Thermal Expansion of Investment Casting Shells

Tom Branscomb, Director of Technology
Buntrock Industries

Abstract:

A review of the thermal expansion of typical shells used for investment casting is presented. Discussion of differences between types of shell systems and practical implications in the foundry is given. Data are presented for typical commercial foundry shells which are comprised of fused silica, alumino-silicate, and fused silica / alumino-silicate combinations. Data and discussion are also given for shells made of zircon-alumina which are typically used for directionally solidified and single crystal applications. The thermal expansion curve for a zircon substitute is presented. Materials for ultra-high temperature shell systems are investigated.

Introduction

Thermal expansion is a very important property of materials and must be considered for most applications. A common example is expansion joints in bridges and highways. The concrete and steel must be allowed to expand and contract or cracking and ultimately failure will occur in the structure or road. Relating to investment casting, everyone is familiar with the issue of wax thermal expansion causing cracks during dewax.

When considering the ceramic shell for investment casting, there are several reasons to be interested in and to understand its thermal expansion.

1. Thermal cycling (heating and cooling) of the shell.
2. Final dimension of the casting
3. Wax tooling from other shops
4. Changing materials for the shell
5. Shell distortion at moderate temperatures
6. High temperature stability

Thermal expansion of ceramic shells is measured using an instrument called a dilatometer. One common instrument is made by The Orton Ceramic Foundation. See Figure 1. A prepared sample is placed in the alumina tube holder. An alumina rod is in contact with the sample and the movement of the rod is measured with a sensitive LVDT. The sample is heated by a silicon carbide tube furnace. See Figure 2. Since the LVDT is measuring the movement of the entire system, an alumina standard is used and a correction factor is determined first.

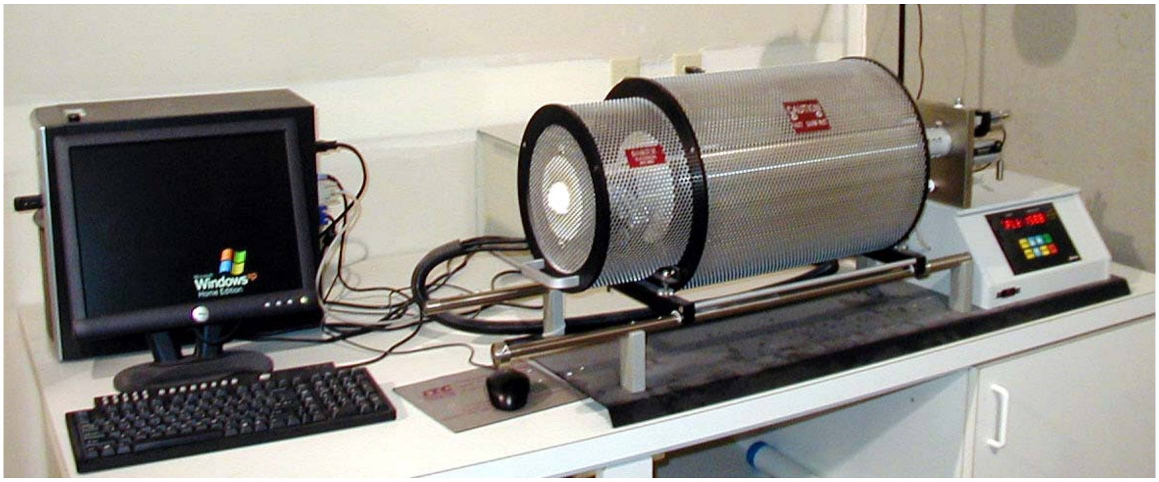

Figure 1. Orton Dilatometer 1600C

Figure 2. Sample, Holder, Rod

Experimental Results

Many investment casting foundries producing castings for general commercial applications use either alumino-silicate slurries or fused silica slurries with either fused silica or alumino-silicate stucco. For this study, only materials from CE Minerals were used. Three slurries were made with fused silica, Mulgrain 47, and Mulgrain 60 flour. Each used Bindsol 830 colloidal silica, water, and polymer. Wax strips were dipped in the slurries and stuccoed with fused silica, Mulgrain 47, or Mulgrain 60 sand. Thermal expansion was then determined for each combination. The results are presented in Figures 3, 4, 5 and 6.

