

# Foundry Processes in Sand-Molded Casting of Steel

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**Abstract** – Various manufacturing techniques are used by different industries in the production of different equipment or spare parts of complex machines and mechanical assemblies. A place where metal is molten and allowed to solidify to give it a desired shape is called a foundry. Casting, being one of the most ancient and convenient techniques, is used in the making of complex parts of various centrifugal pumps, motors, automobiles, etc. where the metal has to go through various physical phases throughout the manufacturing process. However, many supplementary steps need to be taken to ensure a good quality of casting in order to avoid failure of the entire mechanical system.

**Keywords** – industries, machineries, foundry, casting, quality, failure

## 1. INTRODUCTION

The following paper briefly mentions the different steps involved in the manufacturing of various steel components such as automotive spares, engine blocks, machine tool bases, cylinder heads, centrifugal pumps, etc. using the sand-casting method. Sand casting is the most widely used casting method. The advantage of using sand to manufacture metal products is that sand is very resistant to elevated temperatures. Almost all metal casting materials can be sand cast and these castings range in size from very small to extremely large. It also explains the other necessary measures that need to be taken to prevent failure of the casting and enhance its strength and durability. The paper clearly mentions the various scientific processes also called as foundry processes in a step-by-step manner such as pattern making, core making, molding, melting, pouring, decoring, knockout, various cutting processes, heat treatment cycles, shot blasting, machining, fettling, grinding, dimensional rework, acid pickling, non-destructive testing, finishing, punching, etc., each being equally important from the point of view of the quality, durability and identity of the casting. Also, the microstructure of the material, also called as grain structure, plays an important role in defining the properties of the entire casting. The following paper also focuses on the various heat treatment techniques used to obtain a definite microstructure to impart the desired properties in the casting.

## 2. FLOW OF PROCESSES

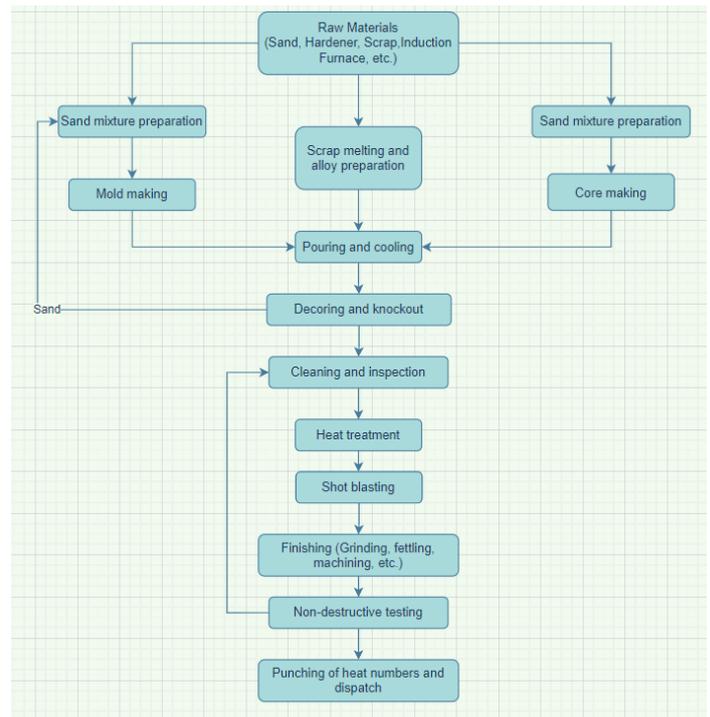


Fig-1: Flow of foundry processes

## 3. PATTERN DESIGNING

A pattern is an exact replica of the casting which is used for mold fabrication. Based on the volume of production and how frequently the pattern would be used, a decision is made upon the material to be chosen for the pattern. Wooden patterns are usually sprayed with aluminium to provide a better finish and prevent sand from sticking to it. Once the pattern and the corresponding production drawing is received from the manufacturer, the pattern is mounted on a wooden base with the help of bolts. Then, the locations where the different parts of the gating system (such as risers, runners, sprue, in-gates, funnel) need to be formed with the casting are marked. The locations where chills are to be placed are also marked. This process is known as Methoding. The purpose of the gating system and chills shall be discussed in further sections of the paper. Modifications in the pattern (if required) are done using machining tools like lathe machine, drills, etc. Then, the pattern is sent to the molding section. The core pattern (called core box) does not need to be mounted on a base.

