Oregon Resources Corporation
Chromite sand

Foundrymen have been using chromite sand for the production of steel castings and in applications when it is desirable to capitalize on the exceptional heat transfer capabilities of this unique mineral. There are chromite deposits around the world and foundrymen are generally familiar with the properties of chromite from certain deposits and the characteristics they demonstrate when used in their particular processing activities.

When chromite sand is mentioned, foundrymen assume that the chromite will be crushed. from agglomerated grains and chromite ore, the crushed sand will be angular, due to the crushing and the crystalline structure of the chromite mineral, and that it will be a four sieve distribution , with an A.F.S. Grain fineness Number of 48 to 51. These physical properties became the foundry standard as there had not been alternative chromite sources that could provide the unique properties that the Oregon Resources Corporation's chromite deposit can provide.

The Oregon Resources Chromite is mined in the Southwestern corner of Oregon and has properties that are unlike any other chromite deposit. This chromite sand is located approximately 60 miles east of a subduction zone, where the Pacific plate moves under the North American plate, causing an up-lift of previously submerged mineral deposits. Due to the ocean's wave action, these mineral particles have been rounded, polished, separated by specific gravity and classified into a very consistent, narrow, two sieve size distribution, with an 85 to 90 AFSGFN.
This mineral deposit contains seven different minerals and each of these minerals must be separated by electrostatic, low intensity magnetic separation and separation by rare earth magnets. The other minerals include Ilmenite, magnetite, zircon, kyanite, staurolite and garnet. Separating these aids in reducing the costs associated with the chromite product and offers other commercial minerals to various markets, providing at this stage in the cycle a robust economic model.

In comparing the ORC chromite with other chromites, it was evident that the ORC chromite sand provided improved core properties, excellent casting finishes and improved heat transfer. Both the higher core tensile properties and the higher heat transfer capabilities are due to the rounded grain shape, and narrow particle size distribution, allowing the rounded grains to pack together tightly, providing increased grain to grain contact and therefore increasing the contact points for the binder to form more binder bridges, with more adjacent grains. These packing characteristics provided a higher heat transfer capability due to the grain to grain contact that chills the casting more effectively than current crushed chromite sand. As with all new products attempting to gain market acceptance and in particular if they vary or differ from the legacy material, it is important that each difference in properties and performance be clearly explained and the advantages proven to be superior by third party evaluation. In this case extensive testing and third party validation provided compelling data.

The following commentary was based on the comparison of the ORC chromite with a South African chromite. In addition to performing one on one comparisons, the two sands were blended , in a 50:50 ratio, to see what the affects would be, if a foundry were to replace their current 48 to 51 AFS GFN, four sieve distribution, chromite sand with a 85 AFS, two sieve distribution chromite sand. This experiment also reflects the changes that would occur if a finer chromite was to continuously dilute the coarse chromite sand, up to the point of total replacement.

Sieve Analyses:
The two sands are quite different in both the particle size distribution and the average particle size (AFSGFN) value. The south African sand has a well balanced four sieve distribution, with an average grain fineness value of 48.10 AFSGFN. The ORC chromite sand is much finer, 87.02 AFSGFN, and has a two sieve distribution. The only set of sieves, used in this testing protocol, complies with the U.S., ASTM E-11, sieve series and sieve opening sizes. These sieves have been both optically and physically compared the ASTM standards and are considered master sieves. We have included the micron values for each sieve size, to assist you in comparing them to the European standard sieve opening and sieve positioning.

Foundrymen are used to the wider, four sieve distribution, and are usually nervous about using a narrow distribution sand, because they feel the wider distribution will allow the finer grains to fill the voids, between the more coarse grains, and provide a better casting finish. Another area of concern was based on the use of silica sand and the thermal expansion of the sand grains. Because the temperature range, for the expansion of the silica sand is very narrow, it was felt that a more narrow distribution would aggravate the expansion, resulting expansion scabs and veining type defects. Since chromite sand has a coefficient of expansion that is $1/6^{th}$ that of silica sand, this is not considered a concern in chromite sands.