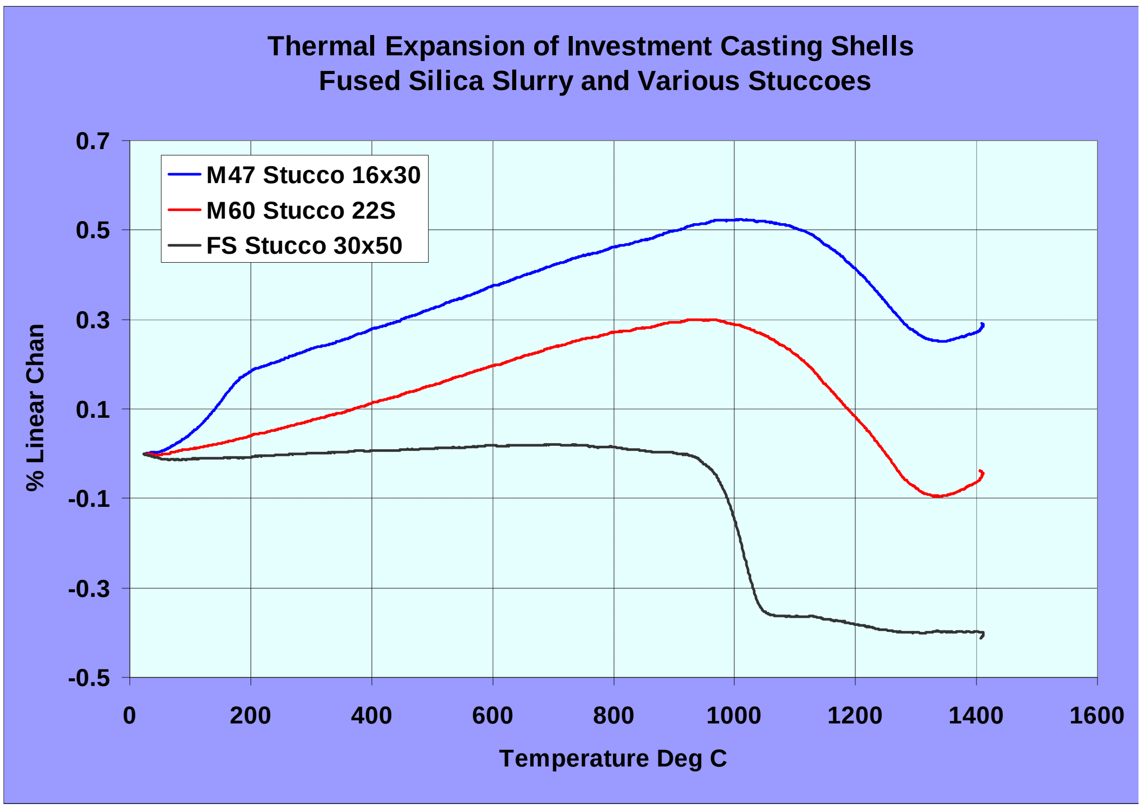

Figure 3. Thermal Expansion of Fused Silica Slurry with Fused Silica, Mulgrain 47, and Mulgrain 60 Stucco.

As can be seen from the above graph, there are significant differences in expansion that occur when different stuccoes are used with fused silica slurry. One can easily estimate the difference in casting size from these curves, if stucco is changed. Assuming that the shell temperature at the time the casting becomes solid is about 1200 C, the Mulgrain 60 casting would be about 0.4% larger and the Mulgrain 47 casting would be about 0.7% larger. For a 10” diameter casting, this is a difference of 0.040” and 0.070” respectively.

These differences may or may not be important depending on casting dimension tolerance and the actual casting dimension being produced. For example, if your current casting is near the maximum for this diameter, changing from fused silica stucco may result in the casting being out of specification.

It is possible to use this same phenomenon to correct dimensional issues. If you normally use fused silica stucco and your dimensions are too small, a simple change to a different type of stucco may solve this problem.

Now, look at what happens when the stucco remains fused silica and the slurry is changed. See Figure 4.