#### 4. CORE MAKING

It is the process of forming a solid sand core so that the actual casting has the desired shaped cavity.

Processes involved:

A suitable composition for the sand-hardener mixture is chosen and prepared and the bottom half of the core box is filled with this mixture. Properly shaped metal rods are placed in the core box for providing additional strength to the core if required, depending on the size of the core. Thermocol or wax strips are then placed in the sand core at appropriate locations which melt during the oven preheating process thus, allowing the gas to escape from the core formed. This is very important to avoid crack formation and weakening of the core. A number of chills are placed in the core at appropriate locations so that they absorb some of the heat during the solidification process of molten metal and improve the cooling rate of the casting. Then the top half of the core box is placed and clamped to the bottom half to prevent core expansion during preheating. The sand mixture is also added in the top half to complete the core. Risers are placed wherever required in the core. Several voids are also created in the core to allow air to escape during preheating. Removal of excess sand takes place and the core is left undisturbed for a specified time to harden. The hardening time depends upon the type of hardener used. The core is sent for dressing and painting where it is spray painted with an inflammable mixture of paint and thinner which is set on fire so that the moisture in the core gets removed. The core is then placed in the preheating oven for 5-6 hours for further hardening and moisture removal. Then the core is sent to the core setting section where it is placed between the two halves of the mold before sending it to the pouring section. This is done by placing the core in the drag (bottom half of the mold) and then placing and gluing the cope (top half of the mold) over it.

of machinaries depending upon the size of the mold. The hardened mold is then spray painted with paint and thinner mixture which is set on fire to remove the moisture from the mold. Both the mold halves are passed through the preheating oven for further hardening and moisture removal. Then the corresponding core is placed in the drag and the cope is then inverted and placed over the drag and glued to it to form the complete mold which is then taken to the pouring section.

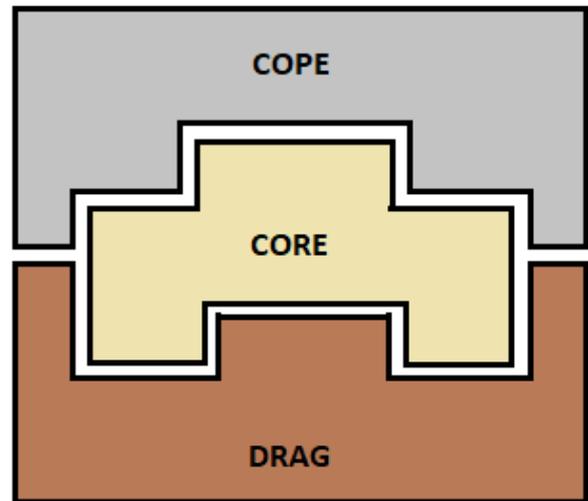


Fig-2: Arrangement of complete mold

#### 5. MOLDING

It is the process of forming a mold of the desired shape that is further filled with molten metal to form the desired shaped casting.

