RESEARCH ARTICLE OPEN ACCESS

Design Of A Sand Casting Method Using Patterns Made Of Sublime Materials For Casting Intricate Shapes.

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ABSTRACT
In today's world every product ranging from a safety pin to huge complex aircraft engines are all manufactured by various manufacturing techniques. It involves various processes like casting, forming, machining, welding etc. Complex machines have numerous parts and elements which may be asymmetric; irregular shaped and might have a different cross-sectional profile. Manufacturing these complex and intricate shaped components to required dimensional accuracy and good surface finish is a tough task and requires use of various processes like machining, bending etc. This induces some amount of residual stresses in the machine component, and thereby makes it more susceptible to catastrophic failure.
To minimize these losses and produce irregular shaped components more efficiently, a unique sand casting process is explained in this paper which makes use of a pattern made of sublime material which when burnt, produces a hollow cavity where the molten metal is poured and the casting is performed. This method eliminates the use of additional finishing processes and gives a good surface finish to the final machine components.
Keywords: Sublime, sand casting, surface finish.

Date of Submission: 20-12-2018 Date of Acceptance: 04-01-2019

I. INTRODUCTION

With the advancement in manufacturing technology, there has been a development of various processes which are used to produce various components. Symmetric components like impeller casing, air inlet manifold, rims etc. are easily casted by using symmetric patterns or by carving the unwanted sand. They are later machined and further processes are carried out. But manufacturing a helix shaped spring is a tough task. It involves extrusion of wire and then it is deformed by bending and pulling. This leaves a lot of residual stresses in the spring element and they act as centres of catastrophic failure under high loads. Heat treatment removes residual stresses up to some extent but changes the microstructure and properties of the metal.

To avoid this the helix shaped spring is casted in its original shape which eliminates the use of bending and heat treatment. This process involves use of pattern made of sublime materials like naphthalene, camphor, iodine crystals etc. which is covered with a layer of moulding clay. This acts like a protective layer on pattern and also helps in improving surface finish. This sublime pattern with clay coating is inserted in moulding box filled with green sand and rammed carefully. The sublime material is then ignited using a torch flame. By burning the sublime pattern, a hollow cavity is obtained in the clay. Then casting is carried out in a regular way.

Sand Casting

Sand casting involves melting metal and pouring it into a mould cavity formed by impression of the pattern. This pattern is nearly of the same dimensions as of the final sized model. A slight tolerance is given by enlarging to account for shrinkage and machining allowances in the final casting. Its shape resembles the shape of the desired product. In this cavity, the molten metal is poured and allowed to solidify. This solidified part is taken out of the mould, cleaned and finished with machining processes to make it suitable for use. Here the sand used is called green sand. Its composition includes 90% base sand, 7% binder and 3% clay.

Properties Of Moulding Sand

Green sand for moulding must fulfil and pack tightly round the pattern under pressure. It must be "**Flowable**".

Green sand for moulding should be able of being deformed slightly without cracking, so that the pattern can be withdrawn. In other words, it must exhibit "**Plastic**"behaviour.

Green sand must have sufficient strength to strip from the patterns and support its own weight without deforming, and withstand the pressure of molten metal when the mould is cast. It must therefore get "**GreenStrength**".

Green sand should be "**Permeable**", so gases and steam can escape from the mould at the beginning of pouring.

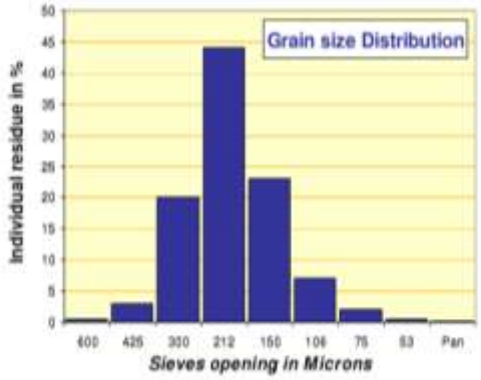
Green sand must get "**DryStrength**" to prevent erosion by liquid metal during pouring as the mould surface dries out.

