THE THERMAL EXPANSION OF SOME COMMON LINAC MATERIALS*

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Abstract

We have endeavored to acquire more precise data on thermal expansion by employing a laser interferometry based measuring process [1] rather than the vitreous silica dilatometer methods that have been used traditionally. Given that all test parameters are controlled appropriately laser interferometry offers an accuracy that can be much better than silica dilatometer based methods. The higher precision method will give a more accurate measure of the response of some common linac materials undergoing thermal growth.

1 INTRODUCTION

The thermal expansion of metal materials has a strong effect in any linac design. Data covering the thermal expansion of materials that are commonly used in linac fabrication is either sparse or contradictory. Data on Glidcop [2], a dispersion strengthened copper, is available but is a little sparse because of its directional dependency. Data on OFE copper is readily available from various sources, but is not consistent from source to source. The work reported in this paper is not intended to remedy all of these situations, but rather to provide some additional data for comparison

Rather than just simply add more data to the existing data sets on thermal expansion this effort sought to provide more accurate data by employing a measurement method with greater precision than methods typically employed in the past.

Thermal expansion measurement methods in the past have typically depended on a dilatometer based method defined by ASTM E228. A dilatometer, or push rod, is inserted between the material specimen and a very sensitive displacement measuring device such as an LVDT. The dilatometer is made of a material with a very low thermal expansion coefficient, such as silica. This measuring method provides data with a precision that is sufficient for many engineering applications. This precision is not high enough, however, when the material is at a high temperature near its melting point, and its strength has decreased significantly. The precision of a dilatometer based method is not high enough to produce a thermal expansion value with an uncertainty that is low enough to be able to demonstrate by calculation that the elevated temperature yield stress value of the material will not be exceeded in a high-temperature application. This type of situation can occur during brazing operations of linac structures.

A thermal expansion measuring method with a precision high enough to avoid the high-temperature inaccuracy relative to the materials' elevated temperature strength is a laser interferometry based method. ASTM E289 describes an interferometry based method for measuring the thermal expansion of materials. In a laser interferometry based method the dilatometer is replaced by placing the sample in a fixture where the laser can interact with one end of the sample. Length changes can be measured to an accuracy that is primarily determined by the half-wavelength of the laser being used.

For the expansion measured in this testing effort the approximate precision per testing method is listed in Table 1.

Table 1: Precision of Measurement Method

Method	$\Delta L/L$ Precision
ASTM E289, Interferometer	+/- 3.0E-8 $^{o}C^{-1}$
PMIC Method, hybrid	+/- 4.7E-5 $^{o}C^{-1}$
ASTM E228, Dilatometer	+/- 8.0E-5 $^{o}C^{-1}$

The precision values stated for the ASTM E289 and ASTM E228 methods apply for a temperature range of 300 ^{o}C or 400 ^{o}C respectively. If the temperature range is widened then the precision will likely decrease due to specimen surface condition changes. The precision of the PMIC method is calculated to be in between a pure interferometer method and a pure dilatometer method because the method uses aspects from both standards. This is done because of the need to measure various materials over a wide temperature range. The PMIC method uses laser interferometry with a silica rod placement test set-up to measure over the temperature range of 22 ^{o}C to 1051 ^{o}C for various types of materials. The silica rod does not contact the material specimen, but is positioned to create an aperture through which the laser beam passes.

2 GLIDCOP MEASUREMENTS

Glidcop is a dispersion strengthened copper that has a room temperature yield stress of approximately 40.4 ksi. Two grades of Glidcop have been measured in this testing effort, AL-15 and AL-25. The material specimens for

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thermal expansion testing of both Glidcop grades came from extruded shapes.

Extruded Glidcop has a directional dependency when it comes to thermal expansion. The expansion in the direction parallel to the extrusion direction is different than in the direction perpendicular to the extrusion direction. Figure 1 shows the thermal expansion plots for the AL-15 and AL-25 materials in the longitudinal direction (parallel to the extrusion direction) and in the transverse direction (perpendicular to the extrusion direction).