Processes involved:

The mold is first divided into two halves viz. cope (top half) and drag (bottom half) and the two halves are formed separately. The mold pattern is placed into the mold box and accessories like the funnel, sleeves, L-blends, fire bricks, etc. are placed at appropriate locations for forming the gating system along with the casting. The sand-hardener-resin mixture is prepared with suitable composition and the mold box is filled with this sand mixture. The sand is then pressed tightly in the mold box and then allowed to solidify. The above processes can be done manually or with the help

#### 6. MELTING

Scrap collected from various sources is first segregated as per the material grade. The scrap is first heated in an oven before sending it to the furnace so that it melts quicker. The furnace used is an induction furnace where a number of copper coils are present around the furnace and carry a huge current that creates an electric field and induces a current (Eddy current) in the scrap. This results in heating of the scrap and melts it. These furnaces are lined inside with refractory material to prevent melting of the furnace walls. Temperature of the furnace is maintained above the melting point of the material grade and the temperature of the molten metal is checked frequently using a thermocouple. Supply of Argon gas is provided through pipes at the bottom of the furnace. This gas, being inert, does not react with the metal but lifts the impurities present in it. These impurities are adsorbed by the slack powder sprinkled over the furnace. Specific amounts of Aluminium (ingot and shots) and Calcium Silicide are added to the molten metal for deoxidation of steel. Otherwise, reaction of the metal with oxygen may alter its properties.

#### 7. POURING

The molten metal is poured into certain ladles that are lined inside with refractory material. The lining is done to prevent the ladles from melting as the temperature of the

molten metal is very high. Also, the ladle is first heated to a certain temperature before pouring molten metal into it to reduce the cooling rate of the metal. Otherwise, the molten metal may solidify even before reaching the entire mould thus, resulting in undesirable casting. Ladles are of two types viz., lip pouring and bottom pouring and have a steering to control the orientation of the ladle. Lip pouring ladles need to be tilted to pour the metal whereas bottom pouring ladles have an opening at the base that can be opened or closed by lifting or releasing a heavy rod called bottom pouring rod. Slack powder is then sprinkled on top of the ladle to remove impurities. The lid of the ladle is covered with an insulating material like glass wool to prevent heat losses to the surrounding. Molten metal is then poured in the pouring basin and is further carried to the entire mold by the gating system (sprue, runners, in-gates, risers). Also, the gas in the mold is allowed to burn to prevent it from getting trapped in the mold. A riser (feeder) is used to prevent cavities in the casting that can form due to shrinkage of the metal on solidification. This is done by providing excess metal to the mold so that the cavity forms in the riser and not the casting. Anti-piping Compound (APC) powder is then added on top of the riser opening. This has the following advantages. Firstly, it prevents the sparks of the molten metal from reaching the workmen. Also, the metal in the riser is exposed to atmosphere because of which the cooling and solidification may start from the riser itself which is undesirable. Addition of APC breaks this exposure and the use of sleeves (made of exothermic material) keeps the metal in the riser molten for a longer duration than the casting. The casting cools at a comparatively faster rate due to the presence of chills. A small amount of metal is poured in a sample/test mold that is further used for inspecting the quality and properties of the casting

## 8. DECORING AND KNOCKOUT

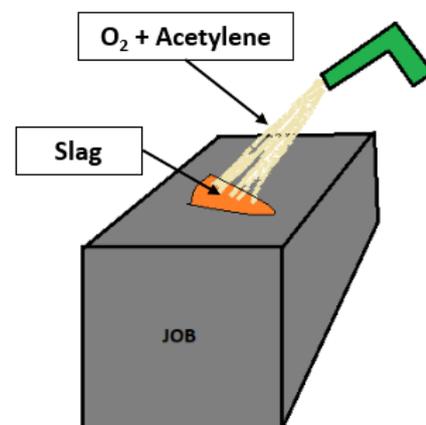
Both the test sample and the casting are allowed to solidify and then taken to the casting decorating area where the mold is broken down and the casting is removed. The pieces of sand mold are sent to the knockdown section by a motorized trolley where heavy vibrations of the container result in breakdown of the mold pieces to fine sand. This sand, being a mixture of various sands, is sent for purification and reuse. The casting can also be removed in the knockout section itself. The casting is then allowed to cool using air quenching or water quenching.

## 9. GAS CUTTING, POWDER CUTTING AND ROD GOUGING

After the casting is cooled by quenching, it is taken to the cutting and gouging section to remove the unwanted parts that are not required in the casting i.e., funnel, risers, runners, gates, sprue, etc.