Green sand must guarantee a good "**Refractoriness**" to withstand the high temperature involved without melting or fusing with the metal.

Green Sand Composition

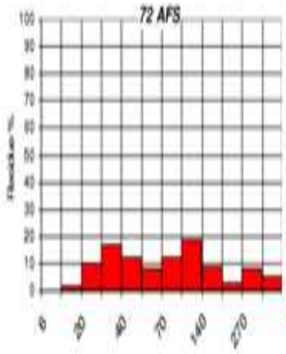
Green sand is a mixture of foundry sand (silica sand), binder (bentonite), additives, moisture (water) and dead clay. Sand, due to its high refractoriness, and also being inexpensive is the primary and basic material used for preparing moulds. The major types of base sands are silica sand, olivine sand, chromite and zircon.

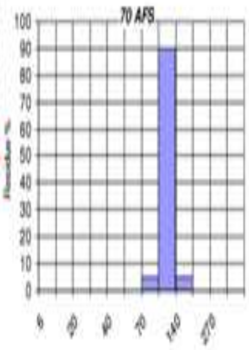
In this method we have used silica sand as base sand.



•AFS No = 55 - 60

•3 Screens Distribution with 80 % min on cumulative ASTM sieves 50, 70, 100

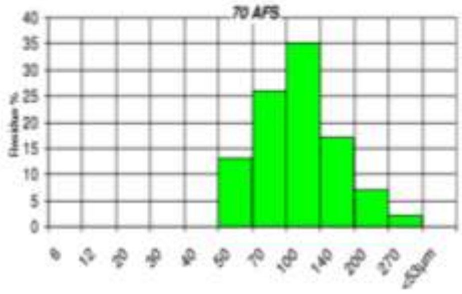


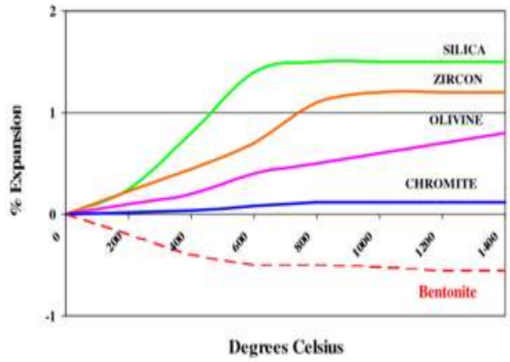


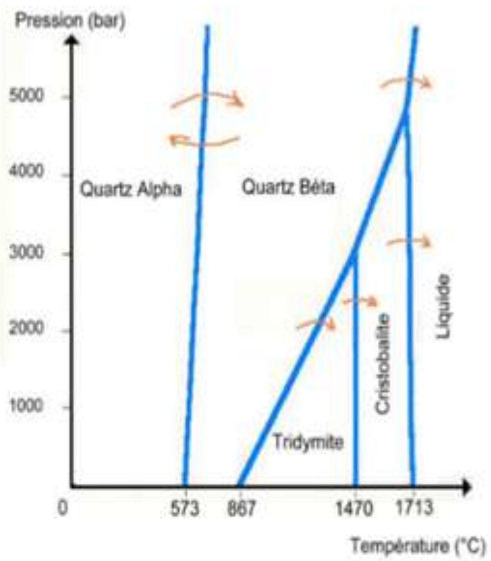
Foundry Sand

Silica sand is quite economic to use and has sufficient thermal resistance. The grain size is adequate and is suitable for most casting process. Its chemical composition includes

SiO_2=Min 98%, Al_2O_3=Max 0.13% and Fe_2O_3=Max 0.06



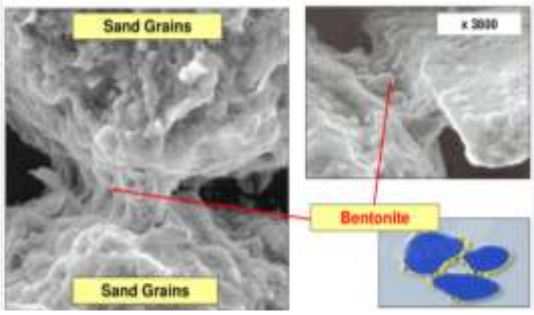




This thermal expansion graph shows that silica sand has highest percentage expansion from 0-600 deg C. It follows a linear expansion till 600 deg C and after that there is no significant expansion observed. It remains constant with the increase in temperature.