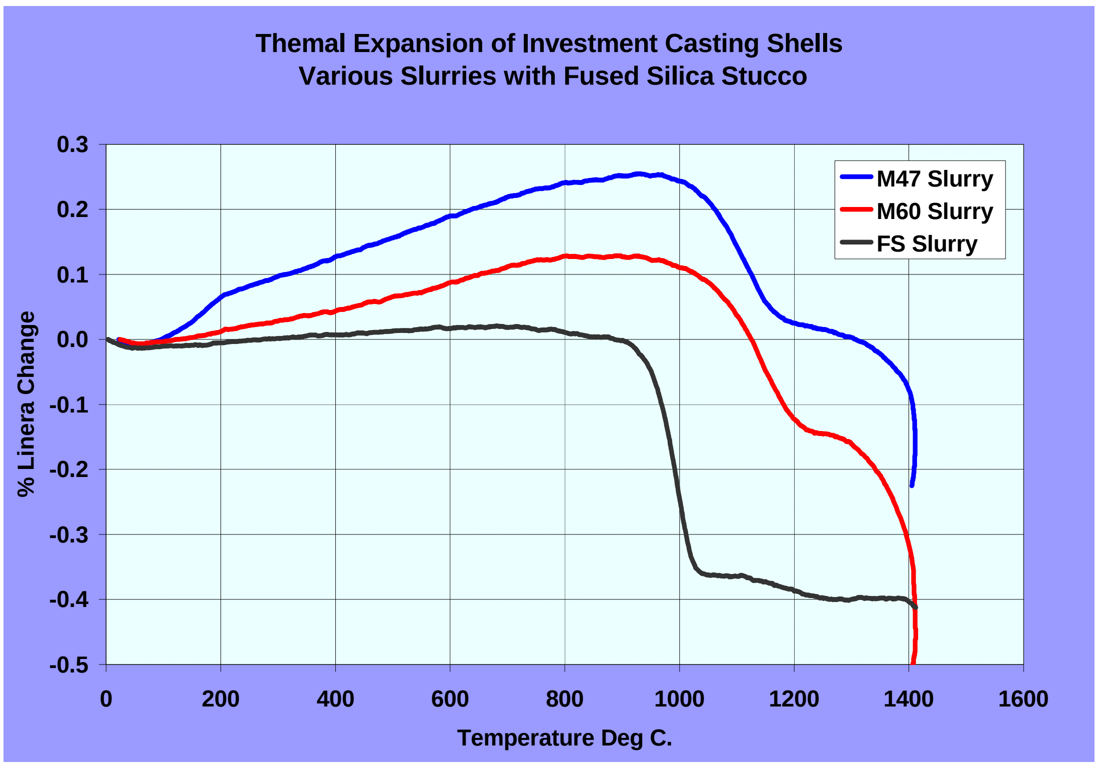

Figure 4. Thermal Expansion of Shells made with Different Slurries all using Fused Silica Stucco

There are two things that are noticeably different from the previous chart. First the magnitude of the difference is much less. That is to say that changing stucco has a larger impact than changing slurry. The other difference is that at or above 1300 C, the Mulgrain slurries shrink dramatically. This indicates that for large castings and high pour temperatures shell integrity may be compromised.

