"Stresses (compressive, tensile, or shear) due to unequal temperature distribution and non-uniform temperature gradients, cause more failures in high-temperature equipment than all other influences combined amounting to approximately 90% of the total number of cases. It is destructive chiefly because the engineer does not include in his design proper allowance for or provision against temperature inequalities or because the operator imposes temperature differentials which cause localized dimensional changes with accompanying stresses greater than the elastic strength of the alloy at the given temperature."

F. A. Fahrenwald. Some Principals Underlying the Successful Use of Metals at High Temperatures, Proceedings of ASTM, 1924 V. 24

Little has changed over the last 90 years. The vast majority of failures reported to Rolled Alloys, involving breaking or deformation in service, are due to restraint of thermal expansion. For successful design and installation of high temperature equipment it is critical to take thermal expansion into account, and to be able to calculate the amount of expansion to be expected. Below is a simple table for calculating total expansion, in inches per foot of length, for a given temperature.

Thermal Expansion

Total Thermal Expansion, inches/foot

Temp, °F	Carbon Steel	446	304	309	310	RA 253 MA	RA330	RA333	601	600	RA 602 CA
70-200	0.0139	0.00874	0.0145	0.0137	0.0131	0.0141	0.0129	0.0109	0.0119	0.0115	0.0103
70-400	0.0376	0.0225	0.0372	0.0356	0.0348	0.0370	0.0341	–	0.0317	0.0305	0.0297
70-600	0.0623	–	0.0604	0.0591	0.0569	0.0610	0.0566	–	0.0516	0.0502	0.0496
70-800	0.0885	0.0526	0.0876	–	0.0806	0.0859	0.0797	–	0.0727	0.0710	0.0710
70-1000	0.0904	0.0681	0.115	0.108	0.106	0.111	0.104	0.0960	0.0949	0.0937	0.0915
70-1200	0.113	0.0854	0.144	–	0.133	0.137	–	0.122	0.120	0.117	0.115
70-1400	–	0.102	0.174	–	0.160	0.164	–	0.148	0.147	0.142	0.144
70-1600	–	0.123	–	0.185	0.186	0.193	0.180	0.173	0.175	0.167	0.174
70-1800	–	0.152	–	–	0.214	0.224	0.208	0.201	0.204	0.193	0.201
70-2000	–	–	–	–	0.245	–	–	–	0.236	–	0.227

To convert these numbers to the metric system, multiply by 83.33 to get millimeters of expansion for every meter of length, for the stated temperature, which is in Fahrenheit

For an example of how to use this table, consider a 20 foot long muffle made of RA330, operating at 1800°F. Read 0.208 inch/ft from the chart above, multiply by 20 feet for a total expansion of 4.16 inches

The more general way to calculate thermal expansion is to use the mean coefficients of thermal expansion, such as those given on the next page.

To use the table on page 2, multiply the length of the part in inches, times the difference between room temperature and operating temperature, times the expansion coefficient. Note that these coefficients are all multiplied by 10^{-6}, which is the same as dividing by one million.

For example, consider that 20 foot long muffle made of RA330, operating at 1800°F:

$$20 \text{ feet} \times 12 \text{ inches/foot} \times (1800\text{-}70°F) \times 10.0\times10^{-6} = 240 \text{ inches} \times 1730°F \times 10\times10^{-6} = 4.152 \text{ inches.}$$

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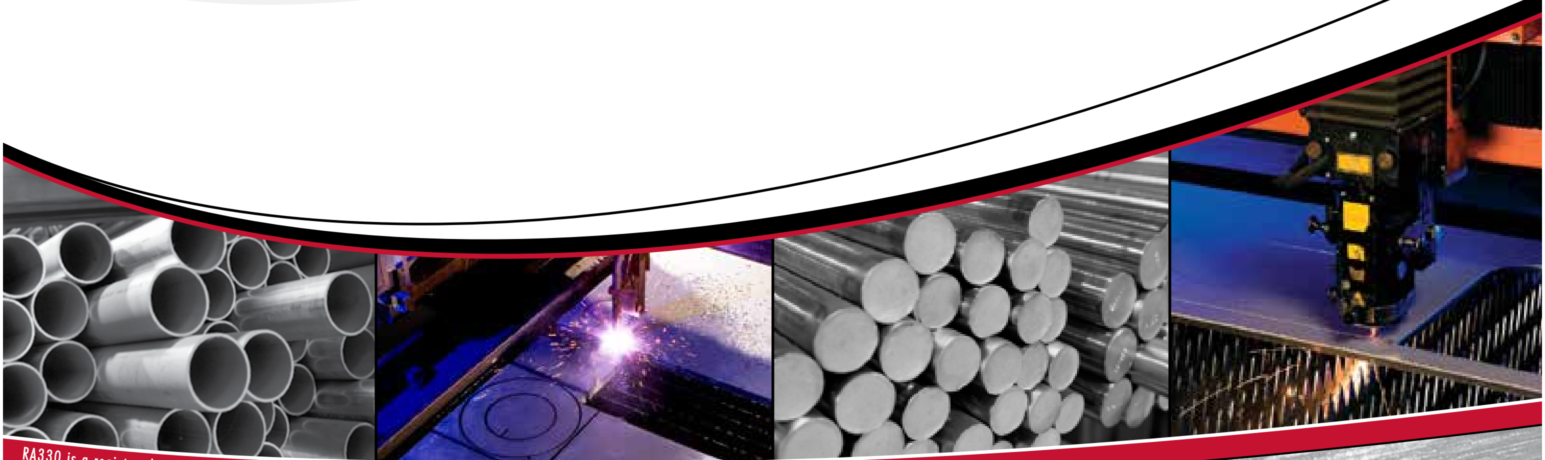
Mean Coefficient of Thermal Expansion

