(54) Title: SAND CASTING FOUNDRY COMPOSITION AND METHOD USING THERMALLY COLLAPSIBLE CLAY MINERALS AS AN ANTI-VEINING AGENT

(57) Abstract:
A sand casting foundry composition reduces thermal defects that cause veining in metal parts cast from sand casting foundry shapes formed from the foundry composition. Foundry sand grains are mixed substantially uniformly with thermally collapsible clay mineral particles, and a curable binder coats the sand grains and the thermally collapsible clay mineral particles to establish...
Abstract (continued):

core and mold foundry shapes used to cast the metal part. Anti-veining capability occurs because the thermally collapsible clay mineral particles exhibit an inherent characteristic of crystal structure collapse upon exposure to temperatures encountered in casting the metal part. The crystal structure collapse yields space which is consumed by thermal expansion of the sand grains in the foundry composition. This compensatory effect avoids the creation of mechanical forces and stresses within the foundry shape that cause the cracks and fissures in the foundry shape that lead to veining.
Abstract of the Disclosure

A sand casting foundry composition reduces thermal defects that cause veining in metal parts cast from sand casting foundry shapes formed from the foundry composition. Foundry sand grains are mixed substantially uniformly with thermally collapsible clay mineral particles, and a curable binder coats the sand grains and the thermally collapsible clay mineral particles to establish core and mold foundry shapes used to cast the metal part. Anti-veining capability occurs because the thermally collapsible clay mineral particles exhibit an inherent characteristic of crystal structure collapse upon exposure to temperatures encountered in casting the metal part. The crystal structure collapse yields space which is consumed by thermal expansion of the sand grains in the foundry composition. This compensatory effect avoids the creation of mechanical forces and stresses within the foundry shape that cause the cracks and fissures in the foundry shape that lead to veining.
SAND CASTING FOUNDRY COMPOSITION AND METHOD
USING THERMALLY COLLAPSIBLE CLAY MINERALS AS AN
ANTI-VEINING AGENT

5 Cross-Reference to Related U.S. Application

This invention and application is related to and claims the benefit of U.S.
Provisional application titled "Method for Producing Foundry Shapes," Serial No.
60/332,679, filed November 14, 2001, of which the present applicants are
inventors. The subject matter of this provisional patent application is incorporated
herein by this reference.

Field of the Invention

This invention relates to foundry techniques used to create sand cast metal
parts. More particularly, the present invention relates to a new and improved sand
casting foundry composition and method using thermally collapsible clay minerals
as an anti-veining agent to prevent veining defects in the cast metal parts.

Background of the Invention

Sand casting is a process used in the foundry industry to produce cast
parts. In sand casting, disposable foundry shapes are made by forming a sand-
based foundry composition into predetermined configurations and curing the
composition to preserve those foundry shapes. A binder in the foundry
composition maintains the predetermined configuration of the foundry shape. The
foundry shape which defines the exterior of the resulting cast part, known as a
mold, is positioned relative to the foundry shape which defines the interior of the
cast part, known as a core. With the mold and the core foundry shapes oriented
as desired, molten metal is poured between them. The foundry shapes confine the
molten metal while it cools and solidifies into the resulting cast part.

The binder must have the capability to preserve the predetermined
configurations of the mold and core foundry shapes while those foundry shapes
are oriented in the appropriate relationship to create the cast parts and during the
time while the molten metal solidifies into the cast part. The typical type of foundry sand used for this purpose is silica sand, although other useful foundry sands include chromite, zircon and olivine sands. Two basic types of binders are commonly employed: inorganic binders, such as clay, and chemical binders, such as phenolic resin binders.

The most widely used inorganic binder for a sand-based foundry composition is bentonite clay. The foundry composition of the sand and bentonite clay binder is referred to as green sand. Green sand is a water tempered sand mixture having plasticity. A green sand foundry composition is typically formed by mulling silica sand, bentonite and a small amount of tempering water. The tempering water allows the bentonite to become sufficiently plastic so that it may be smeared relatively uniformly and thinly over the sand grains during the mulling process. The thin coating of the bentonite on each sand grain interacts with the thin coating on the adjacent sand grains causing the sand grains to be held in place in the mold and core foundry shapes. Green sand molding is economical and is widely used to cast ferrous as well as non-ferrous metal parts. Green sand molding permits high quantity, high quality foundry production, particularly for smaller cast parts.

Chemically-bonded, sand-based foundry compositions use a variety of polymerizable or curable organic and inorganic resin binders to hold the sand grains together in the desired mold or core shape. Chemical bonding involves mixing the sand and a polymerizable or curable binder. Once the mixture of the sand grains and the uncured binder have been shaped into the desired configuration, the chemical binder is polymerized or cured by the addition of a catalyst and/or heat, resulting in converting the shaped configuration into hard, solid, cured mold or core foundry shapes. Examples of curable resin binders include phenolic and furan resins. In a typical no-bake process, i.e. one which does not involve the addition of heat for curing, the sand, binder, and a liquid curing catalyst are mixed and compacted to produce the desired configurations of the mold or core foundry shapes. A commonly used no-bake binder is a
polyurethane binder, derived by curing a polyurethane forming binder material with a liquid tertiary amine catalyst.

When subjected to the heat of the molten metal, the sand grains in mold and core foundry shapes expand. If the sand grains in the molds and cores are too close together, the sand grains expand in size and push on the adjacent sand grains. The thermal expansion opens up small cracks and fissures in the molds and cores, and the molten metal penetrates into those cracks and fissures. When the molten metal solidifies, raised, narrow ridges on the surfaces of the cast part result at those locations where the molten metal penetrated into the small cracks and fissures. The resulting narrow ridges are referred to as “veins” or “veining”. The veining may make it necessary to surface grind or machine away the projecting veins. Of course, such surface grinding or machining increases the cost of producing the cast part.

Another type of foundry shape defect is caused by gas formation, particularly within core foundry shapes. Water in green sand casting foundry compositions will volatilize into steam in the presence of the hot molten metal. Trapped steam may cause pin holes or cracks in the foundry shape, resulting in the metal penetration into the foundry shape. The gas may also create an uneven or discontinuous surface in the cast part. Gas pressure also results from the volatilization of certain chemical constituents in foundry compositions. It is desirable to use chemical binders which are not susceptible to excessive volatilization, particularly in core foundry shapes.

Expansion and cracking from gas pressure is more of a problem in core foundry shapes, because core foundry shapes are typically surrounded by the molten metal due to their internal position. Those binders which produce significant amounts of gas when exposed to metallurgical temperatures may only be used in foundry shapes where the confined gas has an avenue to escape, otherwise the gas itself may induce cracks, fissures and pin holes. Mold foundry shapes are exposed to the ambient atmosphere and therefore provide avenues for the gas pressure to escape, although the gas pressure may nevertheless create
defects in mold foundry shapes. To avoid excessive gas creation where a clay binder is used, the amount of tempering water used to activate the clay binders and allow it to be smeared over the sand grains is limited.

A wide variety of different agents have been added to sand casting foundry compositions in an attempt to improve the properties of core and mold foundry shapes to avoid veining and other casting defects. These additives, known generically as anti-veining agents, include starch based products, dextrin, fine ground glass particles, red talc and wood flour, i.e. particles of wood coated with a resin, granular slag, pulverized sea-coal, alkaline earth or alkaline metal fluoride, and lithia-containing materials, among many other things. Several types of iron oxide are also used as anti-veining agents. These include red iron oxide, also known as hematite (Fe₂O₃), black iron oxide, also known as magnetite (Fe₃O₄), yellow ochre, and a black hematite known as Sierra Leone concentrate.

Each of these anti-veining agents are theorized to function in a different way to avoid or reduce the incidence of cracks, fissures and the other defects in the foundry shapes which cause veining. It is generally believed that the iron oxides increase the hot plasticity of the sand mixture by the formation of a glassy layer between the sand grains. The glassy layer deforms without fracturing at metallurgical temperatures, to prevent fissures in the foundry shapes. Grains of slag are thought to become soft at metallurgical temperatures permitting the sand grains to expand. Sea-coal and other combustible anti-veining agents are believed to form volatile gas at metallurgical temperatures leaving void space into which the sand grains expand.

