THERMAL EXPANSION COEFFICIENTS OF SOME MATERIALS USED FOR HOM LOAD ABSORBERS

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INTRODUCTION

For HOM loads proposed for the Energy Recovery Linac injector cavities we used different materials for absorption, two kinds of ferrites and a ceramic-like material with a trade name "ceralloy". These materials were brazed or soldered to a metal substrate. One important requirement to the bonding of absorbers and substrate is a very large temperature range where a good mechanical and thermal contact is needed: from the highest temperature of bonding to 77 K. Such a low working temperature was chosen to accommodate the HOM load inside the cryomodule close to the superconducting cavities at 2K. The necessary condition for reliable bonding of absorber and substrate is a close correspondence between their coefficients of thermal expansion.

Some details for the choice of these pairs are discussed in this paper.

DESIGN AND BONDING OF ABSORBERS

The absorbers represent metal plates with four absorbing tiles brazed or soldered to them, two on each side, Fig. 1. Two different sizes of plates were used, and two sizes of tiles were used for each type of plate. The tiles represent rectangular parts with rounded corners. Sizes of the biggest tile are $2'' \times 1.04'' \times 0.125''$, of the smallest - $1.6'' \times 0.75'' \times 0.125''$. For bonding, the tiles were placed into flat "pockets" machined on the plates. Alloy for bonding in the form of foil 3 mils thick was placed between the tiles and the plate. According to American Welding Society, joining with temperature of filling metal (solder) having a liquidus above 450°C is brazing, and below this value – soldering [1]. In our case we have soldering at 320-340°C of ferrites TT2-111R and Co2Z [2] to Copper-Tungsten compositions, so called Elkonites [3], in Ar atmosphere. Ferrite tiles were sputtered for soldering by Ti + TiCu + Cu composition. Elkonite plates were copper-plated. Bonding of ceralloy [4] with the alloy Tungsten 18 [5] is brazing as it is performed at 900 - 930°C in vacuum. For soldering the foil of 90% Sn – 10% Ag was used, and for brazing – TiCuSil foil (4.5 % Ti, 26.7 % Cu, 8.8 % Ag).

COEFFICIENTS OF THERMAL EXPANSION

Ideally, the materials of bonded tiles (ferrite or ceralloy) should have exactly the same coefficient of thermal expansion (CTE) as the metal substrate. Since this is difficult over a wide range of temperatures, it is better when the tile material is slightly compressed when cooled down to the lowest working temperature, and not stretched. Excessive stretching of the bonded tile will lead to cracks in the tile body. However, excessive relative compression of the tiles by the substrate makes the tile pop out from the plate.

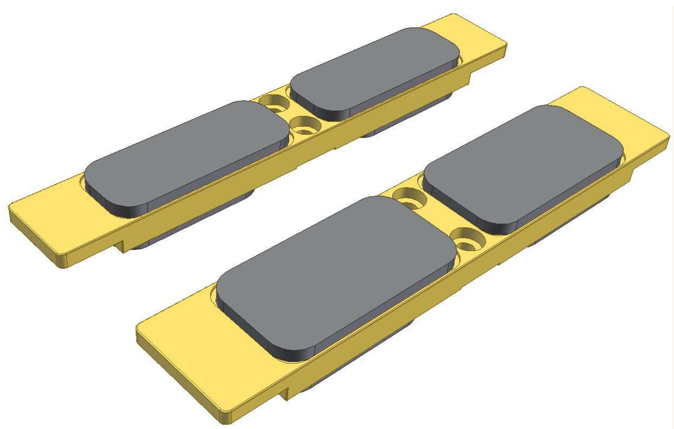

Fig. 1. Absorber plates.

There was a good experience of soldering TT2-111R ferrite tiles to Elkonite 10W3 substrate for the "porcupine" HOM load used in the superconducting RF system of CESR [6]. However the lowest temperature of this load is the temperature of cooling water and requirements to bonding are not so severe. We checked the behavior of this pair of materials at lower temperatures by cooling the soldered plates immersing them into liquid nitrogen. No cracks appeared on the tiles even after such a harsh test.

For understanding of the mutual shift of bonded materials, measurements of the thermal expansion coefficient were performed at our request at the Advanced Plastic and Material Testing Inc., Ithaca, NY. Results of all measurements are presented in Fig. 2.