Binder (bentonite)

Bentonite is widely used binder for bonding sand particles. It is activated in presence of water. It is a type of clay whose main constituent is Montmorillonite belonging to the smectite group.



The following microscopic image at x3800 shows the binding of sand grains with the help of bentonite.

Additive

These mainly include organic carbohydrates such as starch, sea coal, silica flour, iron oxide and graphite. They impart certain property to the sand like elasticity, erosion and abrasion resistance and also reduce expansion defects.

Moisture (Water)

It is one of the most important binding agents. It enhances and develops moulding sand properties. It is treated and made free from impurities such as dissolved salts which affect bentonite's electrostatic binding properties.

Dead clay

A part of bentonite is heated beyond 500 deg C during which it loses its structural water and settles itself on the sand grain. It loses it properties and becomes dead clay. This Oolitisation process reduces expansion of green sand and permits to fix a part of the free water in the mould.

II. SUBLIMATION PROCESS

Sublimation is the transition of a substance directly from the solid to the gas phase without passing through the intermediate liquid phase. It is an endothermic phase transition that occurs at temperatures and pressures below a substance's triple point in its phase diagram. The reverse process of sublimation is Desublimation or Deposition, in which a substance passes directly from a gas to a solid phase. Sublimation has also been used as a generic term to describe phase changes between solid and gas that avoid the liquid state without specifying the direction of the transition.

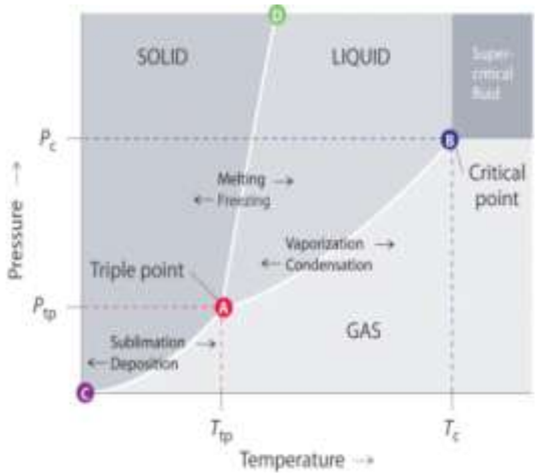


Figure shows phase diagram depicting the triple point A. The direct transition from solid to gas takes place along curve CA.

At normal pressures, most chemical compounds and elements possess three different states at different temperatures. In these cases, the transition from the solid to the gaseous state requires an intermediate liquid state. The pressure referred to is the partial pressure of the substance, not the total (e.g. atmospheric) pressure of the entire system. So, all solids that possess an appreciable vapour pressure at a certain temperature usually can sublimate in air (e.g. water ice just below 0 °C). For some substances, such as carbon and arsenic, sublimation is much easier than evaporation from the melt, because the pressure of their triple point is very high, and it is difficult to obtain them as liquids.

Sublimation requires additional energy and is an endothermic change. The enthalpy of sublimation (also called heat of sublimation) can be calculated as the enthalpy of fusion plus the enthalpy of vaporization.

The enthalpy of sublimation has commonly been predicted using the equipartition theorem. If the lattice energy is assumed to be approximately half the packing energy, then the following thermodynamic corrections can be applied to predict the enthalpy of sublimation.