Summary of the Invention

The present invention relates to the use of thermally collapsible clay mineral particles as an anti-veining agent in a sand casting foundry composition used to create foundry shapes for casting metal parts. The thermally collapsible clay mineral particles include clay minerals that undergo crystal structure collapse when the foundry shape is heated by the molten metal during casting. With a sufficient concentration or volumetric quantity of thermally collapsible clay mineral
particles distributed within the foundry shape, and with sufficient sizes of the thermally collapsible clay mineral particles, the collapse of the crystal structure will cause the thermally collapsible clay mineral particles to yield space within the foundry shape sufficient to compensate for the thermally-induced physical expansion of the sand grains. The net result is a negligible change in volume of the foundry shape during heating, thereby avoiding the mechanical forces which cause cracks and fissures in the foundry shape that result in veining.

The volumetric quantity of the thermally collapsible clay mineral particles necessary to yield the physical volume sufficient to compensate for the physical expansion of the sand grains may be achieved by using a relatively larger number of relatively smaller physically-sized particles or a relatively smaller number of relatively larger physically-sized particles in the foundry composition. An advantage of using a relatively smaller number of relatively larger sized particles is that less resin binder is consumed by the thermally collapsible clay mineral particles. Resin binder is added to and mixed with the mixture of the sand grains and thermally collapsible clay mineral particles to form the foundry composition. Since resin binder is expensive, it is important to limit the quantity used to the smallest amount necessary to achieve adequate tensile strength of the foundry shapes to resist breakage or deformation when the foundry shapes are positioned to cast the metal part and while confining the molten metal as its solidifies into the cast part. More surface area is exhibited by a larger number of smaller sized particles as compared to a smaller number of larger sized particles which occupy the same volumetric space. The amount of resin binder consumed is directly related to the surface area of the particles which must be coated with that resin binder, and it is for this reason that a relatively fewer number of relatively larger sized thermally collapsible clay mineral particles is preferred.

These and other improvements are obtained in a number of different forms of the present invention. A sand casting foundry composition reduces thermal defects that cause veining in metal parts cast from sand casting foundry shapes formed from the foundry composition. Such a foundry composition comprises a
plurality of foundry sand grains, a plurality of thermally collapsible clay mineral particles substantially uniformly distributed among the sand grains to form a matrix of sand grains and thermally collapsible clay mineral particles, and a curable binder coating the sand grains and the thermally collapsible clay mineral particles to hold sand grains and the thermally collapsible clay mineral particles in position within the matrix upon curing. A method of making the foundry composition involves mixing a plurality of foundry sand grains with a plurality of thermally collapsible clay mineral particles to form a mixture in which the thermally collapsible clay mineral particles are substantially uniformly distributed within the sand grains in the mixture, and coating the mixture of sand grains and the thermally collapsible clay mineral particles with a binder sufficient to hold sand grains and thermally collapsible clay mineral particles in position relative to one another after curing of the binder. A method of making a foundry shape from the foundry composition involves mixing a plurality of foundry sand grains with a plurality of thermally collapsible clay mineral particles to form a mixture in which the thermally collapsible clay mineral particles are substantially uniformly distributed among the sand grains in the mixture, coating the mixture of sand grains and thermally collapsible clay mineral particles with a binder sufficient to hold the sand grains and clay particles in place relative to one another after curing of the binder, shaping the binder-coated mixture into a predetermined configuration of the foundry shape, and curing the binder while maintaining the predetermined configuration. A method of casting a metal part using core and mold foundry shapes formed in this manner involves positioning the core and mold foundry shapes relative to one another to define the metal part to be cast, pouring molten metal in the space between the core and mold foundry shapes, and solidifying the molten metal while confined between the core and mold foundry shapes.

These aspects of the invention may also be supplemented by further preferable improvements. The thermally collapsible clay mineral particles are selected to have a clay mineral with a crystal structure that collapses upon
exposure to the temperature created by molten metal used in casting the metal part. Upon collapse of the crystal structure, the thermally collapsible clay mineral particles yield sufficient volumetric space to compensate for and counterbalance the additional volumetric space consumed by the thermal expansion of the sand grains, thereby avoiding the creation of mechanical forces and stresses within the foundry shape that lead to veining. The volumetric concentration and size of thermally collapsible clay mineral particles determines the desired yield volume to compensate for the thermal expansion of the sand. The binder is preferably added after the sand grains and thermally collapsible clay mineral particles have been mixed, thereby facilitating the homogenous distribution of the thermally collapsible clay mineral particles among the sand grains while evenly coating the sand grains and thermally collapsible clay mineral particles sufficiently to hold them together in the predetermined desired foundry shape. This sequence of addition will lead to less use of binder than if the binder is added before the sand grains and the thermally collapsible clay mineral particles have been mixed together. There are many other desirable improvements described herein which may be practiced with the different aspects of the present invention.

A more complete appreciation of the scope of the present invention and the manner in which it achieves the above-noted and other improvements can be obtained by reference to the following detailed description of the presently preferred embodiments taken in connection with the accompanying drawings, which are briefly summarized below, and by reference to the appended claims.

Brief Description of the Drawings

Fig. 1 is a combined diagrammatic illustration of the components of a sand casting foundry composition and a flow chart of the steps of making the sand casting foundry composition and of the steps of using the sand casting foundry composition to produce core and mold foundry shapes, according to the present invention.

Fig. 2 is a flow chart illustrating the use of the foundry shapes formed as shown in Fig. 1 to produce a cast part.
Fig. 3 is an idealized structural illustration of a few randomly oriented sand grains which are separated by a thermally collapsible clay mineral particle in the sand casting foundry composition and foundry shape described in Fig. 1.

Fig. 4 is an enlarged partial view of Fig. 3, showing in an idealized, magnified manner a compensatory effect of the thermally collapsible clay mineral particle as the sand grains expand from the effects of the temperatures to which the foundry shapes are subjected during the casting process shown in Fig. 2.

Fig. 5 is an enlarged illustration similar to a portion of Fig. 4 illustrating a negligible anti-veining effect created by a sand casting foundry composition which utilizes thermally collapsible clay mineral particles of insufficient volumetric concentration and size.

**Detailed Description**

A sand casting foundry composition 10 of the present invention, illustrated in Fig. 1, comprises sand grains 12 and thermally collapsible clay mineral particles 14 which are mixed together relatively uniformly at 16 to form a mixture 18. The mixture 18 is then coated at 20 with a binder 22. The resulting sand casting foundry composition 10 is thereafter shaped into mold and core foundry shapes at 24, after which the binder 22 is allowed or caused to cure (set up) at 26 to hold the uniformly mixed sand grains 12 and thermally collapsible clay mineral particles 14 into integral, structurally-sound foundry shapes 28.

The foundry shapes 28 formed from the sand casting foundry composition 10 are then used to produce cast metallic parts as shown in Fig. 2. The cured core and mold foundry shapes 28 (Fig. 1) are placed in a desired relationship with respect to one another to define the cast part which will ultimately be produced, as shown at 30. With the foundry shapes in the desired orientation at 30, the molten metal is poured at 32 into the spaces defined by and existing between the positioned foundry shapes. The molten metal is allowed to cool and solidify into the desired shape of the cast part at 34. Once the molten metal has solidified sufficiently, the cast part is removed from the foundry shapes as shown at 36. The thermally collapsible clay mineral particles 14 act as an anti-veining agent in the
foundry shapes 28 (Fig. 1) to reduce thermal expansion defects, such as veining, in ferrous and non-ferrous cast metal parts produced.