To trace the mutual motion of the bonded pairs, these curves can be shifted so that they coincide at the maximal temperature. Unfortunately, maximal possible temperature of CTE measurements was 300°C, not the temperature of bonding. However, one can presume that (1) the point of mechanical stress equilibrium is lower than the temperature of bonding alloy melting, and (2) because behavior of CTE of both materials is close, there is possibly not a big mistake if the benchmark point is shifted.

The temperature dependence of elongation/shrinkage of the pair TT2-111R and Elkonite 10W3 shifted to coincide at 300°C is shown in Fig. 3.

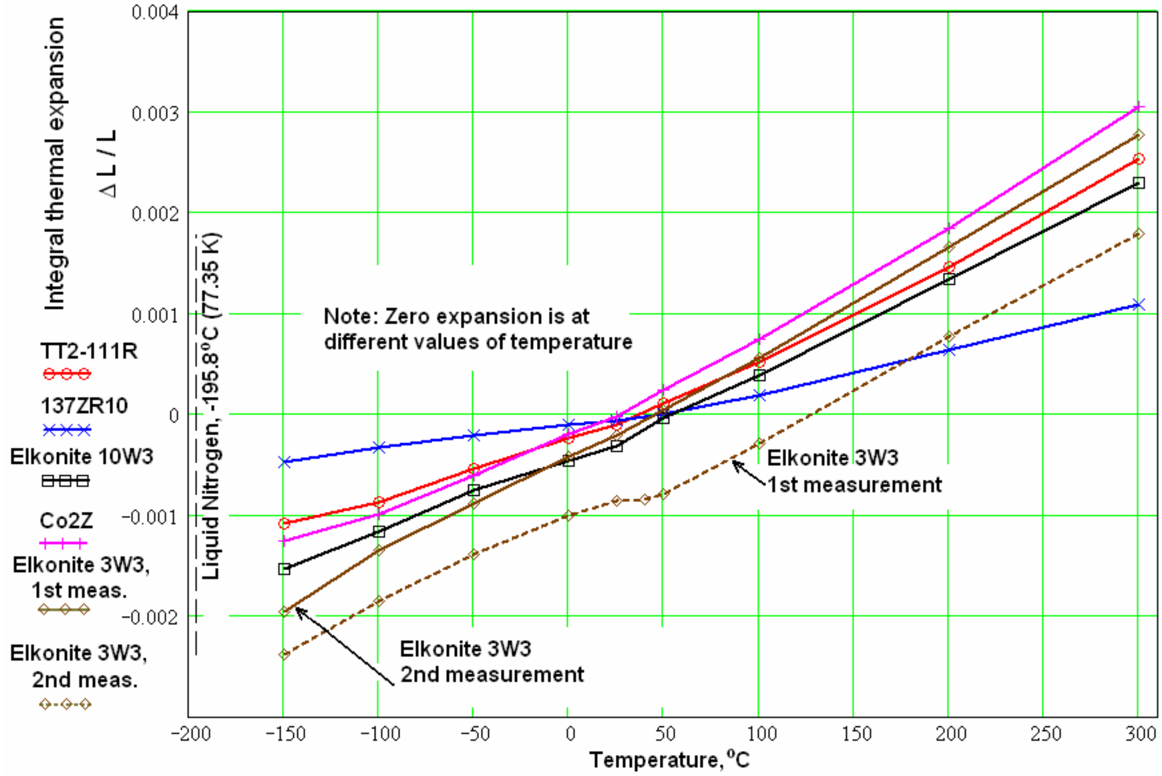

Fig. 2. Digitalized curves for materials measured by Advanced Plastic and Material Testing Inc.

The pair of ferrite Co2Z with the same Elkonite 10W3 was bonded using the same technology. However, after the cold test with liquid nitrogen, several ferrite tiles cracked. It was this situation that initiated the consecutive measurements of CTE.