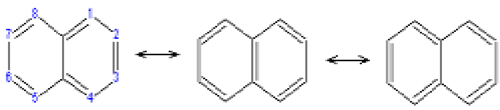
Assuming a 1 molar ideal gas gives a correction for the thermodynamic environment (pressure and volume) in which PV = RT, hence a correction of 1RT. Additional corrections for the vibrations, rotations and translation then need to be applied. From the equipartition theorem gaseous rotation and translation contribute 1.5RT each to the final state, therefore a +3RT correction. Crystalline vibrations and rotations contribute 3RT each to the initial state, hence −6RT. Summing the RT corrections; −6RT + 3RT + RT = −2RT. This leads to the following approximate sublimation enthalpy. A similar approximation can be found for the entropy term if rigid bodies are assumed.

$$\Delta H_{sublimation} = -U_{lattice\ energy} - 2RT$$

Naphthalene

Naphthalene isan organicCompound with formula $C_{10}H_8$.It is the simplest polycyclic aromatic hydrocarbon, and is a white crystalline solid with a characteristic odour that is detectable at concentrations as low as 0.08 ppm by mass. As an aromatichy drocarbon, naphthalene's structure consists of a fused pair of benzene rings. It is best known as the main ingredient of traditional mothballs. A naphthalene molecule can be viewed as the fusion of a pair of benzene rings. (In organic chemistry, rings are fused if they share two or more atoms.) As such, naphthalene is classified as a benzenoid polycyclic aromatic hydrocarbon (PAH). There are two sets of equivalent hydrogen atoms: the alpha positions are positions 1, 4, 5, and 8 on the drawing below, and the beta positions are positions 2, 3, 6, &7.

Unlike benzene, the carbon–carbon bonds in naphthalene are not of the same length. The bonds C1–C2, C3–C4, C5–C6 and C7–C8 are about 1.37 Å (137 pm) in length, whereas the other carbon–carbon bonds are about 1.42 Å (142 pm) long. This difference, which was established by X-ray diffraction, is consistent with the valence bond model of bonding in naphthalene and in particular the phenomenon of cross-conjugation. This theorem would describe naphthalene as consisting of an aromatic benzene unit bonded to a diene but not extensively conjugated to it (at least in the ground state). As such naphthalene possesses several resonance structures.



Two isomers are possible for mono-substituted naphthalene, corresponding to substitution at an alpha or beta position.

Combustion Of Naphthalene

Naphthalene upon combustion yields carbon dioxide and water. This process releases certain amount of heat which solidifies or hardens the surface of mould cavity. It releases heat of 5154kJ.

$$C_{10}H_8\,(s) + 12\,O_2\,(g) \rightarrow 10CO_2\,(g) + 4\,H_2O(l)$$

$\Delta H^o_{comb} = \Delta E^o_{comb} + \Delta nRT$

Where $\Delta n = nCO_2 - nO_2$ = 10 mole-12 mole = -2 mole

ΔH^o_{comb} = -5154 kJ+(-2 mole)(8.314 J/mole-K)(298.15 K)(1 kJ/1000J)

ΔH^o_{comb} = -5154 kJ+ (-4.958 kJ) = -5159 kJ = -5.16 x 10^3 kJ

Melting point: 80.26 °C **Boiling point:** 218 °C **Flash point:** 79-87 °C
Molar mass: 128.1705 g/mol **Density:** 1.14 g/cm³ **Flame Temperature:** 600-800 °C

III. PROCEDURE FOR CASTING INTRICATE SHAPES USING PATTERNS MADE OF SUBLIME MATERIAL

1. **Preparation of intricate pattern by using sublime materials like Naphthalene**

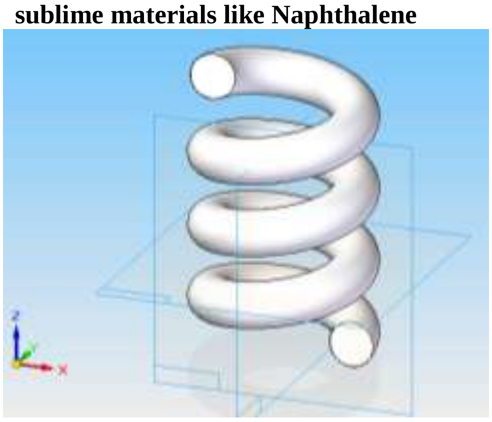
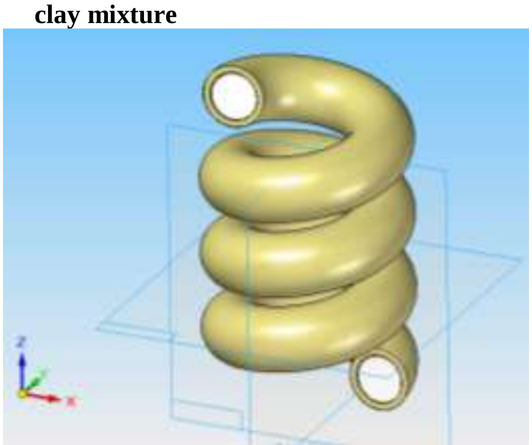