With respect to the finer grains filling the voids, and producing a smoother casting surface, the ORC chromite has a rounded grain structure and will pack easily with vibration or pneumatic compaction of the sand. Another area of concern is that angular or crushed sands have significantly more surface area, for the binder to coat, and the finer the particle size, the greater the degree of angularity. The ORC chromite sand is unique, with its rounded grain structure, and does not contain the high level of fractured grains in these finer particle size fractions. Given the finer particle size, the narrow distribution, and the increased packing efficiency, of the ORC chromite, we have observed higher tensile strength, for the cores, and an improved casting finish.

With every advantage there are perceived disadvantages. One area of concern, for every foundryman, is the permeability of the sand and its ability to vent the decomposition gases through the print areas and not into the castings. This concern has been addressed by various techniques and is not a new problem for the foundry. Using typical stick vent procedures, vent hose, non-contact venting, offset venting and many other procedures, foundrymen have found they could use very fine sands, without gas related defects.

Typically, a finer sand requires additional binder to obtain sufficient strength to handle the cores. In the case of the ORC chromite, the rounded grain shape and narrow distribution reduce the surface area of the sand and allow more contact points between the grains. A typical chromite sand may have an average of 6 to 8 contact points with adjacent grains, where the ORC chromite has 10 to 12. This may allow for reductions in the binder addition, but they may not be significant, however any reduction in the binder addition will reduce the amount of gases that must be vented from the core or mold.

pH and Acid Demand Values (A.D.V.):
The ORC deposit has a slightly acidic pH (6.26), as compared with the South African chromite's (7.6) pH, which is more basic. This typically, but not always, can have an affect on the acid demand value of the sand, with the more basic sand requiring a greater amount of acid to catalyze an acid cured binder system and shortening the bench life of a gas catalyzed phenolic urethane binder systems.

The acid demand value of the ORC chromite is a negative value (-0.1 ml) whereas the South African chromite has a value of 1.5 ml. Both of these values indicate that any contaminants, in the sand, are not interacting with alkaline materials and that they both should work well with typical foundry binder systems.

A.F.S. Clay Content (≤ 20μ):
The AFS clay content of the South African chromite sample was higher than that of the ORC chromite. A higher AFS clay content can be caused by soluble particles, dispersed in the sand, or as a coating, produced when a high clay content, in the wash water, is dried on the surface of the grains.

When a chemical binder is applied onto the surface of the sand grains, and the sand grains are compacted, the binder forms binder bridges, due to capillary action, between the adjacent sand grains. These binder bridges provide sufficient strength to resist failure, when a mold or core is stressed by improper handling or from the thermal input from the metal. The strength of the cores can be evaluated by tensile strength measurements or in elevated temperature testing to determine if the core has sufficient strength to resist these adverse conditions.

The binder bridge, between these sand grains, can fail in two ways. As the core is stressed, if the bond of the binder to the surface of the sand grain is strong, the failure will occur through the binder bridge areas, connecting the two sand grains, and will result in a cohesion failure. The second method of failure is an adhesion failure, this occurs when the binder bridge, between the sand grains, is stronger than the bond to the sand's surface. This adhesion failure results from the binder peeling away from the surface of the sand grains. This type of failure is typically due to a coating on the surface of the sand that impedes the ability of the binder to adhere to the sand's surface. These adhesion failures can come from high clay coatings, excessive release agent on the pattern, hydraulic oil, etc.

The AFS clay content of the South African chromite is twice that of the ORC chromite. Foundries have had problems related to inconsistent washing, resulting in high clay contents of the South African chromite sands. In most cases the processing plants have a difficult time keeping a clean water supply to wash and rinse the sand prior to drying. Although the clay level of the RSA chromite sample used for this particular test is not exceptionally high, it is still much higher than the ORC chromite. The ORC chromite is naturally devoid of any significant clay due its natural occurrence and processing.