**Gas cutting:** Mixture of oxygen and Acetylene is used to preheat the metal to its ignition temperature (for steel, 700-900 degree Celsius) but below its melting point. A jet of oxygen is directed into the preheated area initiating a vigorous exothermic chemical reaction between the metal and oxygen to form a metal oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut through it. Ignition temperature of the material must be lower than its melting point otherwise, the material would melt and flow away before cutting. Oxide melting point should be lower than that of the surrounding material so that it can be mechanically blown away by the oxygen jet. Oxidation reaction between the oxygen jet and metal must be sufficient to maintain the ignition temperature. Minimum gaseous reaction products should be formed so as not to dilute the cutting oxygen.

**Powder cutting:** It is similar to gas cutting with an addition of iron powder to the oxygen jet. Stainless steel, cast iron, nonferrous metals form refractory oxides (Oxides whose melting point is higher than the material). Hence, powder is injected into the flame to form a fluid slag with low melting point. Acetylene, propane, MAPP (Methylacetylene-propadiene), propylene, natural gas are the commonly used fuel gases among which acetylene produces the highest flame temperature.



**Fig-3:** Gas cutting

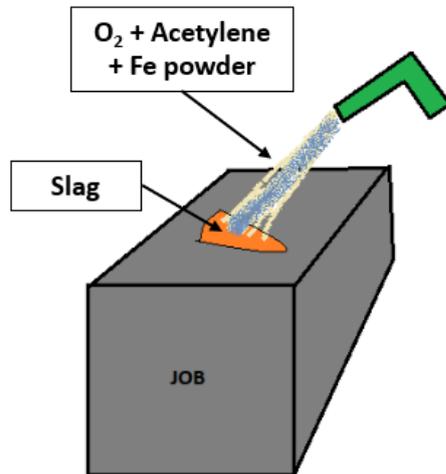


Fig-4: Powder cutting

Rod gouging (Air carbon arc gouging): It is the process of removing material by means of heat generated by carbon arc. It removes excess material from casting and requires a carbon/graphite electrode, compressed air, standard power source (like welding rectifier). An intense electric arc produced between tip of rod and workpiece cuts and melts the workpiece. Compressed air is used for blowing away the molten metal thoroughly from the casting surface. The metal is gouged (cut) in the airflow direction. It is used to remove excess weld beads also. The power source must have a constant current output characteristic otherwise, the high voltage current can cause the electrode tip to explode when touched to the workpiece. Copper coating is given to the graphite rod to reduce electrode erosion. Sometimes, water is poured simultaneously on the surrounding area to prevent it from cracking due to excess heat.

## 10. HEAT TREATMENT

Process of heating the casting below its melting point to relieve internal stresses developed by forging, welding or during solidification itself. It is used to increase/decrease hardness of the material by achieving the desired grain structure.

Processes involved:

The heat treatment furnaces are first lined with insulating material (glass wool) on the inside to prevent heat losses. Heat treatment process is controlled by heat treatment furnace control panel. The furnace temperature is increased to a specific set point in multiple cycles. This process is called as Ramping. The starting time of the process is noted. Once the temperature of the furnaces reaches the desired maximum, it is held for a specific time. This process is called as Soaking. The cooling method to be used is predefined. For air quenching, the number of running fans is already specified. Multiple burners are provided inside the furnace

to maintain a uniform temperature throughout the casting. The temperature at different locations within the casting are measured using thermocouples.

