A Practical Approach to Replacing Zircon

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Abstract

The replacement of zircon flour and sand is discussed in practical terms. Results of trials using Cerabeads 60 as alternate sand are given. Replacement of zircon flour is discussed. Casfill 85 is demonstrated to have promise for zircon flour replacement. A molten metal lab test was developed to compare various flours to zircon.

Introduction

Because of market forces, the escalating price of zircon flour and sand has increased the cost of making investment castings. In particular, the cost of the ceramic shell has increased, which erodes the profit on the castings that use zircon in their shell. Thus, lower cost and available alternatives are needed. The higher the price of zircon, the more foundries demand alternatives.

Zircon is widely used in investment casting because it works well and until fairly recently, it was readily available and low in cost. Most commercial and aerospace alloys can be cast by using zircon flour in the prime slurry and zircon sand as the prime stucco. Titanium alloys can not use zircon as a first coat. This paper does not cover Titanium alloys.

Zircon possesses several properties and features other than its non-reactive nature with most alloys, which make it useful for investment casting. Some of these are:

1. Low Thermal expansion (but more than fused silica)
2. High density
3. High Specific Heat
4. Round shape of sand particles
5. pH in water is mildly acidic (negative for high pH binders)

There are differences in zircon sources and in the processing of the zircon. All zircons are not created equal. Radioactivity of zircon can exceed limits needed for transportation as a non-hazardous material.

Because zircon has been such a universal material and in use for many decades, foundries have learned how to use this material taking advantage of some features and learning to deal with others. This is the reason, I believe, that many foundries have not been more willing to look at alternatives. The fact of the matter is that, changing away from zircon is not a simple thing. It takes someone committed to following up on test parts and looking very closely at the subtle changes that come with any change in material. In short, it takes a champion in the foundry to make sure all goes correctly during the test and who can make the necessary observations and measurements to determine that the change is positive, neutral, or negative. If negative aspects are noticed, the champion needs to be willing to work with suppliers, to mitigate these issues.

Alternatives

Other than zircon, materials used as flours and sands for prime coats are mostly: Alumina, Silica, and Alumino-Silicates. All of which have several common forms and in some cases blends of these materials may offer unique advantages. Not all materials are suitable for all alloys. Generally, the higher the melting temperature of the alloy to be melted, the more difficult it becomes to find a suitable alternative for zircon. Aluminum alloys, because of their low melting temperatures, can and do use inexpensive alumino-silicates as face coat material. Most commercial alloys can use silica, alumina, or possibly higher alumina content alumino-silicates. Medical alloys and vacuum cast aerospace alloys can normally use alumina in place of zircon, but re-qualifying parts on fixed process is expensive and time consuming. The medical, aerospace foundries and some commercial foundries know quite well that if they are to change from zircon, they will likely need to qualify new parts in a new process rather than convert existing parts to a different face coat material.

Section I. Zircon Stucco Alternatives

There may be some applications for fused silica sand on first dip. CE Minerals makes an 80x100 mesh product that is suitable in size for prime sand. Fused silica sand in small mesh sizes seems to be a little difficult for the next slurry coat to be able to soak (wet) into. The thermal expansion of fused silica is near zero and may separate from a higher expansion backup shell. It is generally preferred to have a first dip stucco that is somewhat higher in thermal expansion than the backup shell. Best chances for success occurs if you have an all fused silica shell.

Alumino-Silicate materials are generally not available in sizes suitable for prime stucco, but 60 or 70% alumina would likely work, especially for smaller castings. Some of the largest investment casting shells ever made have been made using 47% Alumina stucco on second dip for both air and vacuum cast aerospace alloys.

Tabular or Fused Alumina work quite well for prime stucco from the perspective of reactivity with the metal. Alumina has a high thermal expansion especially when compared to fused silica. If multiple primes are used, the primes may cause distortion of the shell. Normally, these sands are available in suitable sizes. Do not use alumina stucco if using fused silica in prime slurry. In fact, avoid the mixture of alumina and fused silica whether in flour or sand when making ferrous based castings. The reason is that iron from the alloy can combine with alumina and silica to form low melting compounds and “burn in".

One alternative that has promise as a near “drop in” substitute for zircon sand is the Cerabeads 60 and Wing Beads products both made by Itochu Ceratech in Japan. These products are classified as synthetic mullite. The reason is that these products are generally compatible with many alloys and offer particle size and shape similar to zircon sand. This makes the issue of converting from zircon sand much less difficult. Very likely, the same dip card could be used, just change the stucco in the first dip stucco hood.

Below in Picture 1 are two photos of a 17-4 alloy casting made using a shell having a zircon/fused silica prime and Cerabeads 60 stucco. The backup shell was all fused silica. The pour temperature was 2900F. No reaction at all was observed. Half of the casting surface is in the as cast condition and half is sand blasted. No problems were encountered making this casting. A close up of the casting shows no reaction with the Cerabeads 60 stucco.

Picture 1. Casting of 17-4 SS at 2900F using Cerabeads 60 Stucco

Several other castings were also made at various foundries using Cerabeads 60 with no problems encountered. No process adjustments were made. Alloys poured included 304, 4130, 347, IN718, 316, Monel M35-1, and Aluminum Bronze 958.

The Wing Beads are reportedly an improvement over the Cerabeads 60 and will be covered in another paper. I have not tried a direct comparison between the two types, but there are differences between the two materials. One may turn out to be better in trials than the other.

Section II. Zircon Flour Alternatives

The material choices are the same for flour as already discussed for stucco, Alumina, Silica, and Alumino-silicates. There are, however, significantly more challenges involved in replacing zircon flour than zircon stucco. For one, the metal is in direct contact with the ceramic used. Ideally, the ceramic would be completely inert to the metal. Generally, this is not the case. The ceramic must also be stable with the binders used to make slurries allowing for long slurry life and ideally, zero slurry throw out. Additionally, the particle size of the flour must be such that the slurry has desirable rheology or draining characteristics for the operator.