In order to effectively separate the various minerals present in the ORC deposit, the sand is attritioned at a 70 to 80% solids content, the ultra fines and clay removed with a counter flow separator, and the sand rinsed prior to drying and heating. If the surface of the ORC chromite is not clean, the electrostatic separators, low intensity magnets and rare earth magnets will not be able to effectively separate the various minerals, the product would fail all of the established quality testing parameters and the sand would have to be discarded or reprocessed. Typically ORC processed sand results in a AFS Clay content near 0.15%.

Loss on Ignition (L.O.I. test):
In the majority of the aggregates, used in the foundry to produce cores and molds, the loss on ignition test is an excellent tool for determining the residual binder level for reclaimed sand and for quantifying the amount of binder that was added at the mixer. Due to the high iron content of chromite sand, and the conversion of the iron from FeO to Fe3O4 and ultimately Fe2O3, these tests are either performed in an inert atmosphere, covering the test sample with a pre-burnt carbon sand to minimize any oxidation of the iron, or by running a un-bonded sample of the chromite as a reference and compensating for the oxidation associated with the chromite sand.

In testing chromite sand for its L.O.I., it could be assumed that a higher iron content would produce a higher weight gain, when the chromite is exposed to high temperatures in an oxidizing atmosphere. In the case where the South African chromite is compared with the ORC chromite, the South African sample had a higher iron content, 29%, versus ORC's chromite's 26%, the South African sample gained 0.43% and the ORC gained 0.82%. This anomaly is due to the finer sand's higher surface area allowing a greater amount of oxidation in this first exposure to high temperatures, in an oxidizing atmosphere. Referring to the L.O.I. values on the attached chemical analyses data sheet, this trend is reversed, with the South African chromite providing an L.O.I. gain in weight of 2.02%, versus ORC's gain of 1.6%. We are currently testing to determine if multiple exposures of the South African and ORC chromite sand's, to high temperatures in an oxidizing atmosphere, will stabilize after a specific number of exposures. We will append this data as soon as it is completed.

Permeability:
The permeability of the ORC sand is lower than that of the South African chromite and this is a concern for all foundrymen. This area of concern has been partially addressed in the sieve analyses section of this report, although we would like to point out some interesting characteristics of the ORC chromite versus the South African chromite. The

South African chromite provided a base (un-bonded) permeability value of 268, versus the ORC's base permeability of 43. When the two sands were coated with binder, formed into cores and the core's permeability evaluated, the South African chromite core's permeability increased from the 268, base permeability value, to 286 in the bonded core, an increase of 6.7%. The base permeability of the ORC chromite is 43, but the permeability of the test cores increased to 98, a change of 55 permeability units and 128%.

Although a 100 permeability value may cause concerns for many foundrymen, it is always suggested that the foundry use all of the venting techniques available to reduce the incidence of opportunity for producing gas related defects. Foundrymen have adjusted to lower permeability values when they utilize zircon sand, for specialty cores and molds, or in foundries where zircon is the primary aggregate. We would be happy to provide you with information regarding the various techniques used for venting cores and molds. When a foundry uses good venting techniques, they can reduce their reliance on the sand's permeability, allowing them to use a finer sand, and obtain an improvement in the casting's surface finish, reducing cleaning time.

Chemical Composition:

Attached is a summary sheet, comparing the chemical composition of the four individual runs, of the ORC chromite processed at the Hazen Laboratories, with the blended product that represents the sample you will be receiving shortly as well as the chemical composition of the South African chromite.

The most significant areas where the chemical composition, of the ORC chromite, varies from the South African chromite include:

- Silica content (SiO2):
  The silica content of the South African chromite sample was determined to contain 1.0% SiO2. The SiO2 content of the Hazen Chromite Blend #6 was determined to be 0.96%. Since the SiO2 contents for all of the individual Hazen products and blends were consistently between 0.41 and 0.65%, we felt that this analyses was not representative and have submitted it for a second analyses. We also felt that the 1.0% SiO2 level for the South African sample could be an error and we have also re-submitted this sample, for a second analyses. We will provide the second analyses, for both of these sands, as soon as they are completed.