The thermally collapsible clay mineral particles 14 (Fig. 1) useful as anti-veining agents in the present invention must be composed of a clay mineral with a crystal structure that has an inherent characteristic and capability to collapse, contract, compress and/or weaken physically and structurally, under the influence of the typical temperatures to which the mold and core foundry shapes are subjected by the hot molten metal when the metal part is cast (Fig. 2). Upon collapse of the crystal structure, the thermally collapsible clay mineral particles also collapse, contract, compress and/or weaken physically and structurally to yield volumetric space within the foundry shape sufficient to accept and compensate for the physical expansion of the sand grains in response to the elevated temperature from the molten metal. The net result is a negligible change in volume of the foundry shape, thereby avoiding the mechanical forces which cause the cracks and fissures that result in veining. Although the characteristic of crystal structure collapse in some clay minerals is known, the advantageous use of such characteristics for anti-veining agents in foundry compositions and foundry shapes is not known to have been previously recognized or used.

The thermally collapsible clay mineral particles are obtained as particles of naturally occurring clays. Naturally occurring clays are composed predominantly of one or more clay minerals which were formed from the in situ chemical alteration of parent rocks or sedimentary materials as part of a process of dissolution and reprecipitation. Such clay minerals will form the predominant proportion of commercially mined naturally occurring clays from which the thermally collapsible clay mineral particles are obtained for use as anti-veining agents in accordance the present invention.

In addition to the clay minerals, the thermally collapsible clay mineral particles will also include a considerably smaller amount of other non-clay minerals. The non-clay minerals are residuals which resulted from the natural clay formation process when relatively insoluble minerals present in the parent material
survived the dissolution process intact or when non-clay minerals were co-precipitated along with the clay minerals. For this reason the mineral composition of naturally occurring clays may vary considerably between deposits. The non-clay minerals are inherently a part of commercially mined clay minerals, because the non-clay minerals cannot be readily separated on a commercial basis from the clay minerals. The non-clay minerals present in the thermally collapsible clay mineral particles used as anti-veining agents in the present invention will be a small fractional component of clay minerals and will be insufficient to prevent the thermally collapsible clay mineral particles from contracting or reducing in physical size or diminishing in strength to facilitate crushing or breaking, to yield sufficient volume to compensate for the expanded sand grains at the elevated temperatures which result from casting the part.

The clay minerals with a collapsible crystal structure useful in the present invention include, but are not limited to: illite, illite-smectite mixed layer clay minerals, chlorite, halloysite, kaolinite, sepiolite, palygorskite, and clays from the group of smectite minerals consisting of montmorillonite, beidelite, nontronite, saponite and hectorite. A few commercially-available natural clays containing one or more of these clay minerals include bentonite, kaolin and attapulgite. Many clay minerals have exchangeable cations associated with them. Where cations are present, such as with clays of the smectite group, they may be of any type, although sodium or calcium cations, or mixtures of both, are most frequently found. Thermally collapsible clay mineral particles are characteristically non-fissile, instead forming angular-spherical particles of a variety of shapes.

Examples of non-clay minerals found in the thermally collapsible clay mineral particles used as anti-veining agents in the present invention include calcite, dolomite, muscovite and biotite mica, pyrite, feldspar, gibbsite, quartz and opal (amorphous silica). The quartz may be present as single, larger, discrete crystals (sand) or as small agglomerations of very fine grains (chert). The non-clay mineral component of the thermally collapsible clay mineral particles does not contribute significantly to particle durability or to significantly reduce porosity. The
non-clay mineral component plays no significant role in the present invention and is present only because of the practical impossibility of mining the thermally collapsible clay mineral particles on an economic basis without also including relatively small portions of the inseparable non-clay mineral components.

The crystal structure collapse in the thermally collapsible clay mineral particles is preferred to occur under the influence of temperatures in a preferred range of about 600°C to about 700°C, although some crystal structure collapse may occur under the influence of temperatures as low as about 450°C to as high as about 1,000°C. The temperatures noted are the peak endothermic temperatures, as defined by differential thermal analysis, which are the temperatures at which the crystal structure collapse is complete or maximized. In most cases, the crystal structure collapse will start at lower temperatures and progress as the temperature increases to the peak endothermic temperature. The progressive nature of the crystal structure collapse coordinates with the gradual expansion in size of the sand grains with increasing temperature, so that the collapse of the crystal structure and the expansion of the sand grains generally occur on a coincident and counterbalancing basis.

Anti-veining agents which react to heating at too low a temperature may weaken the foundry shape or evolve void space between the sand grains prematurely before the sand grains are able to swell in response to heating from the molten metal. This premature reaction can create flaws in the surface of the foundry shape resulting in metal penetration into the foundry shape. Similarly, anti-veining agents which react to heating at temperatures above the point at which most swelling of the sand grains takes place may allow stresses to develop in the foundry shape which cause it to fracture before the anti-veining agent can function to relieve these stresses. This may allow the molten metal to penetrate the foundry shape causing surface defects in the casting. For this reason it is an important aspect of the present invention that the crystal structure collapse in the thermally collapsible clay mineral particles occur at temperatures that are
generally coincident with temperatures at which the sand grains undergo thermally induced expansion.

The collapse of the crystal structure at elevated temperatures deprives the particles of adequate strength to maintain their physical size and shape, in which case the thermally collapsible clay mineral particles may contract or reduce in physical volumetric size to yield additional space into which the sand grains can expand. In other cases, the crystal structure collapse will diminish the strength of the particle itself sufficiently so that it is crushed, compacted or deformed with considerably less external force than would otherwise be required if the crystal structure collapse had not occurred. The weakened thermally collapsible clay mineral particles are more easily broken or reduced in physical size and shape by the application of external forces from the expanding sand grains. These thermally-induced crystal structure collapse effects may occur coincidentally and to various degrees in the thermally collapsible clay mineral particles which are useful as anti-veining agents in the present invention.

The manner in which the thermally collapsible clay mineral particles are believed to act as an anti-veining agent may be understood by reference to the idealized and generalized illustrations of Figs. 3 and 4. A single thermally collapsible clay mineral particle 14a is used for illustration purposes in Figs. 3 and 4 to represent the effect of the present invention. A multiplicity of smaller thermally collapsible clay mineral particles which occupy approximately the same volumetric space as a single larger thermally collapsible clay mineral particle 14a would also have essentially the same effect as is described with respect to the single thermally collapsible clay mineral particle 14a. An angular spherical shape of the thermally collapsible clay mineral particle 14a has been shown for illustration purposes in Figs. 3 and 4, but other shape or shapes of the thermally collapsible clay mineral particle or particles would also have essentially the same effect under the influence of crystal structure collapse. Fig. 3 is also intended to represent characteristics and results achieved by the mixing step 16 and coating step 20 illustrated in Fig. 1, again on an idealized and illustrative basis.
Three sand grains 12a, 12b and 12c and a single thermally collapsible clay mineral particle 14a are shown in Fig. 3 in one of many different possible types of random orientations in a much larger matrix 40 of the sand grains 12 and thermally collapsible clay mineral particles 14 which are held together by the binder 22 (not shown) in the foundry shapes 28 (Fig. 1). The size of a single thermally collapsible clay mineral particle 14a is significant relative to the size of the sand grains 12a, 12b and 12c such that the single thermally collapsible clay mineral particle 14a separates the sand grains 12a, 12b and 12c from one another and props the sand grains apart. The cured binder (not shown), which coats the sand grains 12a, 12b and 12c and the thermally collapsible clay mineral particle 14a, maintains the orientation of the sand grains relative to the clay particles to separate the sand grains from one another. It is not necessary that all the sand grains within the foundry shapes 28 (Fig. 1) be separated from one another, but it is important that the volumetric concentration of the thermally collapsible clay mineral particles and the size of the thermally collapsible clay mineral particles be sufficient to provide spaces between a sufficient number of the adjacent sand grains throughout the matrix 40 so that the crystal structure collapse of thermally collapsible clay mineral particles will prevent cracks and fissures in the foundry shapes and thereby obtain the desired anti-veining effect.

