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Copper's Coefficient of Thermal Expansion Varies, But to Little Effect

As sheet metal gutter liners are exposed to the elements, the copper from which they are often constructed can experience large seasonal temperature swings.

Thermal movement in copper gutter liners and the incorporation of expansion joints

Thermally-induced movement can be substantial and must be accommodated with expansion joints (Figure 1) to avoid out-of-plane buckling, kinks, failed seams, and fatigue cracks. Such failures can undermine the gutter liner's performance and result in water leakage to the interior. Knowing how much a given length of gutter might move over an expected service temperature range is helpful in the design and installation of durable gutter liners that will accommodate thermally-induced movement. Specifically, such information allows the expansion space provided for in expansion assemblies to be sized properly.

All materials expand upon heating and contract upon cooling. The rate at which a specific material expands or contracts in response to a change in temperature is referred to as the coefficient of thermal expansion (α). Knowing the material-specific coefficient of thermal expansion, the change in length of an unconstrained material can be calculated as follows:

$$\Delta L = \alpha \cdot L_o \cdot \Delta T$$

Where,

- ΔL is the change in length
- α is the coefficient of thermal expansion
- L_o is the length of the object at the starting temperature
- ΔT is the change in temperature experienced by the object

FIGURE 1
A typical copper built-in gutter liner with an expansion joint at its high point

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The coefficient of thermal expansion for copper used in construction can be found within several sources. The Sheet Metal and Air Conditioning Contractor's National Association's (SMACNA's) *Architectural Sheet Metal Manual*, for example, lists cold-rolled copper's coefficient of thermal expansion as 0.0000094 in./in./°F (9.4×10^{-6}/°F).[1,2] Revere's *Copper and Common Sense* states copper's coefficient of expansion as 9.8×10^{-6}/°F.[3] The Copper Development Association (CDA) gives the same numerical value as Revere, but clarifies that it is applicable between the temperatures of 68°F and 572°F.[4] As suggested by the CDA's guidance, copper's coefficient of thermal expansion is not constant, but rather is dependent on temperature. Therefore, it is often given as an average over a specific temperature range (Table 1).[5] Table 2 shows copper's coefficient of thermal expansion for specific temperatures, a portion of which are more likely to be experienced on a building site (see highlighted rows). Using the data contained in Table 2, copper's average coefficient for a temperature range likely to be experienced by installed built-in gutters (-45°F to 155°F), calculates to 9.2×10^{-6}/°F, slightly lower than that provided by SMACNA, Revere, and CDA.[6]

The rate of thermal expansion generally increases with temperature. The relationship, however, is not linear (Figure 2). From -460°F (0°K) to about -100°F (200°K) the coefficient of thermal expansion increases rapidly, then the curve begins to flatten out from -100°F to 1970°F (1350°K).[8]

Although copper's variable coefficient of thermal expansion may not be commonly known, its practical impact on the design and performance of copper gutter liners is negligible. Using a constant coefficient of thermal expansion of 9.8×10^{-6}/°F, an

Average Coefficient of Linear Thermal Expansion (α) for Copper at various Temperature Ranges[7]

Temperature °C	Temperature °F	α (cm/cm/°C x 10^{-6})	α (in./in./°F x 10^{-6})
20 to 100	68 to 212	16.8	9.3
20 to 200	68 to 392	17.3	9.6
20 to 300	68 to 572	17.7	9.8
20 to 400	68 to 752	17.9	9.9
100 to 200	212 to 392	17.7	9.8
200 to 300	392 to 572	18.5	10.3
25 to 300	77 to 572	17.8	9.9

TABLE 1

Coefficient of Linear Thermal Expansion (α) for Copper at Specific Temperatures[9]

Temperature °K	Temperature °F	α (in./in./°K x 10^{-6})	α (in./in./°F x 10^{-6})
80	-316	8.370	4.65
100	-280	10.550	5.86
120	-244	12.111	6.73
140	-208	13.251	7.36
160	-172	14.095	7.83
180	-136	14.738	8.19
200	-100	15.243	8.47
220	-64	15.655	8.70
240	-28	16.000	8.89
260	8	16.292	9.05
280	44	16.541	9.19
300	80	16.759	9.31
320	116	16.960	9.42
350	170	17.14	9.52
400	260	17.56	9.76
450	350	17.93	9.96
500	440	18.27	10.15
550	530	18.59	10.33
600	620	18.91	10.51

TABLE 2

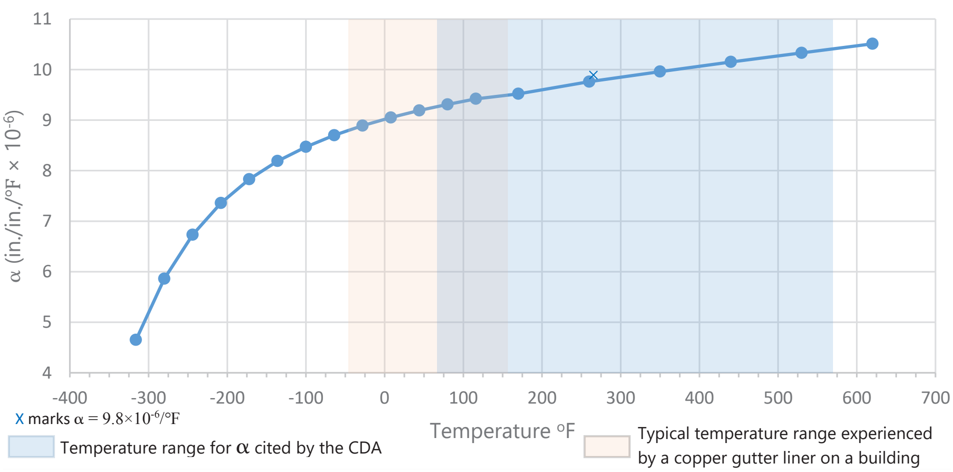

FIGURE 2

Coefficient of Expansion for Copper at the Specific Temperatures Contained in Table 2