Fused silica is compatible with many commercial alloys but its rheology is generally not as good as desired. With some development work, a proper draining fused silica slurry might be possible.

Alumina flour, whether tabular or fused, is not very stable with colloidal binders. Short slurry life in a prime is a problem with these materials.

Alumino-Silicates are stable with the normal binders and do have good rheology. The question becomes do they have the required inertness to molten alloys.

Two years ago, I presented a paper at the Fall ICI meeting, that demonstrated a suitable replacement material for zircon flour for the backup shell. The slurry was a proprietary alumina and alumino-silicate mixture made for Buntrock Industries by CE Minerals. Using this material, which we named ThermaFrac, slurry was made in our lab and shipped overnight to ShellCast in Michigan. The slurry was re-mixed and hand poured onto a wax. All other aspects of the shell were the same as production. The casting alloy was 17-4 SS and was poured at 2900 F. The casting quality was equivalent to production castings, but more sand blasting was needed to remove the entire prime layer. We believed that there was more reaction of the facecoat material with the metal and thus, more sand blasting was necessary. This material, while suitable for backup dip slurry, needs to be more inert to the metal in order to be used as a zircon substitute for first dip.

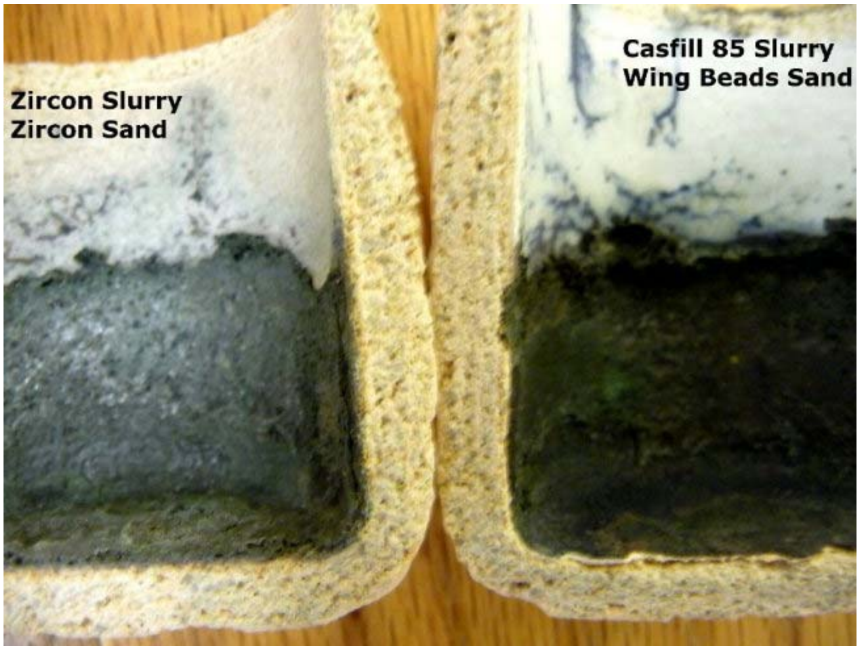
In order to run more experiments without the risk of trials at customer's foundries, we developed a lab test that could screen zircon replacement materials for air melt alloys. The test involves producing a small crucible using a double prime of the material to be investigated as a replacement for zircon flour and also appropriate stucco. Following the double prime, zircon flour backup slurry and 60% alumina stucco is used to build up thickness to support the metal. The crucible is then fired to 1800F and cooled back to room temperature. Metal is then loaded into the crucible and the crucible containing the metal is heated at a prescribed rate in an electrical resistance furnace to an appropriate pouring temperature for the alloy being used. In order to make the test severe enough to measure differences between materials, the peak temperature is held for 15 minutes and power is shut off. This results in the metal being liquid for approximately 30-40 minutes counting cool down time to solidus temperature. After cooling, the crucible is sectioned and the metal – crucible interface is evaluated against a crucible made with a zircon double prime. See Picture 2 that shows some crucibles.

Picture 2. Crucibles made of various inner materials to be evaluated as zircon substitutes.

Three crucibles were evaluated with the following double prime layers.

1. Zircon slurry with zircon stucco
2. Tabular Alumina slurry with Wing Beads stucco
3. Casfill 85 slurry with Wing Beads stucco

Casfill 85 is an alumino-silicate sintered with alumina made by Itochu Ceratech. For this test the alloy chosen was a cobalt base alloy F75 which is used for castings for orthopedic implants. The melt point of this alloy is about 2462 F (1350 C) and a test temperature of 2775 F (1525 C) was chosen as representative of typical metal temperature at pour. Picture 3 compares the Zircon with the Casfill 85 crucible. Picture 4 was the Tabular Alumina inner layer crucible.



Picture 3. Comparison of zircon and Casfill 85 inner layers

Picture 4. Tabular Alumina Prime layers with Wing Beads Stucco

Evaluating these crucibles at the interface using a microscope shows little difference between the materials. All three have a reaction layer that penetrates through the first dip up to the second dip.

Conclusions

1. Fused silica and Alumino-Silicates (both 47 and 60% Al2O3) are potential replacements for zircon sand on many alloys.
2. Cerabeads 60 has been shown to be a “drop in” replacement for zircon sand in several cases.
3. Alumina is probably best to replace zircon sand in higher temperature alloys and larger castings.
4. More work needs to be done on zircon flour replacement. Casfill 85 has promise for replacing zircon flour.
5. The task of changing from zircon to any alternative is not without effort and risk.