The anti-veining effect achieved by the thermally collapsible clay mineral particles may be understood from Fig. 4, by viewing the impact of the thermally collapsible clay mineral particle 14a on the three sand grains 12a, 12b and 12c within the matrix 40 when the foundry shape 28 (Fig. 1) is subjected to the elevated temperature caused by the heat of the molten metal poured between the foundry shapes (32, Fig. 2). The relatively high temperature of the molten metal, for example at least about 1,540°C for iron, causes the crystal structure collapse in the particle 14a, thereby diminishing the exterior physical size of the thermally collapsible clay mineral particle 14a or permitting the forces from the thermally expanded sand grains 12a, 12b and 12c to readily crush, compress, deform or break the particle 14a. The diminished size or crushed shape of the particle 14a is
illustrated in idealized form by the dashed lines, while the solid outline represents
the previous dimension of the particle 14a prior to thermal collapse or
compression. The reduction in physical size, which weakens the particle 14a as a
result of the crystal structure collapse, yields or creates additional volumetric
space within the matrix 40 as represented by the difference between the dashed
lines and the solid outlines of the particle 14a.

The relatively high temperature of the molten metal (34, Fig. 2) causes the
sand grains 12a, 12b and 12c to expand to an increased physical size illustrated
by the dashed lines compared to the solid outline of the sand grains which
represent their previous dimension prior to thermal expansion. The sand grains
12a, 12b and 12c expand into the added volumetric space yielded by the thermal
collapse of the crystal structure of the clay mineral component of the particle 14a.
Thus, the collapsed or more readily compressible particle 14a within the matrix 40
of the foundry shape 28 (Fig. 1) yields enough space so that the sand grains 12a,
12b and 12c can expand into that added space. The mechanical forces induced
by thermal expansion of each sand grain on the sand grains adjacent to it within
the foundry shape is thereby avoided, and as a result, the cracks and fissures in
the foundry shapes that allow metal penetration and cause veining in the cast part
are avoided.

The rate and amount of expansion of the sand grains is dependent on the
amount and type of natural impurities contained within the sand grains. For quartz
sand grains, the rate of thermal expansion increases substantially with increases
in temperature until temperatures of about 650°C are reached, and then after
about 650°C, further expansion almost levels off with either a slight reduction in
physical size or a further increase in expansion of about 10% occurring over the
temperature range of from about 650°C to about 1,000°C. The temperature
(650°C) correlates very closely with the preferred peak endothermic temperature
range (about 600°C to about 700°C) at which crystal structure collapse occurs in
the thermally collapsible clay mineral particles, particularly in comparison to the
much higher temperatures to which the foundry composition and foundry shapes

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are subject from the much hotter molten metal when a metal part is cast. Accordingly, the yielding effect achieved by the thermally collapsible clay mineral particles occurs on a generally coincident and coordinated temperature basis with the expansion of the sand grains to avoid inducing the mechanical stresses that cause cracks and fissures in the foundry shapes. The degree of thermal expansion for the typical silica sand used in the North American foundry industry is typically in the range of about 1.3 to 1.6% of the original sand volume, with approximately 90% of that increase having occurred upon reaching temperatures of about 650°C.

The thermally collapsible clay mineral particles 14 are distributed throughout the resulting foundry shape 28 in such a manner that the idealized response described in connection with Figs. 3 and 4 is generally achieved throughout the foundry shape 28. While the orientation of the sand grains and the thermally collapsible clay mineral particles within the matrix 40 will not usually take the idealized form shown in Figs. 3 and 4, but instead will be a variety of different random orientations, the results are substantially similar if the quantity of the thermally collapsible clay mineral particles and the size of the thermally collapsible clay mineral particles are sufficient to separate a significant number of sand grains so that the collapse, contraction, compression or breakage of the thermally collapsible clay mineral particles yields adequate space to accept and compensate for the thermal expansion of the sand grains.

In the present invention, thermally collapsible clay mineral particles of adequate size and sufficient volumetric quantity yield a sufficient amount of volume within the foundry shape to accept and compensate for the thermally-induced expansion of the sand grains. The size and quantity of the thermally collapsible clay mineral particles required is related in significant part to the amount of void volume or space between the sand grains. A larger amount of void volume between the sand grains will require more and larger thermally collapsible clay mineral particles in the mixture 18 (Fig. 1) to obtain the desired anti-veining effect. Although the thermally collapsible clay mineral particle size and the amount
of thermally collapsible clay mineral particles used are interrelated, the effective range of sizes of these particles in the mixture 18 (Fig. 1) relates to the size of the average void space or volume between adjacent sand grains. A thermally collapsible clay mineral particle which occupies somewhat more than the average void space between adjacent sand grains will separate those adjacent sand grains sufficiently so that their thermal expansion will be counterbalanced by the thermal collapse of the thermally collapsible clay mineral particle. On the other hand, the anti-veining effect of a larger size thermally collapsible clay mineral particle can also be achieved by a multiplicity of smaller sized thermally collapsible clay mineral particles which provide the same volumetric separation and collapse capability as a single larger sized particle.

When the thermally collapsible clay mineral particles are too small and when there is an insufficient volumetric quantity of particles mixed with the sand grains, very little or no significant anti-veining effect will be achieved. Fig. 5 illustrates the lack of significant anti-veining effect created by thermally collapsible clay mineral particles which are too small in physical size and of insufficient volumetric quantity. In the idealized illustration of Fig. 5, a single thermally collapsible clay mineral particle 14b is again used for illustration purposes, but this single particle 14b could also be replaced by a larger number of relatively smaller thermally collapsible clay mineral particles having approximately the same volumetric size as the single particle 14b. Again, like Figs. 3 and 4, an angular spherical shape of the thermally collapsible clay mineral particle 14b has been illustrated, but other shapes of the thermally collapsible clay mineral particle or particles would also have essentially the same effect under the influence of thermally-induced crystal structure collapse and expansion pressure from the sand grains at the elevated temperatures from the molten metal.

The situation illustrated in Fig. 5 is similar to that illustrated in Fig. 3 except that the thermally collapsible clay mineral particle 14b is not sufficiently large to prevent the sand grains 12d, 12e and 12f from touching one another when thermally expanded. The influence of the elevated temperature causes the
particle 14b to collapse, contract, compress or break, but this reduction in size is of no significant benefit because it does not yield sufficient space into which the sand grains 12d, 12e and 12f can expand. Consequently the thermal expansion of the sand grains causes them to contact one another and to induce the mechanical stress on the foundry shape which causes it to crack or fissure, allowing the molten metal to invade the cracks and fissures to cause the undesirable veining.

Taking into account the size of the thermally collapsible clay mineral particles, a volumetric quantity of particles which is too small within the foundry composition and the foundry shape is one which does not yield enough space due to thermal crystal structure collapse to accept the thermal expansion of the sand grains. Although thermally collapsible clay mineral particles which are too small and of insufficient quantity might nevertheless have some capability to separate the sand grains, the degree of separation is insufficient if the amount of space they yield is insufficient to compensate for the greater amount of thermal expansion of the sand grains. Under such circumstances the quantity and size of the thermally collapsible clay mineral particles is insufficient to prevent the sand grains from contacting one another and inducing the mechanical stress in the foundry shape that opens the cracks and fissures which lead to veining in the cast part.

Thermally collapsible clay mineral particles that are too large are more difficult to mix and distribute evenly throughout the sand grains in the mixture. Thermally collapsible clay mineral particles which are not sufficiently evenly mixed with the sand grains are not effective in preventing the cracks and fissures uniformly throughout the foundry shape. Large numbers of relatively small thermally collapsible clay mineral particles negatively impact the tensile strength of the foundry shape. Large numbers of smaller thermally collapsible clay mineral particles also consume more binder. The effectiveness of the thermally collapsible clay mineral particles as an anti-veining agent also depends on the amount of collapse achieved by those particles. Having regard for all of these factors, an acceptable size and volume of thermally collapsible clay mineral particles must be
generally be determined experimentally and in relation to the type of foundry sand and the degree of collapse of the thermally collapsible clay mineral particles used.

The sand grains 12 used in the foundry composition 10 (Fig. 1) are conventional foundry sands, typically silica sand, although other useful foundry sands include chromite, zircon and olivine sands. An example of commercially available foundry sand is Wedron 520 available from Fairmount Minerals. Sand grains of Wedron 520 have an American Foundry Society (AFS) size or grains fineness number (GFN) of 59-65, which range corresponds to about the range between U.S. standard (ASTM) No. 30 and No. 140 mesh sizes.