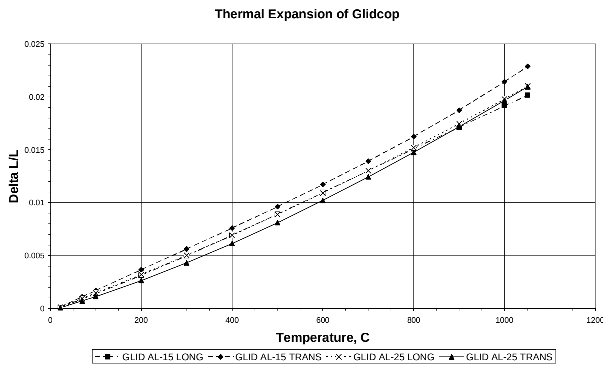

FIGURE 1
Glidcop Thermal Expansion
Equation for TE of Glidcop AL-15 Longitudinal
$\Delta L/L = -3.459E\text{-}12T^3 + 7.345E\text{-}9T^2 + 1.549E\text{-}5T - 2.314E\text{-}4$
Equation for TE of Glidcop AL-15 Transverse
$\Delta L/L = 4.748E\text{-}12T^3 - 3.337E\text{-}9T^2 + 2.032E\text{-}5T - 3.0E\text{-}4$
Equation for TE of Glidcop AL-25 Longitudinal
$\Delta L/L = 1.940E\text{-}13T^3 + 3.353E\text{-}9T^2 + 1.647E\text{-}5T - 2.191E\text{-}4$
Equation for TE of Glidcop AL-25 Transverse
$\Delta L/L = -2.049E\text{-}12T^3 + 9.552E\text{-}9T^2 + 1.236E\text{-}5T - 2.0E\text{-}4$

The directional dependency of the thermal expansion in extruded Glidcop can be affected by post extrusion rolling in both directions [3]. The directional dependency changes, but is not predicted to go away completely. Figures 2 and 3 plot the resulting data for comparing extensively rolled AL-25 with the unrolled as-extruded specimens of AL-25 already plotted. This comparison is qualified by the fact that only one specimen in each case of extensively rolled AL-25 was used.

In the longitudinal direction the as-extruded specimen and extensively rolled specimen are measured to have almost identical responses to a given temperature change.

The data indicate that the directional dependency in the transverse direction may be tailored by controlling the amount of rolling. Further testing of this aspect is needed to determine if the material does indeed respond in this manner to post extrusion rolling. The rolled specimens used were rolled extensively in both directions.

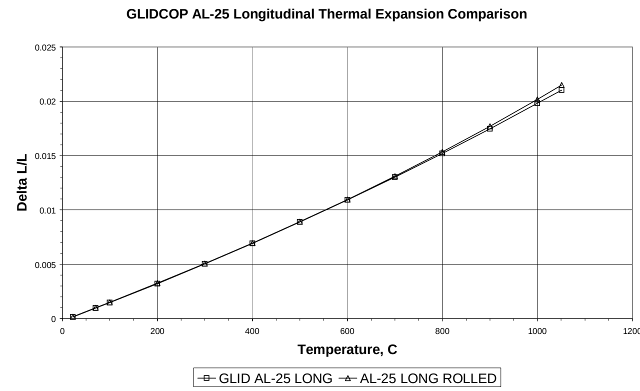

FIGURE 2
Glidcop AL-25 Longitudinal Thermal Expansion Comparison for Rolled and Non-Rolled Material
Equation for TE of Glidcop AL-25 Long. Rolled
$\Delta L/L = 1.402E\text{-}12T^3 + 2.197E\text{-}9T^2 + 1.679E\text{-}5T - 2.059E\text{-}4$

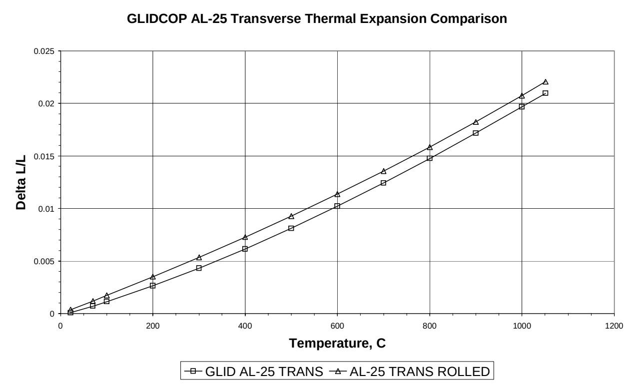

FIGURE 3
Glidcop AL-25 TransverseThermal Expansion Comparison for Rolled and Non-Rolled Material
Equation for TE of Glidcop AL-25 Trans. Rolled
$\Delta L/L = 1.151E\text{-}12T^3 + 2.628E\text{-}9T^2 + 1.696E\text{-}5T + 0.0$

3 OFE COPPER MEASUREMENTS

Thermal expansion data is available from several sources for OFE copper. The drawback is that the data are not consistent among the various reports, making it difficult to make reliable stress and strain predictions for elevated temperature conditions. This testing effort has involved using a method with a high precision. Comparison of this test data to some historical test data will be done to demonstrate a reliable set of thermal expansion data for OFE copper.

Figure 4 plots the thermal expansion data for OFE copper as measured by this testing effort against that reported by Touloukian [4].