CTE of Co2Z was measured and it was found that the Co2Z ferrite appeared **stretched** at low temperature. The difference in dimensions with 10W3 becomes as big as 0.5 micrometers per 1 mm of initial length ($\Delta L/L = 5\cdot 10^{-4}$), Fig. 4, curves 1 and 2. An analysis of CTE of Elkonites with different content of Copper was done, Fig. 5. Values of CTE were taken from the manufacturer website [3] and from literature [7]. Comparison of Co2Z CTE with this curve showed that the best fit can be achieved with the next available type of this material, Elkonite 3W3. Data presented in Fig. 5 correspond to the room temperature but we believe that main dependencies are still valid for some temperature range.

Let us return to the CTE curves in a temperature range presented in Fig. 4. One can see that the first measurement of Elkonite 3W3 showed that Co2Z tiles are still stretched when cooled down, especially in the region 0...-100°C. We doubted if the curve 3 is true. The doubt was based on the fact that there is a horizontal segment on this curve in the region 25...50 degrees. This segment may be explained by a mistake in the process of measurement. These measurements begin from the coldest point when the measured sample is cooled down to the minimal temperature, with help of liquid nitrogen as well, and then slowly warmed up. If the sample is not placed in a dry, purged atmosphere, the water vapors of air can condense on the sample making it “thicker”. This ice will of course melt at 0° but being in a very small gap between the sample and the holder will kept there by forces of surface tension until evaporates slowly. The shift of the curve corresponds to 2 micrometers of ice for the 10 mm thick measured sample.

We ordered a repeat of this measurement and our assumptions proved correct, see curve 4 in Fig. 4. Let us remark that even taking the discussed cause of the mistake into account, curves 3 and 4 illustrate a general accuracy in CTE measurements.

A new set of brazing, of Co2Z with Elkonite 3W3, was done and better results obtained. One tile of 32 (8 plates) was cracked but all other were intact and survived the sequential cooling to 77 K.

There were no problems up to now with ceralloy 137ZR10 tiles brazed to Tungsten-18 plates. Curves in Fig. 6 show that these materials have a “correct” behavior when cooled: ceralloy is slightly compressed and difference in length is small enough (scales in Figs .2 – 4, 6 are different).

As can be seen from Figs. 3, 4, 6 relative **compression** at -150°C $\Delta L/L$ is $4.5\cdot 10^{-4}$ for Ceralloy and Co2Z and $2\cdot 10^{-4}$ for TT2-111R. Actual compression of Ceralloy can be higher than shown value because it is brazed at 900 - 930°C and actually is not matched at 300° as supposed in Fig. 6. However, this is a very mechanically strong material, its original destination is usage in bulletproof jackets [4].