The thermally collapsible clay mineral particles which have proved useful with the Wedron 520 sand have a granular or particulate form having an average particle size of from about 74 micrometers to about 3.4 millimeters. More particularly, the thermally collapsible clay mineral particles may range in size from about 105 micrometers to about 2.0 millimeters. The most effective particle size of the thermally collapsible clay mineral particles is from about 425 micrometers to about 2.0 millimeters. Other sizes of thermally collapsible clay mineral particles may be optimal for other sizes of foundry sand, for the reasons noted above. Particles having an average size of about 74 micrometers or greater are those which are generally retained on the surface of a U.S. standard (ASTM) No. 200 mesh sieve screen. Particles having an average particle size of 105 micrometers or greater are those which are generally retained on a surface of a U.S. standard No. 140 mesh sieve screen. Particles having an average particle size of 425 micrometers or greater are those which are generally retained on a surface of a U.S. standard No. 40 mesh sieve screen. Particles having a nominal size of less than about 2.0 millimeters are those which generally pass through a U.S. standard No. 10 mesh sieve screen. Particles having an average size of less than about 3.4 millimeters are those which generally pass through a U.S. standard No. 6 mesh sieve screen.

In general, to establish and control the anti-veining effect achieved by the thermally collapsible clay mineral particles, it is desirable to use predetermined
desired sizes of the particles so that the desired degree of volumetric space
achieved by the physical yielding of the thermally collapsible clay mineral particles
is controlled by the quantity or weight of the particles added to the mixture 18 (Fig.
1). It is therefore preferable to avoid substantial disintegration of the thermally
collapsible clay mineral particles 14 originally added for mixing at 16 (Fig. 1) into
smaller sizes.

The binder used in the present invention is preferably a conventional
chemical resin used in conventional foundry processes, such as phenolic hot box,
phenolic urethane, furan, sodium silicate including ester and carbon dioxide
system, polyester binders, acrylic binders, alkaline binders, epoxy binders, and
furan warm box systems. A particularly useful binder is a no-bake resin binder
system available from Ashland Chemical Company of Covington, Kentucky. This
resin binder system comprises a three part phenolic urethane system which
includes a series of binders and a liquid catalyst.

The moisture content of the thermally collapsible clay mineral particles can
also affect the anti-veining capability. If the moisture content of the thermally
collapsible clay mineral particles is too high, the foundry shape can potentially
crack or fissure because of the excessive amount of steam created by vaporization
of the moisture by the heat of the molten metal. It is therefore believed that the
incidence of veining decreases with decreasing moisture levels. Further, many of
the chemical binders used to produce this type of foundry shape are not
compatible with water. When using these binders the moisture content of the
foundry composition is inversely related to the tensile strength of the cured foundry
shape. Therefore, it is necessary to keep the moisture level of the thermally
collapsible clay mineral suitably low in order to maximize the tensile strength of the
cured foundry shape of the present invention. From a practical standpoint, the
thermally collapsible clay mineral particles will typically have a moisture level of
from 0.1% to about 12%. Preferably the moisture content of the thermally
collapsible clay mineral particles used in present invention should be within the
range of about 3 to 5% on a weight basis, with an optimal target moisture level of about 4%.

A method of making the sand casting foundry composition 10 is illustrated by Fig. 1. The method of making the foundry composition comprises the step 16 of mixing the sand grains 12 and the thermally collapsible clay mineral particles 14 into the mixture 18. The mixture 18 contains a relatively uniform distribution of the thermally collapsible clay mineral particles 14 throughout the mass or matrix of sand grains 12. The mixing step 16 may be accomplished by using any conventional mixing process. Thereafter, at step 20, the binder is added to the mixture 18. The binder is added to uniformly coat the sand grains and the thermally collapsible clay mineral particles while maintaining their uniform distribution within the mixture 18. The coating step 20 is preferably executed by employing the conventional techniques used for mixing conventional foundry resin-type binders with foundry sand.

The order of addition of the thermally collapsible clay mineral particles to the foundry composition is important in securing the anti-veining function of the thermally collapsible clay mineral particles within the foundry shape. The sand grains are preferably mixed with the thermally collapsible clay mineral particles first and then the foundry resin binder is added so that the resin coats the surface of the sand grains and the thermally collapsible clay mineral particles and provides a sand casting foundry composition with the thermally collapsible clay mineral particles dispersed throughout. Adding the binder to the mixture of uniformly distributed thermally collapsible clay mineral particles and sand grains does not disturb the uniformity. Adding the binder to the existing mixture of sand grains and thermally collapsible clay mineral particles also reduces consumption of the binder because more binder is distributed uniformly over the sand grains and less binder is available to be sorbed by the thermally collapsible clay mineral particles within the mixture, compared to the case where the binder is added to the thermally collapsible clay mineral particles first and then the binder-coated thermally collapsible clay mineral particles are attempted to be mixed with the sand grains.
Adding the binder to the thermally collapsible clay mineral particles first would provide more of an opportunity for the binder to be sorbed by the thermally collapsible clay mineral particles rather than to be distributed over the sand grains. Coating the sand grains with the binder first and then attempting to uniformly mix in the thermally collapsible clay mineral particles would inhibit the uniform distribution of the thermally collapsible clay mineral particle and would require an excessive amount of mixing to obtain the uniform mixture.

The sand grains 12 typically constitute about 85% to about 98.5% of the foundry composition 10 by weight. The thermally collapsible clay mineral particles 14 typically constitute from about 1% to about 10% of the foundry composition 10 by weight. More preferably, the thermally collapsible clay mineral particles may be present in an amount from about 1% to 7% by weight. Conventional foundry resin-type binder 22 will be added in an amount from about 0.5 percent to about 5.0 percent by weight.

The sand casting foundry composition 10 is formed at step 24 into the foundry shapes 28 as shown in Fig. 1. Depending upon the type of binder 22 added to the foundry composition 10, curing may start to proceed immediately with the coating step 20, in which case, it is necessary to shape the foundry composition 10 into the core foundry shapes and mold foundry shapes on a relatively immediate basis. In other cases, the addition of a physical property or a chemical constituent of binder may be required after the foundry composition 10 has been formed to cause the binder 22 coated at step 20 to set up or cure as shown at step 26. In any event, the desired number and type of core and mold foundry shapes are created by forming the foundry composition 10 into those desired shapes before the foundry composition cures, as shown at 24. Thereafter, once the foundry composition 10 is in the desired shape, the binder 22 is set up or cured as shown at step 26.

The curing which occurs at step 24 (Fig. 1) is achieved by causing or allowing the binder 22 coated at step 20 (Fig. 1) to set up to hold the sand grains and thermally collapsible clay mineral particles in the desired foundry shapes.
this sense, curing includes permitting the binder 22 to become effective for setting up without further influence after the foundry composition has been shaped into the foundry shapes at step 24, and also includes adding physical properties or chemical constituents to the foundry composition before or after shaping the foundry composition into the foundry shapes to cause the binder 22 added to the foundry composition 10 at step 20 to set up. If the type of binder 22 added at step 20 is one which will commence curing only in response to the addition of another chemical constituent, e.g. a catalyst, or in response to the addition of a physical property, e.g. the application of heat or pressure, and that chemical constituent or physical property can be added at a later time so that it permeates the complete shape of the mold or core foundry shape, the step 26 will involve adding the additional chemical constituent or physical property which causes the binder to set up. If the type of binder 22 is one which commences curing once coated at step 20, the cure step 26 will progress without further action as an inherent result of the coating step 20.

Once the binder has cured at step 26, the shapes of the molds and cores established at 24 is fixed, and the foundry shapes 28 are completed. The completed foundry shapes 28 have sufficient tensile strength and integrity so that they may be moved and positioned for use in casting the metal part as has previously been described in connection with Fig. 2. Of course, sometimes casting the metal parts may require only a mold foundry shape and not a core foundry shape, or vice versa.