- The iron content, Fe2O3, of the South African sample (29.0%), is higher than the ORC chromite"s (26.0%). A higher iron content typically relates to a lower fusion point for the chromite sands. This may not be a significant variance, but we felt it should be noted.

- The titanium content, TiO2, of the ORC chromite, is slightly higher than the South African chromite. We feel that this higher TiO2 level could be beneficial, if the TiO2 can aid in reducing nitrogen gas defects. TiO2 is a great scavenger for nitrogen, but we have not determined if this will actually aid in the reduction of nitrogen related defects in steel castings.

- The chromite content, Cr_2O_3 content of the ORC chromite is approximately 2% higher than the South African chromite, when analyzed by AA. The ORC chromite is approximately 5% higher than the South African chromite, when analyzed by the XRF procedure. We feel that both of these values are too high and not typical of the values obtained by chromite suppliers around the world.

  It could be mutually beneficial if the South African chromite suppliers, and ORC, could exchange replicate samples, with known Cr_2O_3 values, so that a higher level of chemical composition credibility could be established. We would like have these analyses performed at multiple laboratories, on chromite samples of various chromite contents, and the data correlated. This cooperation of the chromite suppliers could provide better reference standards and allow the various industries, using chromite, to have a higher level of confidence in their analyses.

  If you are using a commercial laboratory for your analyses, would it be possible for you to provide ORC with contact information, so that ORC can submit duplicate samples to both laboratories and determine a more realistic Cr_2O_3 analytical procedure?

The core tensile, core weight, core permeability and scratch hardness comparisons: ORC appreciates the sample provided of the South African chromite, for direct comparison testing with the ORC #1-A blended chromite product. The only difference between the various ORC chromite products relates to how they were processed. The ORC chromite sample #1 is a blend of all four of the ORC deposits and was produced in a small pilot plant operation. The Hazen #5 sample was produced in the Hazen facility and is a blend of the four separate products produce, sequentially during the processing, and blended at the University of Northern Iowa's Metal Casting Technology Center. The sample, designated Hazen #6, consists of a blend of the four separate processing runs at Hazen, but the entire 31 ton sample was blended and sampled throughout the loading of the bulk containers and is more representative of the samples distributed to various foundries and shell coating operations for their evaluation . We have attached the core tensile and casting evaluation data for these three sands, as well as the South African chromite that was used for this study. The Hazen #5 sample provided average tensile strengths of 374 psi/2,581 kPa, four hours after gassing and 406 psi/2,802 kPa 24 hours after gassing. The Hazen #6 sample provided average tensile strengths of 590 psi/4,068 kPa, four hours after gassing and 481 psi/3,316 kPa 24 hours after gassing.

The attached data sheets and bar graphs show the core weights, tensile strengths, core permeability and the scratch hardness values for four test mixtures. The test mixtures evaluated included a 100% South African chromite sand, a 50% South African chromite/50% ORC Hazen #5 blended chromite mixture and a reference mix, utilizing 100% ORC Hazen blended chromite sand #5. The core tensile strength values for the 50% South African /50% ORC chromite provided tensile strengths exceeded either of the two individual sands. This is a common occurrence, when a coarse sand is blended with a finer sand, providing more grain to grain contact points.

Typically we would like to provide core tensile, scratch hardness, permeability and core weight data on the competitive product as well as 75%:25%, 50%:50%, 25%:75% ratios and a 100% sample of the ORC reference sand. Unfortunately, we were limited by the size of the South African chromite sample and the need to produce both physical analyses cores as well as cores for the test castings.

Casting Analyses:

We have poured step cone castings and have had them sectioned, and cleaned with a wire brush, for examination, numerical evaluations of the casting surface properties and casting photography. If you would like to obtain photographs please contact us.

If you have any questions or require assistance relative to the processes set out in this paper, please contact us.

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