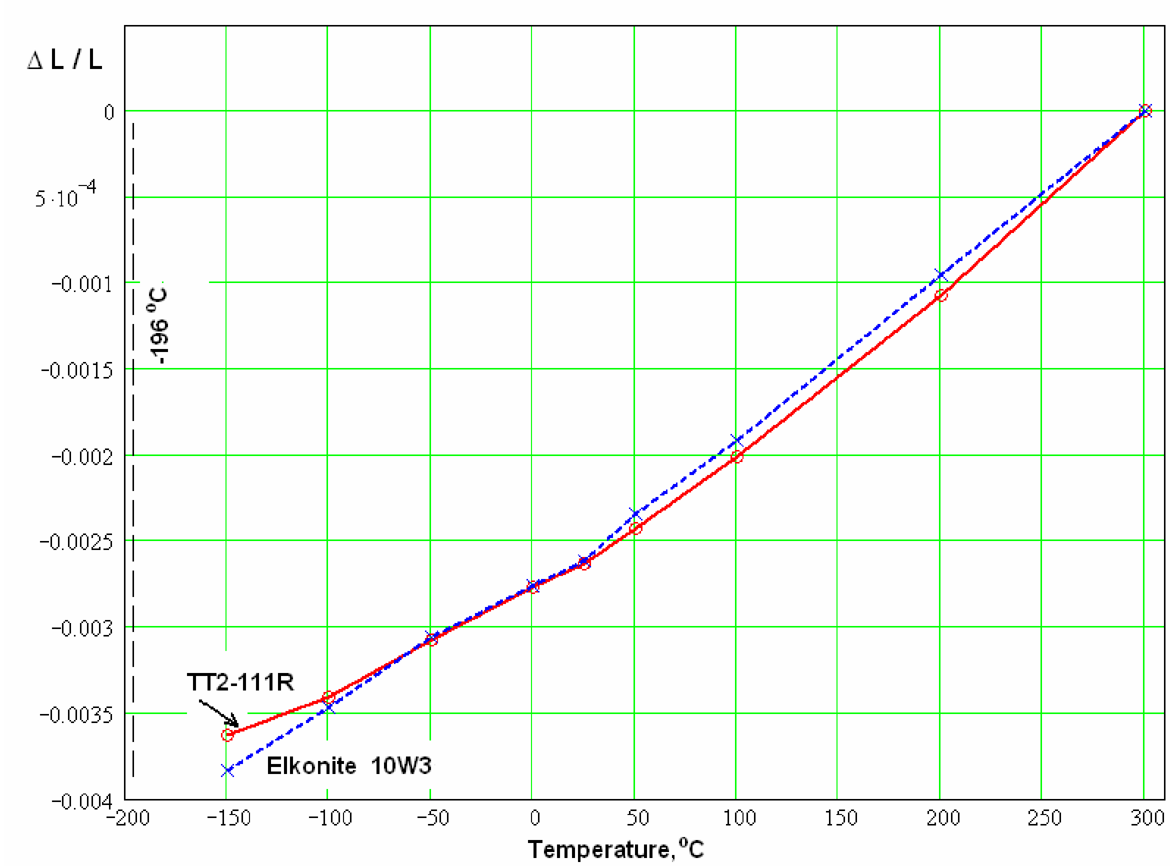

Fig. 3. Relative displacement for the pair “TT2-111R – Elkonite 10W3” if they were matched at 300°C.