ALLOY	Temperature, °F																		
	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
304, 316*	8.9	9.2	9.5	9.7	9.8	10.0	10.1	10.2	10.3	10.4	10.6	10.7	10.8	10.8	–	–	–	–	–
2205	7.2	7.3	7.5	7.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
321	9.3	–	9.4	–	9.5	–	10.0	–	10.3	10.5	10.6	–	10.9	–	11.1	–	11.4	–	–
309	8.8	8.9	9.0	9.2	9.3	9.4	–	–	9.7	–	–	–	–	10.0	10.1	–	–	–	–
310	8.4	8.6	8.8	–	8.95	–	9.2	–	9.5	–	9.8	–	10.05	–	10.15	–	10.3	–	10.6
Carbon Steel*	6.7	6.9	7.1	7.3	7.4	7.6	7.8	7.9	8.1	8.2	8.3	8.4	–	–	–	–	–	–	–
RA 253 MA®	9.06	–	9.34	–	9.59	–	9.81	–	9.97	–	10.14	–	10.3	–	10.5	–	10.8	–	–
410	5.5	–	–	–	–	–	–	–	–	–	6.5	–	–	–	–	–	–	–	–
RA330®	8.3	8.4	8.6	8.7	8.9	9.0	–	9.2	9.3	9.4	9.6	–	–	9.7	9.8	9.9	10.0	–	–
HR-120™	7.95	–	8.29	–	8.56	–	8.80	–	8.98	–	9.24	–	9.52	–	9.72	–	9.87	–	–
353 MA®	8.48	–	8.68	–	8.88	–	9.07	–	9.27	–	9.46	–	9.66	–	9.86	–	10.05	–	–
800H/AT	7.9	–	8.8	–	9.0	–	9.2	–	9.4	–	9.6	–	9.9	–	10.2	–	–	–	–
446	5.6	–	5.7	5.8	–	5.9	6.0	–	6.1	–	6.3	–	6.4	–	6.7	6.9	7.3	–	–
600	7.4	–	7.7	–	7.9	–	8.1	–	8.4	–	8.6	–	8.9	–	9.1	–	9.3	–	–
601	7.6	–	8.01	–	8.11	–	8.3	–	8.5	–	8.87	–	9.19	–	9.51	–	9.82	–	10.18
RA 602 CA®	6.6	–	7.5	–	7.8	–	8.1	–	8.2	–	8.5	–	9.0	–	9.5	–	9.7	–	9.8
RA333®	7.0	–	–	8.0	–	–	–	–	8.6	–	9.0	–	9.3	9.3	9.4	9.5	9.7	–	–
HH	–	–	–	–	–	–	–	–	9.5	–	9.7	–	9.9	–	10.2	–	10.5	–	10.7
HK	–	–	–	–	–	–	–	–	9.4	–	9.6	–	9.8	–	10.0	–	10.2	–	10.4
HT	7.9	–	8.14	–	8.37	–	8.61	–	8.85	–	9.09	–	9.33	–	9.56	–	9.8	–	10.04
HP	–	–	–	–	–	–	–	–	9.2	–	9.5	–	9.8	–	10.0	–	10.3	–	10.6
825	7.8	–	8.3	–	8.5	–	8.7	–	8.8	–	9.1	–	9.5	–	9.7	–	–	–	–
20Cb-3®	8.2	8.3	8.4	–	8.65	–	–	8.9	8.95	–	9.15	–	9.3	9.4	9.5	–	–	–	–
AL-6XN®	7.9	8.3	8.37	8.42	8.6	8.7	8.8	8.85	8.96	–	9.3	–	–	–	–	–	–	–	–
Ti Gr 2	4.8	–	–	–	5.1	–	–	–	5.4	–	5.6	–	–	–	–	–	–	–	–

NOTE: All coefficients are reported as inch/inch °F x 10^{-6}, room temp to indicated temp. Multiply by 1.8 for metric units.

**ASME Section II Part D Table TE-1*



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