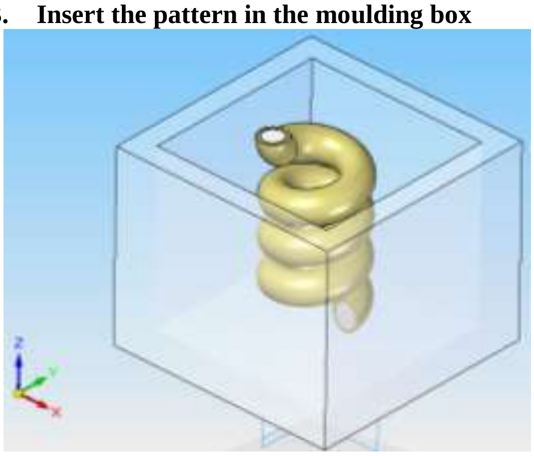
Figure shows the profile of an intricate casting in the shape of a helical spring of circular cross-section. Naphthalene is manufactured by fractional distillation of crude oil or coal tar. The naphthalene vaporizes at 218 °C and these vapours are condensed to roomtemperature in the shape of intricate casting. The pattern so created is dimensionally accurate and shrinkage allowance for the particular metal is also given.

2. **Coating the surface of sublime patterns with clay mixture**



The condensed naphthalene patterns are then coated with a mixture of stoneware clay which is a vitreous or semi-vitreous ceramic. It can be fired at high temperatures and is nonporous which prevents intermixing of naphthalene with green sand components. It has high density and is impermeable or hard to scratch which makes it suitable for this process as it does not disintegrates during metal pouring. There is a small gap left at the top for burning the pattern.

3. Insert the pattern in the moulding box



The moulding box is partially filled with green sand and rammed. Then the pattern is inserted and sand around it is gently rammed till the pattern is completely surrounded by sand. The pattern is so placed that the pattern's surface is exposed at the top for burning.

4. Ignite the Naphthalene pattern

The Naphthalene pattern is ignited using a flame torch and is allowed to burn. This causes a physical change and hence the solid naphthalene changes its phase form solid to gas leaving behind a hollow cavity inside the clay.

5. Metal pouring and casting.

The metal is poured in the pattern cavity. It flows down and takes the shape of the hollow cavity upon cooling. The metal is allowed to cool and solidify. During solidification, slight shrinkage in size takes place. The shrinkage loss is pre-allotted during pattern making.

IV. PROCESS

In this method the sand and clay gets heated two times. First time during naphthalene burning and second time during molten metal pouring.

In the first stage when the prepared naphthalene pattern coated with clay is inserted in the moulding box, the flame torch is used to ignite the naphthalene. During this process, combustion of naphthalene takes place resulting in liberation of carbon dioxide and water. This process also produces heat which causes the water in the clay and green sand to escape due to evaporation. This causes hardening of the sand and clay. Since the clay is in direct contact with the burning naphthalene, the clay is baked and solidified or becomes hard. This produces a rigid and solid clay pattern which does not breaks when molten metal is poured. The stoneware clay has good surface finish and crack-free characteristics which results in formation of a uniform hollow cavity of the desired intricate shape.

When molten metal is poured in the cavity, the hot metal flows down and upon cooling it retains the shape of the cavity. During metal pouring, the sand and clay is once again heated and hence it loses moisture and becomes hard.

Upon cooling, the metal casting is removed from the green sand and the baked stoneware clay is removed by chipping. The casting so obtained is of the desired intricate shape and possesses good surface finish when compared to other casting processes.

Conditions For Good Quality Casting

While casting intricate shapes, certain steps and precautions should be taken to produce good quality castings.

