>Charpy | 75                        | 5.5                          | 100   | 5         |
|  |  |   |                                     | -320                      | 4.7                          | 100   |           |
|  |  |   |                                     | -423                      | 5.0                          | 100   |           |
| 230                                    | Red Brass 85%  | Ann. bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 96.0                         | 95  | 4         |
|  |  |   |                                     | -108                      | 82.6                         | 95  |           |
|  |  |   |                                     | -320                      | 78.5                         | 95  |           |
|  |  |   |                                     | -418                      | 75.5                         | 95  |           |
| 260                                    | Cartridge Brass 70%<br>(70-30 Brass)                           | 3/4 hard bar,<br>0.75-in. diam<br>(Rockwell B88)          | V-notch<br>Charpy                   | 75                        | 15.5                         | 100   | 2         |
|  |  |   |                                     | -108                      | 15.5                         | 100   |           |
|  |  |   |                                     | -320                      | 15.5                         | 100   |           |
| 443                                    | Admiralty Arsenical  | Ann. bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 112                          | 10  | 4         |
|  |  |   |                                     | -108                      | 113                          | 10  |           |
|  |  |   |                                     | -320                      | 114                          | 10  |           |
|  |  |   |                                     | -418                      | 114                          | 10  |           |
| 464                                    | Naval Brass  | Ann. bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 38.8                         | 100   | 4         |
|  |  |   |                                     | -108                      | 41.3                         | 100   |           |
|  |  |   |                                     | -320                      | 37.4                         | 100   |           |
|  |  |   |                                     | -418                      | 35.2                         | 100   |           |
| 510                                    | Phosphor Bronze<br>5% A  | Spring temper bar,<br>0.75-in. diam                       | V-notch<br>Charpy                   | 75                        | 106                          | 95  | 4         |
|  |  |   |                                     | -108                      | 82.2                         | 95  |           |
|  |  |   |                                     | -320                      | 54.5                         | 95  |           |
|  |  |   |                                     | -418                      | 51.1                         | 95  |           |
| 614                                    | Aluminum Bronze D  | Ann. bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 110                          | 95  | 4         |
|  |  |   |                                     | -108                      | 99.3                         | 95  |           |
|  |  |   |                                     | -320                      | 71.5                         | 95  |           |
|  |  |   |                                     | -418                      | 66.5                         | 95  |           |
| 647                                    | Copper Nickel Silicon  | Aged bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 110                          | 90  | 4         |
|  |  |   |                                     | -108                      | 107                          | 90  |           |
|  |  |   |                                     | -320                      | 109                          | 50  |           |
|  |  |   |                                     | -418                      | 116                          | 25  |           |
| 655                                    | High Silicon Bronze A  | Ann. bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 112                          | 5   | 4         |
|  |  |   |                                     | -108                      | 112                          | 5   |           |
|  |  |   |                                     | -320                      | 114                          | 5   |           |
|  |  |   |                                     | -418                      | 116                          | 5   |           |
| 715                                    | Copper Nickel 30%  | Ann. bar, 0.75-in.<br>diam                                | V-notch<br>Charpy                   | 75                        | 115                          | 60  | 4         |
|  |  |   |                                     | -108                      | 114                          | 60  |           |
|  |  |   |                                     | -320                      | 114                          | 60  |           |
|  |  |   |                                     | -418                      | 114                          | 60  |           |

(a) If specimen did not separate into two pieces, the fracture area was less than 100 per cent.

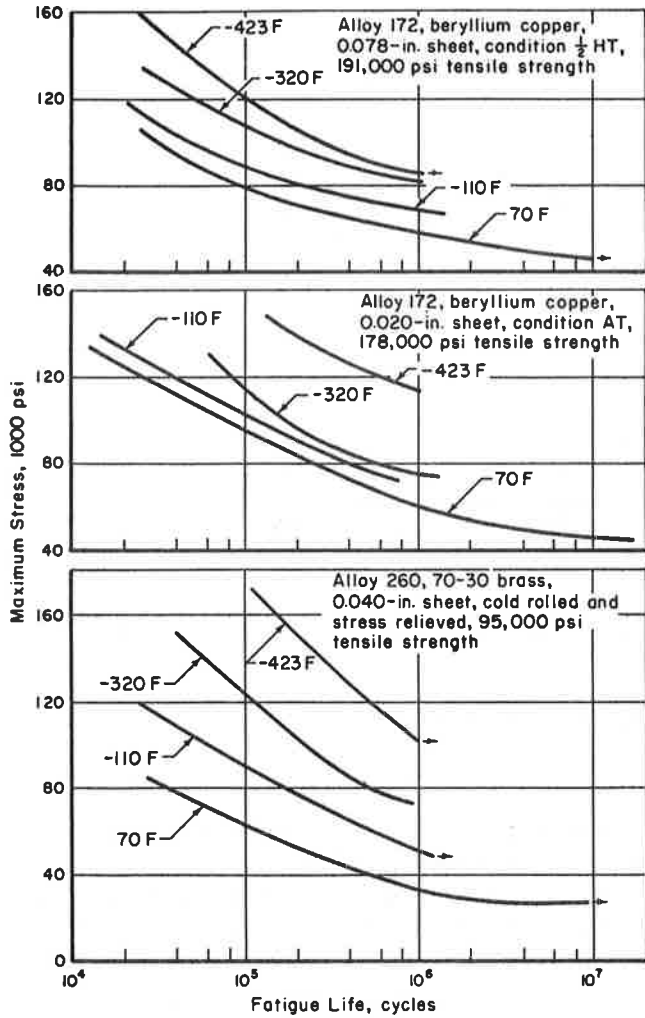


FIGURE 5. FATIGUE PROPERTIES OF COPPER ALLOYS AT LOW TEMPERATURES, SHEET SPECIMENS SUBJECTED TO FLEXURE TESTING WITH  $R = -1$  (6,9)

( $R$  = minimum stress/maximum stress; rate at 75, -110, and -320F was 1800 cpm, at -423F 3450 and 5175 cpm.)