Examples

Different silica sand-based sand casting foundry compositions were prepared for the purpose of evaluating thermally collapsible clay mineral particles as anti-veining agents and comparing the anti-veining effects of thermally collapsible clay mineral particles to other well-known anti-veining agents. Effectiveness in preventing veining and strength of tensile properties in the resulting foundry shapes were evaluated. The thermally collapsible clay mineral particles used in these tests were bentonite, which is composed primarily of the
thermally collapsible clay mineral montmorillonite. A widely used anti-veining agent used for comparison to the thermally collapsible clay mineral particles was "Veinseal" (trademark), a lithia and iron oxide based anti-veining agent which is a widely used and generally accepted as a leading anti-veining agent in the sand casting foundry industry at the present time. The "Veinseal" product is manufactured by Ashland Chemical Company.

Identical silica sand-based compositions were prepared utilizing the anti-veining agents noted in the following Tables. Test samples were prepared by blending Wedron 520 silica sand grains and the anti-veining agent in a mixer for 30 seconds. The addition of the three part Ashland binder system was completed according to the manufacturers recommendations.

Tables 1 and 2 summarize the effectiveness of thermally collapsible clay mineral particles and "Veinseal" anti-veining additives. Table 1 is directed to test results for sand cores coated with EZ Kote Graphite Coating.

<table>
<thead>
<tr>
<th>Material</th>
<th>Control</th>
<th>Example 1</th>
<th>Example 2</th>
<th>Example 3</th>
<th>Example 4</th>
<th>Example 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashland (Part 1)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Pepset XI 1000</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Ashland (Part 2)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Pepset XII 2000</td>
<td>2000</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
<td>1940</td>
<td>1860</td>
</tr>
<tr>
<td>Ashland Catalyst 3502 Sand</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Sodium Bentonite (#40 mesh)</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>100</td>
<td>60</td>
<td>140</td>
</tr>
<tr>
<td>Veinseal</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Comparison of Anti-veining Agents

Veining (Number Observed)

<table>
<thead>
<tr>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>2</td>
</tr>
</tbody>
</table>

Examples 1 and 2 illustrate the effectiveness of thermally collapsible clay mineral particles as anti-veining agents, as compared to the commercially available "Veinseal" anti-veining agent. Examples 3-5 illustrate the effect of thermally collapsible clay mineral particle concentration on veining.

Graphite coatings, such as EZ Kote, are known to reduce the number and severity of veins and other surface defects in castings by providing a more uniform
core surface. In order to create a worst-case condition a series of uncoated cores was also prepared and tested. Table 2 is directed to test results for uncoated sand cores.

### Table 2

**Comparison Of Anti-Veining Agents**

**Uncoated Sand Cores**

<table>
<thead>
<tr>
<th>Material</th>
<th>Formula (wt)(g)</th>
<th>Control</th>
<th>Example 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashland (Part 1) Pepset XI 1000</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Ashland (Part 2) Pepset XII 2000</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Ashland Catalyst 3502</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2000</td>
<td>1900</td>
<td></td>
</tr>
<tr>
<td>Sodium Bentonite</td>
<td>-</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Veining (Number Observed)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>Vertical</td>
<td>4</td>
<td>1 (minor)</td>
</tr>
</tbody>
</table>

The tensile properties of various sand casting foundry compositions were calculated based on retained tensile strength in reference to the control material as indicated in Table 3 below. Tensile strength is important to maintain the desired shape of the mold or core before and during casting.

### Table 3

**Comparison Of Anti-Veining Agents**

**Uncoated Sand Cores**

**Retained Tensile Properties Of Anti-Veining Foundry Compositions**

**Formulation of Prepared Mixtures (wt)(g)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Control</th>
<th>Example 7</th>
<th>Example 8</th>
<th>Example 9</th>
<th>Example 10</th>
<th>Example 11</th>
<th>Example 12</th>
<th>Example 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashland (Part 1) Pepset XI 1000</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Ashland (Part 2) Pepset XII 2000</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Ashland Catalyst 3502</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Dextrin</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sodium Bentonite (#40 mesh)</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>20</td>
<td>7.5</td>
<td>15</td>
<td>22.5</td>
<td>0</td>
</tr>
<tr>
<td>Sodium Bentonite (#200 mesh)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>22.5</td>
<td>15</td>
<td>7.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Iron Oxide</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>22.5</td>
<td>15</td>
<td>7.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Relative Tensile Strength</td>
<td>100%</td>
<td>34%</td>
<td>7%</td>
<td>1%</td>
<td>39%</td>
<td>7%</td>
<td>4%</td>
<td>47%</td>
</tr>
</tbody>
</table>

**Veining (# Observed)**

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>(minor)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vertical</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4 illustrates additional examples of the present invention.

<table>
<thead>
<tr>
<th>Material</th>
<th>Control</th>
<th>Example 14</th>
<th>Example 15</th>
<th>Example 16 (Comparative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashland (Part 1)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Pepset XI 1000</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashland (Part 2)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Pepset XII 2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashland Catalyst 3502</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Sand</td>
<td>2000</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td>Sodium Bentonite (#40 mesh)</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Calcium Bentonite (#40 mesh)</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Veinseal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

**Veining (Number Observed)**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Example 14</th>
<th>Example 15</th>
<th>Example 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>3</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Vertical</td>
<td>4</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Other anti-veining agents may also be incorporated along with the anti-veining thermally collapsible clay mineral particles in the sand casting foundry composition of the present invention. Such additional anti-veining agents may provide further and additional benefits particular to those types of anti-veining agents which, in combination with the thermally collapsible clay mineral particles, result in better resistance to veining or improved foundry shape tensile strength when forming the cast part. For example, lithia and iron oxide anti-veining agents may be particularly useful in conjunction with the anti-veining effect obtained from the thermally collapsible clay mineral particles. The addition rate of other anti-veining agent or agents used in conjunction with the thermally collapsible clay mineral particles of the present invention will be determined by the specific effect that is desired for a particular foundry application, although it generally will fall in the range of about 3 to 1 to 1 to 3, thermally collapsible clay mineral to other anti-veining agent.
Table 5
Comparison Of Anti-Veining Additives
Uncoated Sand Cores

<table>
<thead>
<tr>
<th>5</th>
<th>Material</th>
<th>Control</th>
<th>Example 14</th>
<th>Example 15</th>
<th>Example 17</th>
<th>Example 18</th>
<th>Example 19</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ashland (Part 1)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Pepset XI 1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ashland (Part 2)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Pepset XII 2000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ashland Catalyst</td>
<td>0.5</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sand</td>
<td>2000</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td></td>
<td>Bentonite (#40)</td>
<td></td>
<td>100</td>
<td>-</td>
<td>25</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Veinseal</td>
<td></td>
<td>-</td>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>15</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal</td>
<td>3</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>1 minor</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>4</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>1 minor</td>
<td>none</td>
</tr>
</tbody>
</table>

Mixing the thermally collapsible clay mineral particles with the sand grains
in a sand casting foundry composition substantially improves the performance of
the foundry shapes in producing the cast part. The anti-veining effect of the
thermally collapsible clay mineral particles in the foundry shape can eliminate or
substantially reduce the extent and incidence of veining in the cast part, while
correspondingly eliminating or reducing the need for surface grinding to remove
undesirable veins projecting from the cast part. Eliminating veining by use of the
thermally collapsible clay mineral particles in the foundry composition and foundry
shapes can significantly reduce the cost of producing the cast part. Furthermore,
because thermally collapsible clay mineral particles are considerably less
expensive than some other anti-veining additives, like lithia-containing anti-veining
agents, the cost of producing the cast part may actually be diminished.

A presently preferred embodiment of the present invention and many of its
improvements have been described with a degree of particularity. This description
is a preferred example of implementing the invention, and is not necessarily
intended to limit the scope of the invention. The scope of the invention is defined
by the following claims.