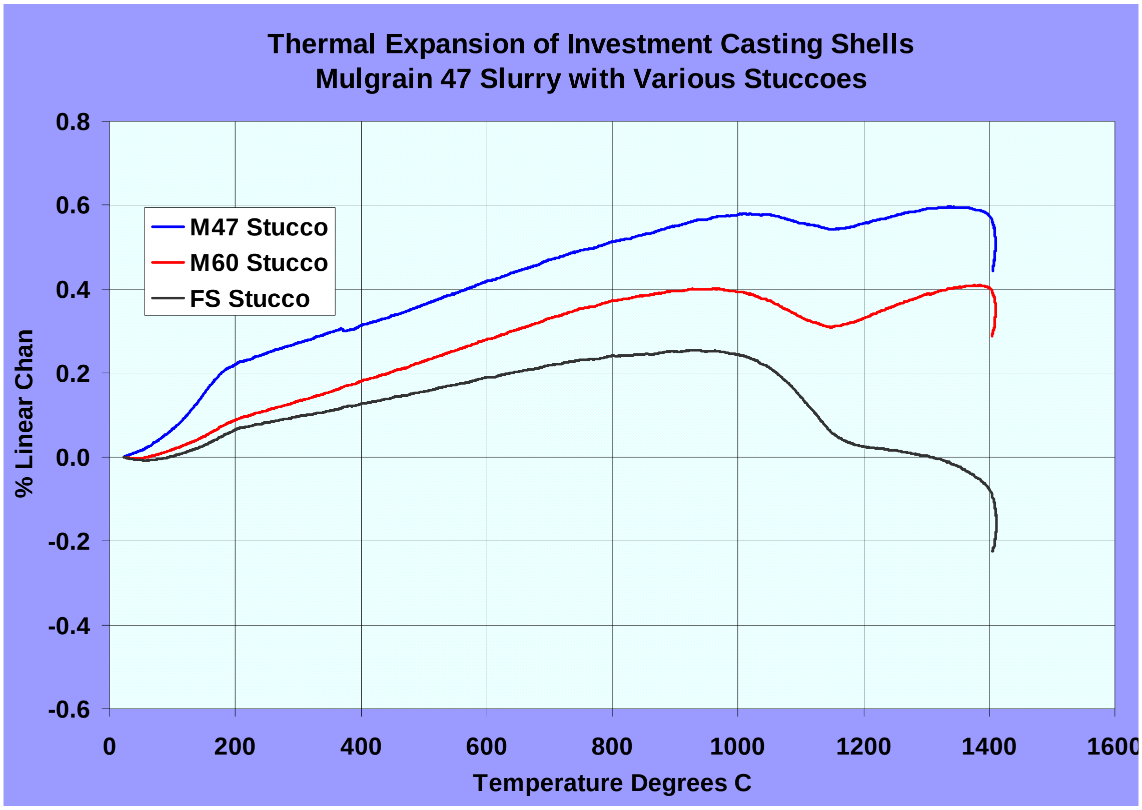

Figure 5. Thermal Expansion of Shells made with Mulgrain 47 Slurry and Various Stuccoes

From Figure 5 we see that when using Mulgrain 47 slurry and stucco, changing to Mulgrain 60 stucco will reduce dimensions, but it appears that changing to fused silica stucco may present dimensional stability issues above about 1100 C. Caution needs to be used in making this change. The use of Mulgrain 60 slurry mirrors what happens with Mulgrain 47 slurry as can be seen from Figure 6 below. In fact, it appears that using Mulgrain 47 slurry with fused silica stucco yields less shrinkage in the 1200 - 1400C temperature range.