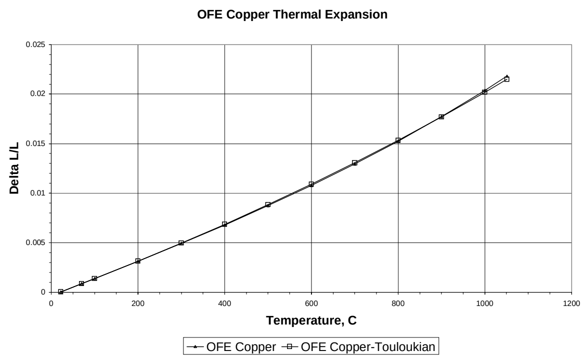

FIGURE 4
OFE Thermal Expansion
Equation for TE of OFE Copper
$\Delta L/L=3.460E\text{-}12T^3\text{-}8.260E\text{-}11T^2\text{+}1.735E\text{-}5T\text{-}3.5E\text{-}4$

The data from the two sources agree very closely. This comparison between two independent tests using two different methods should provide a high level of confidence that the thermal expansion behavior of OFE copper has been properly measured.

4 STAINLESS STEEL MEASUREMENT

Thermal expansion measurements of stainless steel were made also as part of this testing effort. Figure 5 plots the measured data for type 304 and 316 stainless steel.

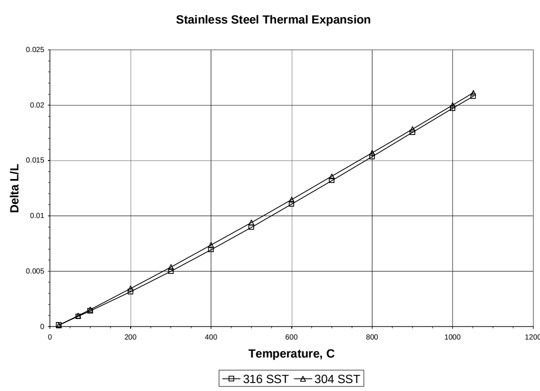

FIGURE 5
Type 304 and 316 Stainless Steel Thermal Expansion

Equation for TE of 304 SST
$\Delta L/L=\text{-}8.479E\text{-}13T^3\text{+}3.087E\text{-}9T^2\text{+}1.807E\text{-}5T\text{-}3.0E\text{-}4$
Equation for TE of 316 SST
$\Delta L/L=\text{-}2.743E\text{-}12T^3\text{+}7.248E\text{-}9T^2\text{+}1.539E\text{-}5T\text{-}2.0E\text{-}4$

5 MOLYBDENUM MEASUREMENTS

The thermal expansion of molybdenum TZM was measured as part of this testing effort. The data are plotted in Figure 6.

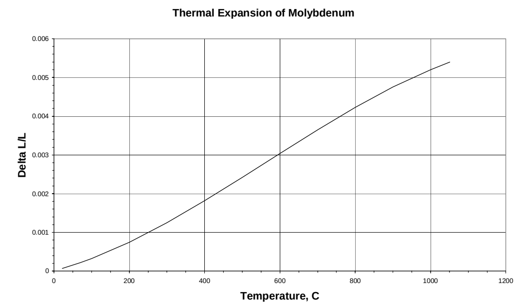

FIGURE 6
Molybdenum TZM Thermal Expansion
Equation for TE of Molybdenum TZM
$\Delta L/L=\text{-}3.810E\text{-}12T^3\text{+}6.476E\text{-}9T^2\text{+}2.529E\text{-}6T\text{+}1.0E\text{-}5$

6 SUMMARY

The thermal expansion of some common linac materials has been measured with a high-precision method that is different from traditional dilatometer methods. The thermal expansion data presented here for Glidcop, combined with other data on Glidcop strength [5] will hopefully provide useful data for the linac designer using this dispersion strengthened copper.

The data presented on OFE copper when compared with data from [4] should provide a set of thermal expansion data with a high-level of confidence for design use. The thermal expansion data on the stainless steels and the molybdenum are provided to be of help in design analysis efforts.

7 REFERENCES

[1] Method developed by Precision Measurements and Instruments Corporation (PMIC), Corvallis, Oregon, USA, web: www.pmiclab.com
[2] Glidcop is a registered trademark of OMG AmericasCorp., Research Triangle Park, N.C., USA.
[3] Communication with J. Troxell of OMG Americas, rolled material supplied by OMG Americas.
[4] Touloukian et al., “Thermophysical Properties of Matter”, 1977.
[5] Valdiviez et al, “The use of Dispersion Strengthened Copper in Accelerator Designs”, Linac2000 proceedings.