26
I claim:

1. A foundry composition which reduces thermal defects that cause veining in metal parts cast from sand casting foundry shapes formed from the foundry composition, comprising:
   a plurality of foundry sand grains;
   a plurality of thermally collapsible clay mineral particles substantially uniformly distributed throughout the sand grains to form a matrix of sand grains and thermally collapsible clay mineral particles; and
   a curable binder coating the sand grains and the thermally collapsible clay mineral particles to hold the sand grains and thermally collapsible clay mineral particles within the matrix in a predetermined position upon curing.

2. A foundry composition as defined in claim 1, wherein:
   the thermally collapsible clay mineral particles have an inherent characteristic of crystal structure collapse upon exposure to a temperature to which the foundry shapes are subjected from molten metal when casting the metal part; and
   the thermally collapsible clay mineral particles are weakened by the crystal structure collapse to achieve at least one of a reduction in physical size of the thermally collapsible clay mineral particles, disintegration of the thermally collapsible clay mineral particles into smaller physical sizes or a reduced capacity to resist compression and deformation from external forces.

3. A foundry composition as defined in claim 2, wherein:
   the thermally collapsible clay mineral particles undergo crystal structure collapse at peak endothermic temperatures in the range of about 600°C to about 700°C.

4. A foundry composition as defined in claim 2, wherein:
   the sand grains have an inherent characteristic of expansion in physical size upon exposure to a temperature to which the foundry shapes are subjected from molten metal when casting the part; and
at least one of the reduction in physical size of the thermally collapsible clay mineral particles, the disintegration of the thermally collapsible clay mineral particles into smaller physical sizes or the compression and deformation of the thermally collapsible clay mineral particles occurs from expansion in physical size of the sand grains.

5. A foundry composition as defined in claim 4, wherein:
   the temperature at which the thermally collapsible clay mineral particles experience crystal structure collapse is within a range of temperatures similar to those at which the sand grains will have achieved their maximum rate of thermal expansion and most of their physical thermal expansion.

6. A foundry composition as defined in claim 5, wherein:
   the temperature at which the sand grains experience their maximum rate of thermal expansion and most of their physical thermal expansion is approximately 650°C.

7. A foundry composition as defined in claim 2, wherein:
   the thermally collapsible clay mineral particles undergo crystal structure collapse at peak endothermic temperatures in the range of about 600°C to about 700°C.

8. A foundry composition as defined in claim 1, wherein:
   the sand grains have an inherent characteristic of expansion in physical size upon exposure to a temperature to which the foundry shapes are subjected from molten metal when casting the metal part;
   the thermally collapsible clay mineral particles have an inherent characteristic of crystal structure collapse upon exposure to a temperature to which the foundry shapes are subjected from molten metal when casting the metal part; and
   the crystal structure collapse of the thermally collapsible clay mineral particles yields sufficient volumetric space within the matrix to compensate for an increase in volume created by the thermal expansion of the sand grains at the
temperature to which the foundry shapes are subjected from the molten metal when casting the metal part.

9. A foundry composition as defined in claim 8, wherein:
   a volumetric quantity of the thermally collapsible clay mineral particles and a distribution of thermally collapsible clay mineral particles within the matrix yield volumetric space distributed within the matrix resulting from the crystal structure collapse which is sufficient to accept an increase in physical dimension of the sand grains from thermal expansion at the temperature to which the foundry shapes are subjected from molten metal when casting the metal part.

10. A foundry composition as defined in claim 8, wherein:
    a volumetric quantity of the thermally collapsible clay mineral particles and a distribution of the thermally collapsible clay mineral particles within the matrix and a size of the thermally collapsible clay mineral particles yield volumetric space throughout the matrix which approximately counterbalances an amount of expansion in physical dimension of the sand grains throughout the matrix at the temperature to which the foundry shapes are subjected from molten metal when casting the metal part.

11. A foundry composition as defined in claim 1, wherein:
    the thermally collapsible clay mineral particles have an inherent characteristic of crystal structure collapse upon exposure to a temperature to which the foundry shapes are subjected from molten metal when casting the metal part; and
    a volumetric quantity of the thermally collapsible clay mineral particles and a size of the thermally collapsible clay mineral particles within the matrix separate a sufficient number of the sand grains from adjoining sand grains within the matrix to yield sufficient volumetric space within the matrix at the temperature at which crystal structure collapse occurs to compensate for an increase in volume created by thermal expansion of the sand grains upon exposure to the temperature to which the foundry shapes are subjected from the molten metal when casting the metal part.
12. A foundry composition as defined in claim 11, wherein:
the thermally collapsible clay mineral particles are particles of clay
selected from the group consisting of bentonite, kaolin and attapulgite.

13. A foundry composition as defined in claim 11, wherein:
the thermally collapsible clay mineral particles are particles of
bentonite clay.

14. A foundry composition as defined in claim 11, wherein:
the thermally collapsible clay mineral particles include clay minerals
selected from the group consisting of illite, illite-smectite mixed layer clay minerals,
chlorite, halloysite, kaolinite, sepiolite, palygorskite, montmorillonite, beidelite,
nontronite, saponite and hectorite.

15. A foundry composition as defined in claim 11, wherein:
the thermally collapsible clay mineral particles are particles of clay
minerals selected from the group consisting of sodium bentonite, calcium
bentonite, a mixture of sodium and calcium bentonite, or a bentonite with any
exchangeable cation.

16. A foundry composition as defined in claim 1, wherein:
the sand grains are foundry sand grains.

17. A foundry composition as defined in claim 16, wherein:
the foundry sand grains are substantially silica sand grains.

18. A foundry composition as defined in claim 1, wherein:
the binder is a resin-type chemical binder.

19. A foundry composition as defined in claim 1, wherein:
the thermally collapsible clay mineral particles are in a free flowing
particulate form prior to distribution within the sand grains and have a particle size
in the range of about 75 micrometers to 3.4 millimeters.

20. A foundry composition as defined in claim 1, wherein:
the thermally collapsible clay mineral particles are in a free flowing
particulate form prior to distribution within the sand grains and have a particle size
in the range of about 425 micrometers to 2.0 millimeters.
21. A foundry composition as defined in claim 1, wherein:
   the thermally collapsible clay mineral particles have a moisture
   content of from 0.1% to about 12% prior to distribution within the sand grains.
22. A foundry composition as defined in claim 1, wherein:
   the thermally collapsible clay mineral particles have a moisture
   content of from 3% to about 5% prior to distribution within the sand grains.
23. A foundry composition as defined in claim 1, wherein:
   the thermally collapsible clay mineral particles form about 1% to 15%
   of the dry weight of the foundry composition.
24. A foundry composition as defined in claim 1, wherein:
   the thermally collapsible clay mineral particles form about 1% to 7%
   of the dry weight of the foundry composition.
25. A method of making a foundry composition which reduces thermal
   defects that cause veining in metal parts cast from sand casting foundry shapes
   formed from the foundry composition, comprising:
      mixing a plurality of foundry sand grains and a plurality of thermally
      collapsible clay mineral particles to form a mixture in which the thermally
      collapsible clay mineral particles are substantially uniformly distributed among the
      sand grains in the mixture; and
      coating the mixture of sand grains and thermally collapsible clay
      mineral particles with a binder sufficient to hold the mixture of sand grains and
      thermally collapsible clay mineral particles in the foundry shapes after the binder is
      cured.
26. A method as defined in claim 25, further comprising:
    selecting the thermally collapsible clay mineral particles with an
    inherent characteristic of crystal structure collapse upon exposure to a
    temperature to which the foundry shapes are subjected from molten metal when
    casting the metal part.
27. A method as defined in claim 26, further comprising:
selecting the thermally collapsible clay mineral particles to weaken by crystal structure collapse upon exposure to the temperature to which the foundry shapes are subjected from molten metal when casting the metal part to achieve at least one of a reduction in physical size of the thermally collapsible clay mineral particles, disintegration of the thermally collapsible clay mineral particles into smaller physical sizes or a reduced capacity to resist compression and deformation from external forces.