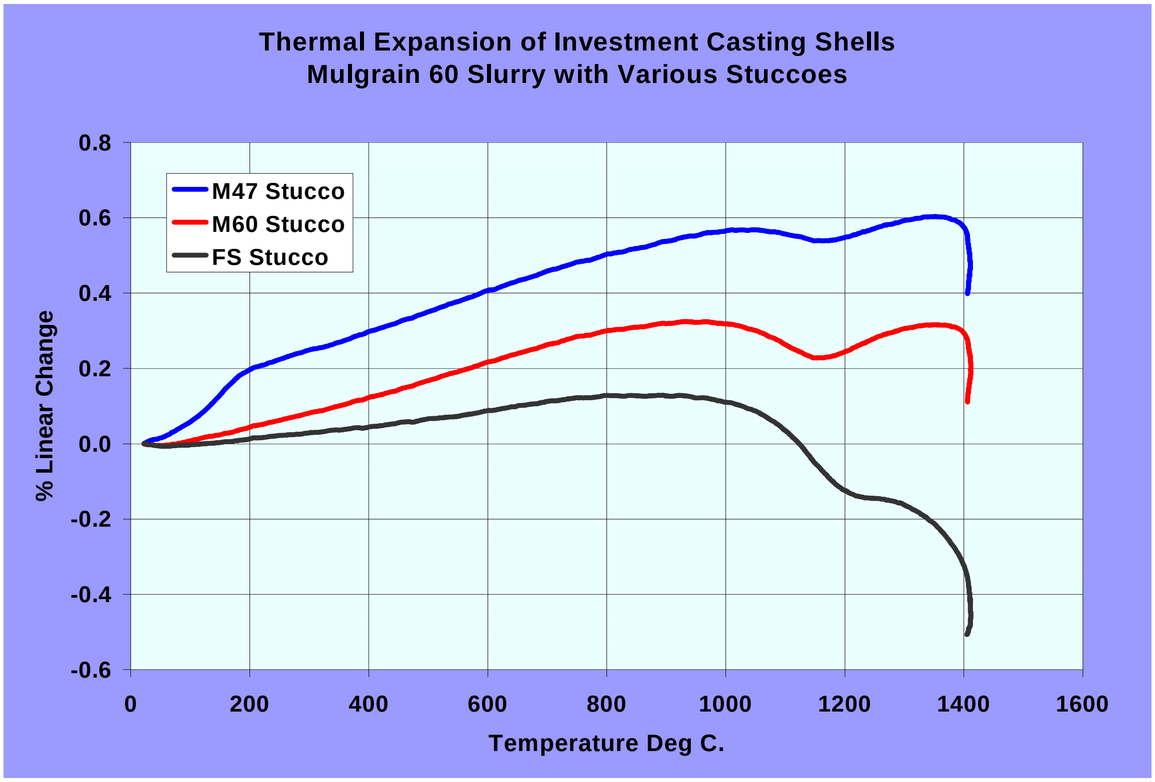

Figure 6. Thermal Expansion of Shells made with Mulgrain 60 slurry and Various Stuccoes

The issue of dimensional stability of the shell at high temperature is more of a concern when making directionally solidified and single crystal castings. This is because the shell temperatures are higher. If a particular shell is shrinking at high temperature, there is a good chance it will not have adequate stability to produce consistent castings dimensionally.

A common shell system used for this type of casting is a zircon slurry with tabular or fused alumina stucco. See Figure 7 below. The expansion of the zircon slurry shell shows good linear behavior up to 1400C and dimensional stability is good in general. Another test was completed with a hold for 1 hour at 1400 C. The zircon slurry shrank some, but the alternative shell did not.

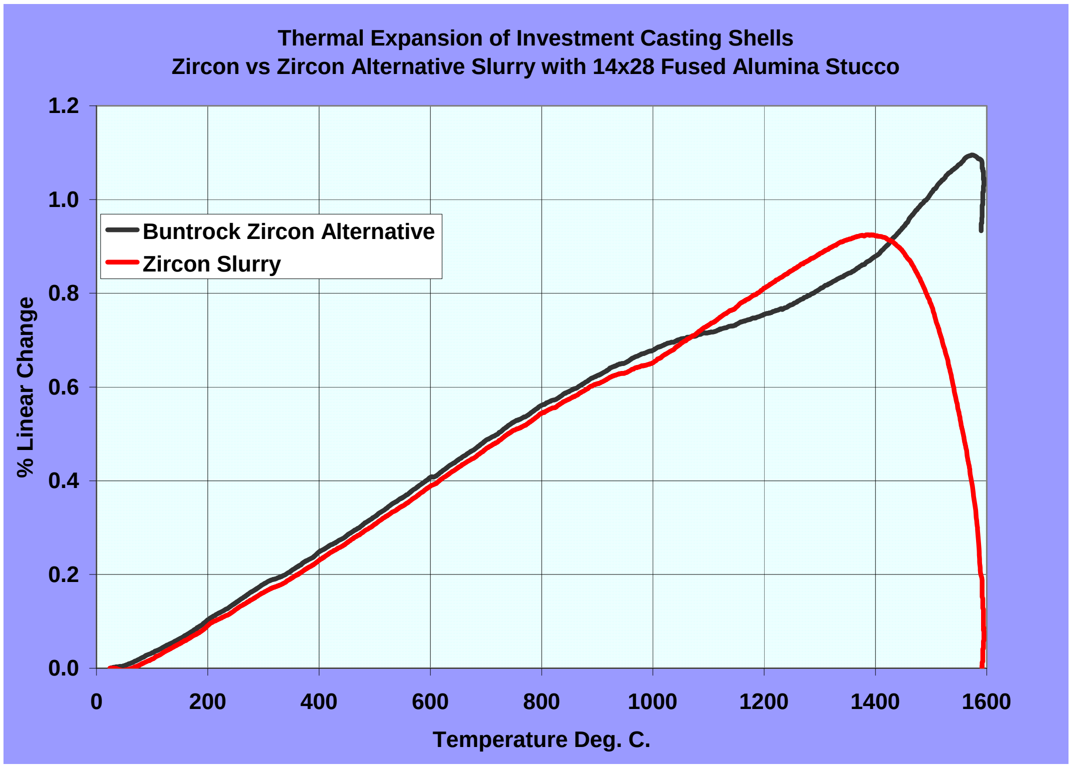

Figure 7. Thermal Expansion of a typical Zircon Slurry, Alumina Stucco DS shell. A Zircon Flour Alternative is also shown.