- Naphthalene patterns should be made to high dimensional accuracy and adequate shrinkage allowance, machining allowance and distortion allowance should be given.
- The naphthalene pattern should be placed inside the moulding box in a specified position to achieve maximum flowability of molten metal to all parts of the cavity
- The clay coating should be done uniformly and no surface should be left uncovered except for top portion for burning naphthalene.
- The green sand should have proper additives and binders which impart special properties. The moisture content in the sand should be adequate and in case of high moisture, Vent holes must be provided for the moisture to escape.
- The ramming of green sand should be done carefully to prevent damage to the pattern
- Molten metal should be of high temperature and should have low viscosity and high flowability.

Advantages

- Simple and tough or intricate shapes can be casted easily.
- There is no need of any additional machining operations like bending, turning etc.

- The final product has improved mechanical properties as the material is casted as a whole.
- There are no residual stresses left in the element as bending operation is not performed.
- Brittle metal like grey cast iron, hardened steels can be casted easily without any cracks.
- High amount if dimensional accuracy and surface finish is observed in the final products.
- This process can also be used in resin casting (for casting plastic) and glass casting (for casting glass artefacts) to manufacture intricate shapes.

Applications

This method importance in the following industrial fields

Automotive sector – parts like engine blocks, springs, joints, rocker arms, brackets etc are manufactured.

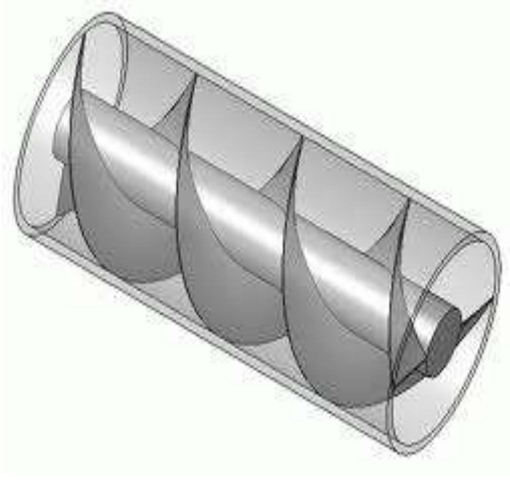
Aircrafts – turbine blades, marine propeller blades and casing.

Machining – cutting tools, machine beds, wheels, pulleys, gears, cams.

Pumps and compressors – frames, bushing, ringsand impeller are fabricated.

Parts of washing machine, refrigerators, air conditioners, valves and agricultural equipment are manufactured.

Few examples of the Intricate shaped which can be casted using this method.



V. RESULTS

In this paper, a novel sand casting method was developed by using sublime materials patterns to produce intricate shapes. The irregular helix shaped pattern was prepared with adequate shrinkage allowance and dimensional accuracy. It is then coated with a layer of stoneware clay. This assembly in carefully inserted in a moulding box filled with green sand. The sand is rammed and then using a torch flame, the naphthalene pattern is ignited and allowed to burn. Combustion of naphthalene takes place and hence it burns changing its state from solid to gas leaving behind a hollow cavity in the shape of the desired product. Later molten metal of low viscosity was poured which flows down easily inside the cavity. This is allowed to cool and later it solidifies. The coated clay is chipped off and the desired shaped casting is prepared.

VI. CONCLUSION

Sublime sand casting technique is suitable in the fields of machine parts manufacturing like springs, gears, brackets, different types of springs such as helical, conical, torsion etc. Casting produces superior quality parts which may do not need further finishing processes. It is also very economical when compared to forging and forming processes. It requires time and effort but the casting so produced are of good quality. It has a wide spectrum of applications and can be used for casting non-metallic materials like plastic and glass.

In conclusion sublime sand casting process is useful to manufacture intricate, irregular and tough shaped casting products. And the castings so produced have high dimensional accuracy, good surface finish, no residual stresses and superior mechanical properties.

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Sameer Rafiq Shah" Design Of A Sand Casting Method Using Patterns Made Of Sublime Materials For Casting Intricate Shapes." International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.12, 2018, pp 64-70