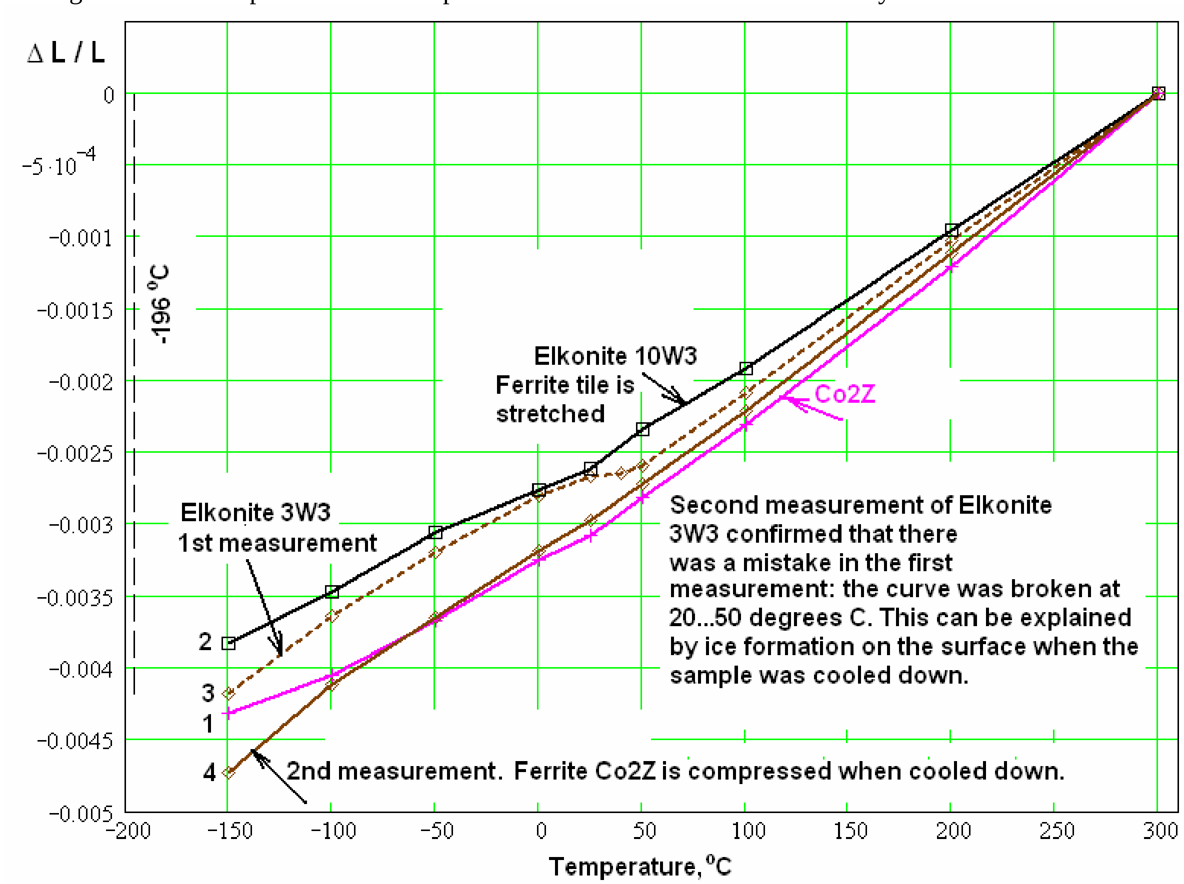

Fig. 4. Relative displacements for ferrite Co2Z, Elkonite 10W3 and Elkonite 3W3 if they were matched at 300°C.

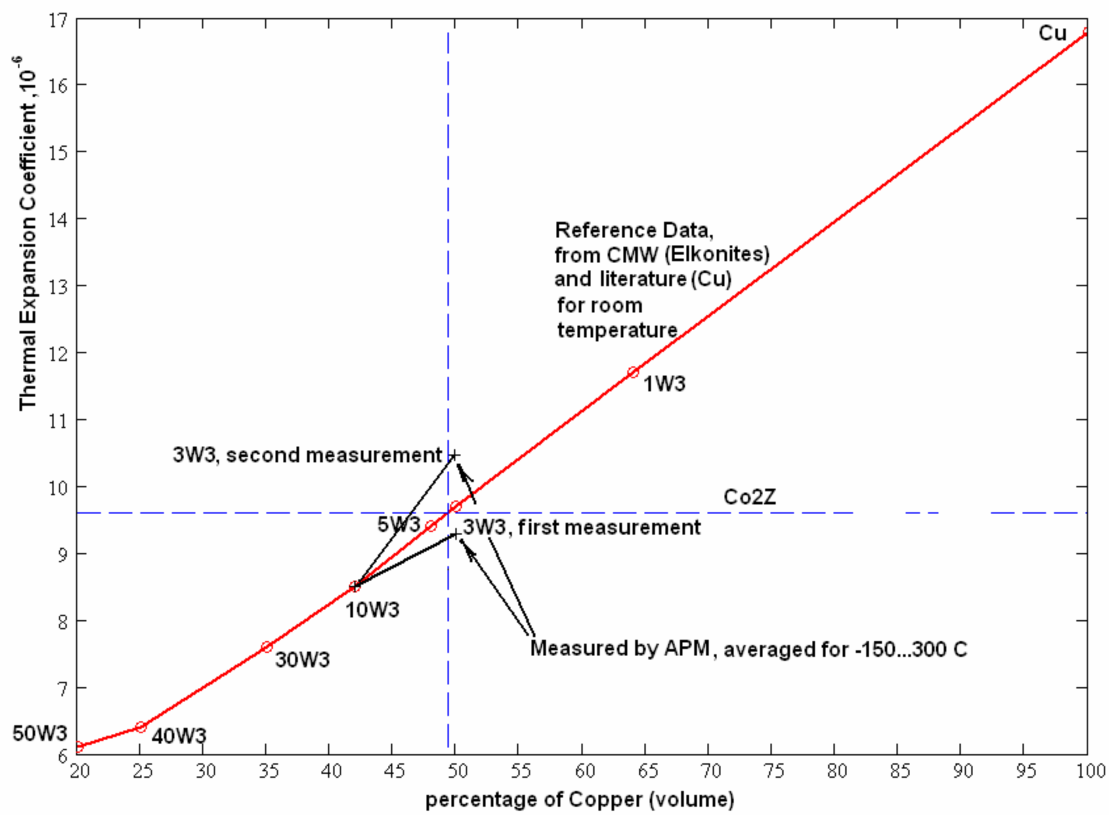

Fig. 5. Dependence of CTE of Elkonite compositions (Cu + W) on relative content of Copper.