The slurry presented as a zircon alternative has better high temperature performance than the zircon shell. However, for next generation very high temperature alloys being considered for DS and Single Crystal castings, there is some concern about the shrinkage at 1600 C shown in Figure 7.

Additional work has resulted in materials that apparently overcome this issue. In Figure 8, a shell system is used that is very stable at 1600 C. Different stuccoes were investigated and White Fused Alumina performed the best.

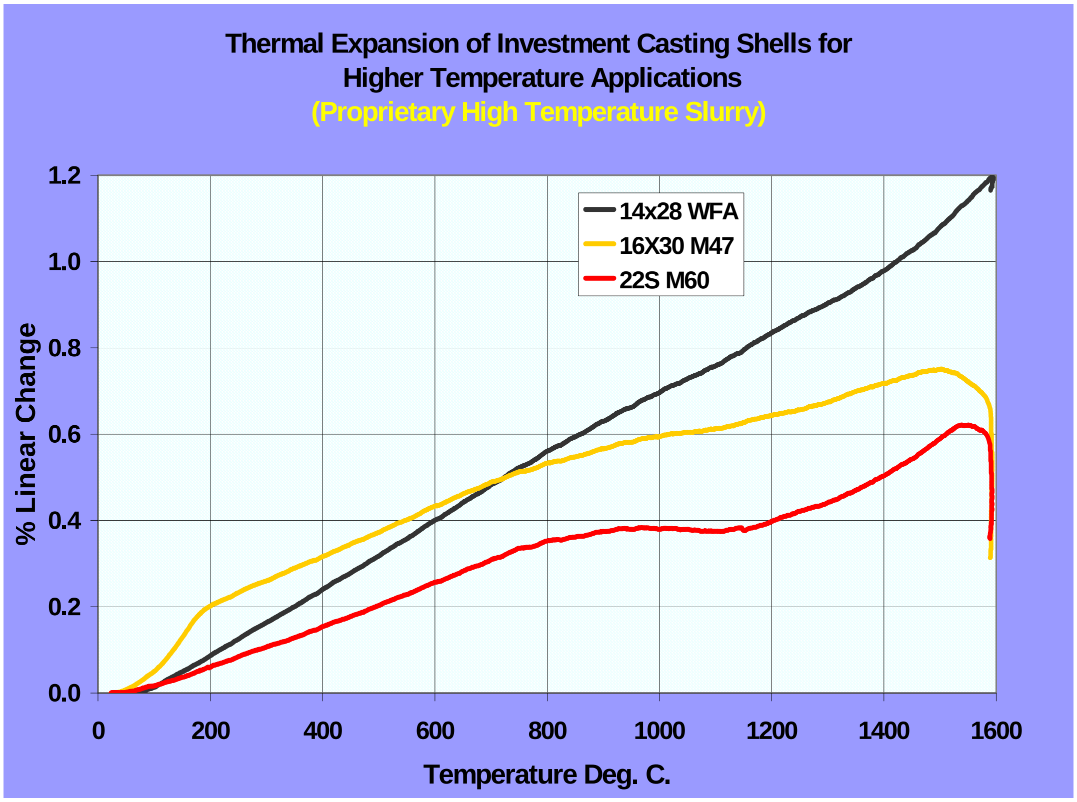

Figure 8. Thermal Expansion of Very High Temperature Shell with Various Stuccoes

Conclusions

1. Thermal Expansion is a good tool for determining the effect a stucco or slurry change may have on dimensions of castings.
2. Be very cautions about using Fused Silica stucco with alumino-silicate slurries.
3. When using fused silica slurry, changing to alumino-silicate stucco appears fine, but casting dimensions will increase.
4. There are materials that appear to match and even improve upon the zircon backup slurries in use.
5. Materials for ultra high temperature shells perform well at 1600 C.