Available data for thermal expansion, thermal conductivity, and electrical resistivity for copper at low temperatures are shown in Figures 6, 7, and 8, respectively. Corresponding data for the alloys are limited, but thermal-expansion data are shown for Alloy 260 and Alloy 172, and thermal conductivity data are shown for Alloy 260.

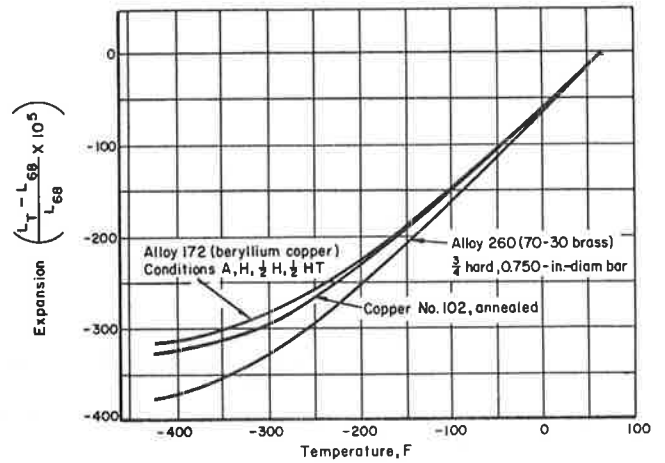


FIGURE 6. THERMAL EXPANSION OF COPPER AND COPPER ALLOYS AT LOW TEMPERATURES (6,10,11,12)

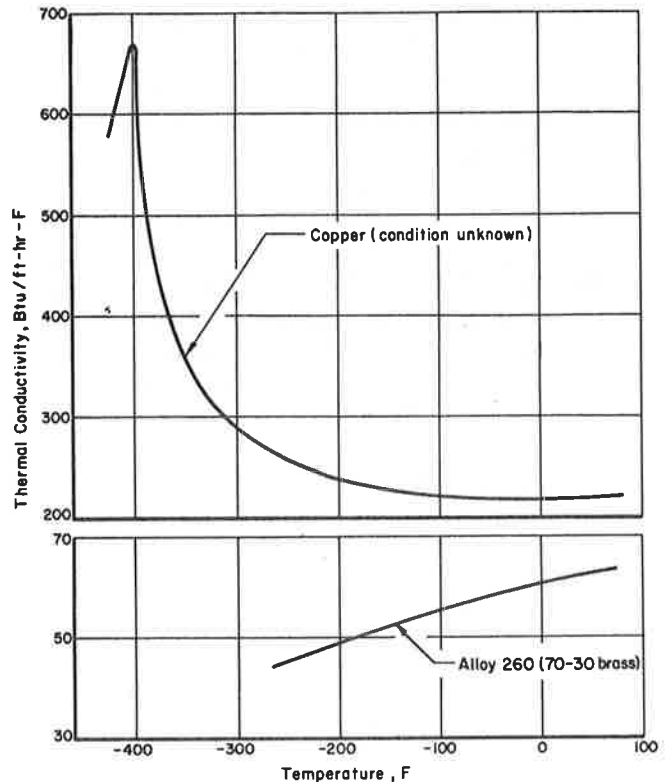


FIGURE 7. THERMAL CONDUCTIVITY OF COPPER AND COPPER ALLOY NO. 260 AT LOW TEMPERATURES (6)

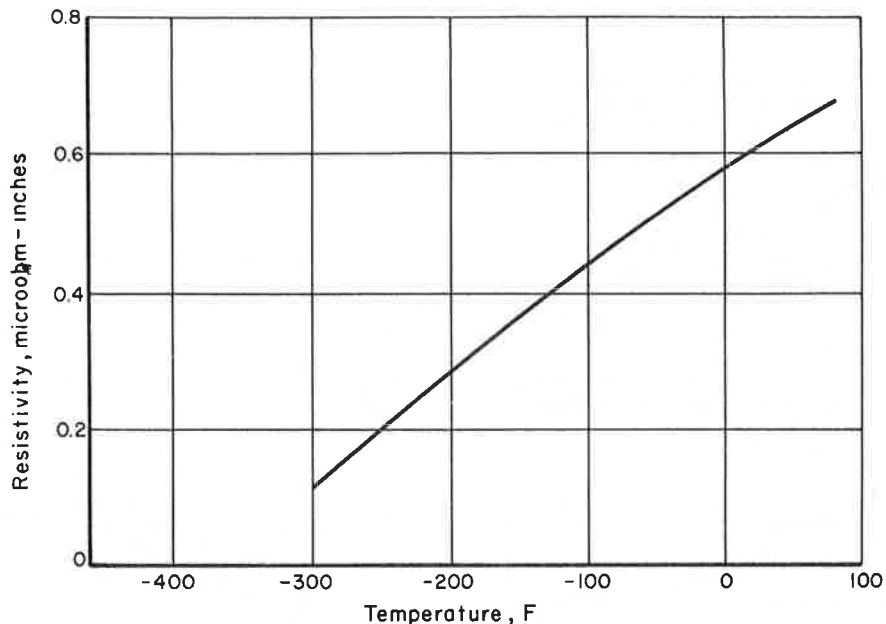


FIGURE 8. ELECTRICAL RESISTIVITY OF ANNEALED COPPER AT LOW TEMPERATURES (6)

(Composition: < 0.01 Cd, Pb, Ag, Si; << 0.01 Fe, Mg)

## REFERENCES

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