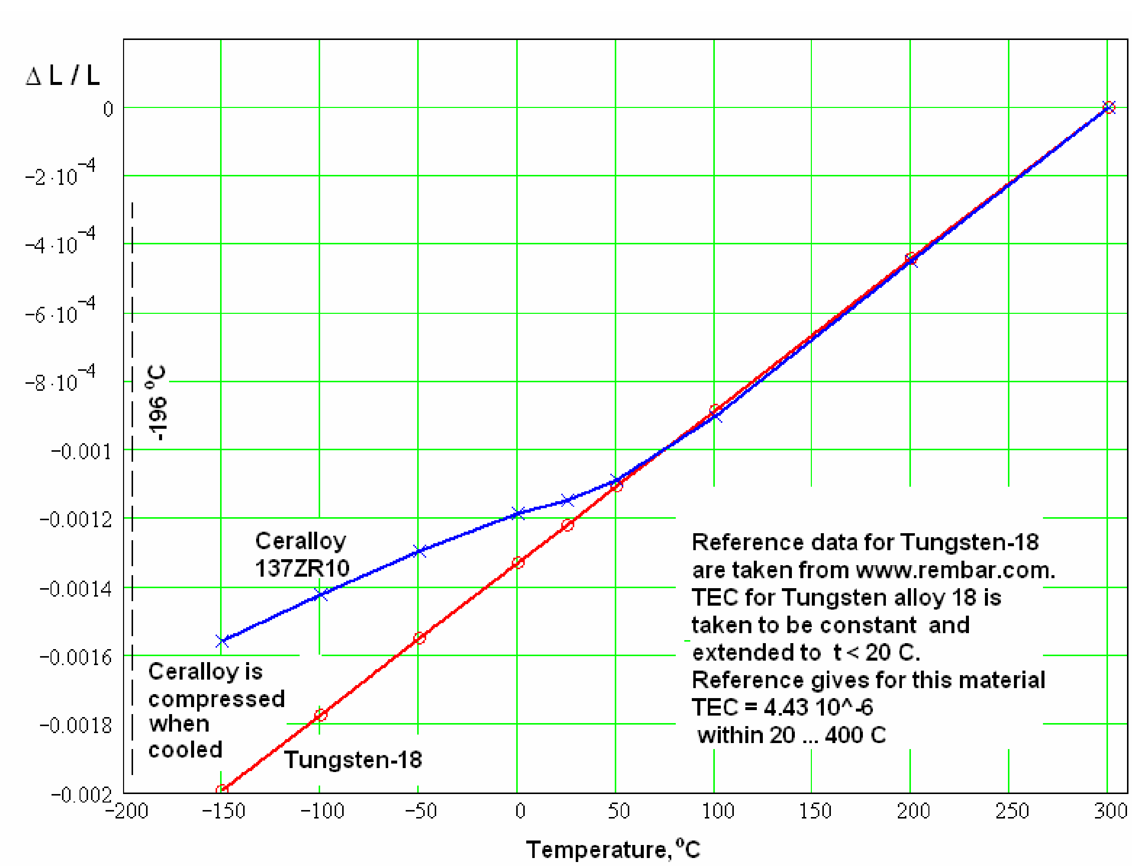

Fig. 6. Relative displacements for the pair “Ceralloy 137ZR10 – Tungsten-18 if they are matched at 300C°

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CONCLUSION

Analysis of thermal expansion in a broad temperature range from -150 to +300°C helped to find concurrent pairs of materials or explain good matching of earlier experimentally found material mates.

ACKNOWLEDGEMENTS

Mechanical and thermal design of HOM loads for ERL injector cavity was done by Valerie Medjidzade, Matthias Liepe and Sergey Belomestnykh. The mate material for Ceralloy: Tungsten-18 was found by James Sears. This material has not only a matched CTE with Ceralloy but is easier to machine than other Tungsten or Molybdenum alloys with low TCE. Brazing of Ceralloy with Tungsten-18 was performed by Neil Sherwood and Terry Gruber. Soldering of ferrites and Elkonites was done by Phil Barnes and Rick Roy. Phil Barnes also organized metal plating of ferrite tiles at JPArgano C^{o} and Elkonite plates at Anoplate Corp., Syracuse, NY, as well as measurement of CTE at APMT Inc. Formulation of the problem and general leadership has been performed by Hasan Padamsee. The author is thankful to Hasan Padamsee and Eric Chojnacki for useful remarks and corrections.

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