unrestrained 10-foot long section of gutter liner will experience a change in length of approximately 0.235 inches over a 200°F temperature change.[10,11] Using the coefficients of thermal expansion shown in Table 2 from -45°F to 155°F, that same 10-foot long section of gutter liner will experience a change in length of approximately 0.219 inches. The difference, 0.016 inches, equates to approximately 1/64 inch, or about the thickness of two pieces of paper. Such a small dimension is of little consequence to the design or performance of a roofing project and certainly beyond the realm of construction tolerances, even when considering a 20- or 30-foot length of gutter.[12,13]

In sum, although the coefficient of thermal expansion associated with cold-rolled copper varies with temperature, the impact on a typical gutter liner is small. As such, use of a constant (average) coefficient of expansion for built-in copper gutter liners is practical and rational. Further, use of the higher coefficient published by Revere and CDA (9.8×10^{-6}/°F) will conservatively—yet reasonably—estimate thermally-induced movement.

References

1 *Architectural Sheet Metal Manual*, Seventh Edition, Sheet Metal and Air Conditioning Contractor’s National Association, Inc., Chantilly, VA: 2012, p.B.2.

2 Because a coefficient of thermal expansion is an indication of change in length per a unit length per a unit of temperature (e.g., inch/inch/°F, m/m/°C), the units of length are inconsequential as they cancel each other. As such, units for coefficient of thermal expansion can also be presented simply as per a unit of temperature (e.g., per °F or °C).

3 *Copper and Common Sense*, Eighth Edition, Revere Copper Products, Inc., Rome, NY: 2005, p.9.A.7

4 Copper Development Association, CDA Publication A4050-04/16: *Copper in Architecture Design Handbook*, Table 1.1.A Properties of Cold Rolled Copper, nd, p.10.

5 The same average coefficient can be derived from the data contained in Table 2 for the temperature range cited by CDA (68°F to 572°F). Interpolating the values for α at the low and high ends of the temperature range, the values for α between 68°F and 572°F are 9.27, 9.31, 9.42, 9.52, 9.76, 9.96, 10.15, and 10.41. Dividing the sum of theses coefficients of expansion (77.80) by eight, the average calculates to 9.73×10^{-6}/°F, which very closely approximates 9.8×10^{-6}/°F.

6 Interpolating the values for α at the low and high ends of the temperature range, the values for α between -45°F and 155°F are 8.78, 8.89, 9.05, 9.19, 9.31, 9.42, and 9.50. Dividing the sum of theses coefficients of expansion (64.14) by seven, the average calculates to 9.2×10^{-6}/°F.

7 Source, first four rows: Hidnert, Peter and Dickson, George, “Thermal Expansion of Some Industrial Copper Alloys,” *Research Paper RP1550, Journal of Research of the National Bureau of Standards*, V31, National Bureau of Standards, U.S. Department of Commerce, August 1943, p.81. Source, last four rows: Hidnert, Peter, “Thermal Expansion of Copper and Some of Its Important Industrial Alloys,” *Issue 410, Scientific Papers of the Bureau of Standards*, Washington, D.C.: U.S. Government Printing Office, 1921, p.151. In both instances data is in °C only.

8 Wang, Kai and Reeber, Robert R., “Thermal Expansion of Copper,” *High Temperature and Materials Science*, V35, 1996, p.184.

[9] Source, between 80K and 320K: Kroeger, Frederick Robert Jr., *The Absolute Thermal Expansion of Copper and Aluminum Between 5K and 330K*, Iowa State University, Ames, Iowa, PhD Dissertation, 1974, p.66. Source, between 350K and 600K: Wang, Kai and Reeber, Robert R., "Thermal Expansion of Copper," *High Temperature and Materials Science*, V35, 1996, p.1859

[10] The calculation is as follows: 200°F × 120" × 0.0000098 in./in./°F = 0.235"

[11] It should be noted that whereas many design manuals assume a 100-degree change in temperature, in many parts of the United States, a 200-degree seasonal temperature change is a more prudent assumption given winter nighttime radiative cooling lows and summer direct sunlight highs well below and above ambient temperatures, respectively.

[12] For gutter lengths that are multiples of ten feet, simply multiply by whatever the multiple is in order to derive the change in length and the difference in change in length. Thus, had the gutter length been 20-feet instead of 10-feet in the two examples given, the changes in length would have been 0.470" and 0.438", respectively, and the difference between the two about 2/64" (roughly the thickness of a thumbnail).

[13] This may not always be the case for other materials used in construction, such as steel members, where the variable nature of the coefficient of thermal expansion can be important.

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