28. A method as defined in claim 27, further comprising:

distributing the thermally collapsible clay mineral particles within the mixture by mixing the thermally collapsible clay mineral particles and the sand grains;

selecting thermally collapsible clay mineral particles of a predetermined size for distribution within the mixture;

selecting a predetermined volumetric quantity of thermally collapsible clay mineral particles at the predetermined sizes for distribution within the mixture;

and

selecting the predetermined sizes and volumetric quantities and distributing the thermally collapsible clay mineral particles to yield volumetric space within the foundry shape resulting from crystal structure collapse which is sufficient to accept an increase in physical dimension of the sand grains from thermal expansion at the temperature to which the foundry shapes are subjected from molten metal when casting the metal part.

29. A method as defined in claim 25, further comprising:

selecting the thermally collapsible clay mineral particles to undergo crystal structure collapse when subjected to peak endothermic temperatures in a range of about 600°C to about 700°C.

30. A method as defined in claim 29, further comprising:

selecting the sand grains with a characteristic of achieving their maximum rate of thermal expansion and most of their physical thermal expansion at temperatures of about 650°C.
31. A method as defined in claim 25, further comprising:
selecting the sand grains with a characteristic of having achieved
their maximum rate of thermal expansion and most of their physical thermal
expansion at approximately a peak endothermic temperature at which the mineral
components of the thermally collapsible clay mineral particles undergo crystal
structure collapse.

32. A method as defined in claim 25, further comprising:
selecting thermally collapsible clay mineral particles of a volumetric
quantity and with a predetermined size to separate a sufficient number of the sand
grains from adjoining sand grains within the matrix to yield sufficient volumetric
space within the foundry shapes at the temperature at which crystal structure
collapse occurs to compensate for an increase in volume created by thermal
expansion of the sand grains upon exposure to the temperature to which the
foundry shapes are subjected from the molten metal when casting the metal part.

33. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles as particles
of clay selected from a group consisting of bentonite, kaolin and attapulgite.

34. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles from the
group consisting of sodium bentonite, calcium bentonite, a mixture of sodium and
calcium bentonite, or a bentonite with any exchangeable cation.

35. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles to include
clay minerals selected from the group consisting of illite, illite-smectite mixed layer
clay minerals, chlorite, halloysite, kaolinite, sepiolite, palygorskite, montmorillonite,
beidelite, nontronite, saponite and hectorite.

36. A method as defined in claim 25, further comprising:
using a resin-type chemical binder to coat the mixture.

37. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles to have a
free-flowing particulate form prior to inclusion in the mixture and with a particle
size in the range of about 75 micrometers to 3.4 millimeters.

38. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles to have a
free flowing particulate form prior to inclusion in the mixture and with a particle size
in the range of about 425 micrometers to 2.0 millimeters.

39. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles to have a
moisture content of from 0.1% to about 12% prior to mixing with the sand grains.

40. A method as defined in claim 25, further comprising:
selecting the thermally collapsible clay mineral particles to have a
moisture content of from 3% to about 5% prior to mixing with the sand grains.

41. A method as defined in claim 25, further comprising:
adding the binder to the mixture after the sand grains and thermally
collapsible clay mineral particles have been mixed to form the mixture; and
coating the mixture with the binder added to the mixture.

42. A method as defined in claim 25, further comprising:
using thermally collapsible clay mineral particles in the mixture in an
amount of about 1% to 15% of the dry weight of the mixture.

43. A method as defined in claim 25, further comprising:
using thermally collapsible clay mineral particles in the mixture in an
amount of about 1% to 7% of the dry weight of the mixture.

44. A method of making a foundry shape which reduces thermal defects
that cause veining in metal parts cast from the foundry shapes, comprising:
mixing a plurality of foundry sand grains with a plurality of thermally
collapsible clay mineral particles to form a mixture in which the thermally
collapsible clay mineral particles are substantially uniformly distributed among the
sand grains in the mixture;
coating the mixture of sand grains and the thermally collapsible clay mineral particles with a binder sufficient to hold the sand grains and thermally collapsible clay mineral particles in position relative to one another after the binder has cured;

shaping the binder-coated mixture into a predetermined configuration defining the foundry shape; and

curing the binder while maintaining the predetermined configuration to establish the foundry shape.

45. A method as defined in claim 44, further comprising:

selecting the thermally collapsible clay mineral particles with an inherent characteristic of crystal structure collapse upon exposure to a temperature to which the foundry shape is subjected from molten metal when casting the metal part.

46. A method as defined in claim 45, further comprising:

selecting the thermally collapsible clay mineral particles to weaken by the crystal structure collapse upon exposure to the temperature to which the foundry shapes are subjected from molten metal when casting the metal part to achieve at least one of a reduction in physical size of the thermally collapsible clay mineral particles, disintegration of the thermally collapsible clay mineral particles into smaller physical sizes or a reduced capacity to resist compression and deformation from external forces.

47. A method as defined in claim 46, further comprising:

distributing the thermally collapsible clay mineral particles within the mixture by mixing the thermally collapsible clay mineral particles with the sand grains;

selecting thermally collapsible clay mineral particles of a predetermined size for distribution within the mixture;

selecting a predetermined volumetric quantity of thermally collapsible clay mineral particles at the predetermined sizes for distribution within the mixture; and
selecting the predetermined sizes and volumetric quantities and
distributing the thermally collapsible clay mineral particles to yield volumetric
space within the foundry shapes resulting from crystal structure collapse which is
sufficient to accept an increase in physical dimension of the sand grains from
thermal expansion at the temperature to which the foundry shapes are subjected
from molten metal when casting the metal part.

48. A method as defined in claim 46, further comprising:
selecting the predetermined sizes of the thermally collapsible clay
mineral particles to separate a sufficient number of the sand grains from adjoining
sand grains within the foundry shapes to yield sufficient volumetric space within
the foundry shapes at the temperature at which crystal structure collapse occurs to
compensate for an increase in volume created by thermal expansion of the sand
grains upon exposure to the temperature to which the foundry shapes are
subjected from the molten metal when casting the metal part.

49. A method as defined in claim 44, further comprising:
selecting a resin-type chemical binder to coat the mixture.

50. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles as particles
of clay selected from a group consisting of bentonite, kaolin and attapulgite.

51. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles from the
group consisting of sodium bentonite, calcium bentonite, a mixture of sodium and
calcium bentonite, or a bentonite with any exchangeable cation.

52. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles to include
clay minerals selected from the group consisting of illite, illite-smectite mixed layer
clay minerals, chlorite, halloysite, kaolinite, sepiolite, palygorskite, montmorillonite,
beidelite, nontronite, saponite and hectorite.

53. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles to have a free-flowing particulate form prior to inclusion in the mixture and with a particle size in the range of about 75 micrometers to 3.4 millimeters.

54. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles to have a free-flowing particulate form prior to inclusion in the mixture and with a particle size in the range of about 425 micrometers to 2.0 millimeters.

55. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles to have a moisture content of from 0.1% to about 12% prior to mixing with the sand grains.

56. A method as defined in claim 44, further comprising:
selecting the thermally collapsible clay mineral particles to have a moisture content of from 3% to about 5% prior to mixing with the sand grains.

57. A method as defined in claim 44, further comprising:
adding the binder to the mixture after the sand grains and thermally collapsible clay mineral particles have been mixed to form the mixture; and
coating the mixture with the binder added to the mixture.

58. A method as defined in claim 44, further comprising:
using thermally collapsible clay mineral particles in the mixture in an amount of about 1% to 15% of the dry weight of the mixture.

59. A method as defined in claim 44, further comprising:
using thermally collapsible clay mineral particles in the mixture in an amount of about 1% to 7% of the dry weight of the mixture.

60. A method of casting a metal part using core and mold foundry shapes formed by the method defined in claim 44, comprising:
positioning the core and mold foundry shapes relative to one another to define the metal part to be cast;
pouring molten metal between the core and mold foundry shapes;
and
solidifying the molten metal while confined between the core and mold foundry shapes.

61. A method as defined in claim 60, further comprising:
removing the cast part from the core and mold foundry shapes after the metal has solidified.

62. A metal part cast by using the method defined in claim 61.
FIG. 1
FIG. 2

1. Position cured foundry shapes
2. Pour molten metal between positioned shapes
3. Solidify molten metal into cast part
4. Remove cast part from foundry shapes