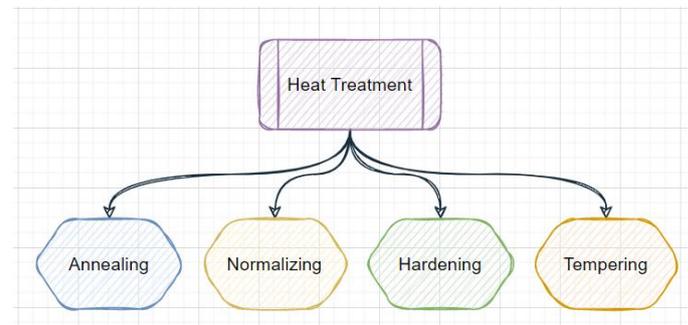


Fig-5: Basic types of heat treatment

### 10.1 Normalizing

It involves heating the casting above recrystallization temperature (727 degrees for steel), then soaking for a specific time till the desired microstructure has been achieved and then cooling by air quenching.

### 10.2 Annealing

This process involves heating the casting above recrystallization temperature (727 degrees), soaking for the specified time and then cooling by controlled furnace cooling.

Air quenching cools at a faster rate than controlled furnace cooling. Faster the rate of cooling, finer is the grain structure hence, greater is the hardness. Normalized casting is harder as compared to annealed casting. Therefore, it is brittle and difficult to machine. Normalizing temperatures are usually higher than annealing temperatures.

Both normalizing and annealing take place in 3 stages viz. recovery stage, recrystallization stage and grain-growth stage.

Recovery stage: In this stage, the furnace or other heating device is used to raise the temperature of the material so that the internal stresses are relieved.

Recrystallization stage: It involves heating the material above its recrystallization temperature but below its melting point so that new grains are formed without any residual stresses.

Grain-growth stage: The material is cooled at a specific rate causing new grains to develop after which the material will be more workable. After annealing and normalizing, various subsequent operations can be carried out to alter mechanical properties.

### 10.3 Hardening

This process is done by heating the casting above recrystallization temperature (727 degrees), then soaking for a specific time and then cooling by dipping in water.

Water cools the casting immediately and this results in a very fine grain structure. Hence, the casting becomes very hard and brittle and thus, difficult to machine.

Water, brine, oil, etc. are used for solution treatment or solution quenching.

### 10.4 Tempering

Normalized or water quenched (solution treated) castings are usually very hard. Hence, to reduce hardness and increase machinability, tempering is done.

Here, casting is heated below recrystallization temperature, soaked for a specific time and then cooled at a specific rate to get the desired properties like hardness, grain structure, machinability, etc. (either by controlled furnace cooling or air quenching). After the heat treatment, the casting is sent for shot blasting and further processes.

In the above processes, the casting is not heated to the final temperature in one step but rather in multiple steps by holding the casting at several intermediate temperatures.

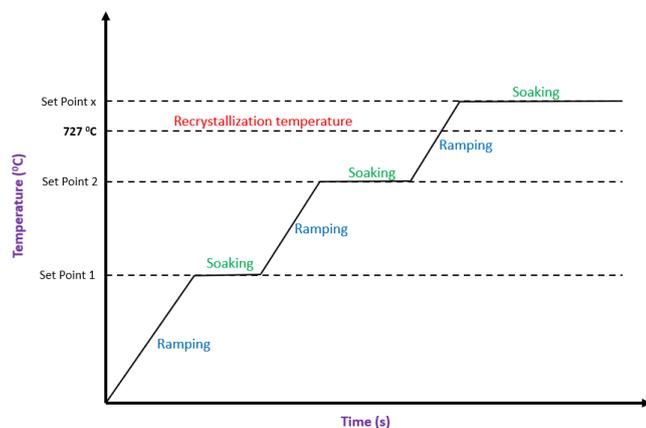


Fig-6: Ramping and soaking

## 11. SHOT BLASTING

The undesirable black rusty layer developed on the casting after heat treatment gets removed by shot blasting. Very fine shots (made of aluminium, steel, etc.) are blasted with high velocity upon the casting with the help of multiple motors and corresponding impellers. The machine works in a cyclic manner i.e., the shots falling down are collected and reused. The castings are taken to and removed from the machine with the help of hangers provided around the machine. The castings are kept in the shot blasting machine

for 5-6 minutes. After the process, the casting becomes clean and greyish in colour. Also, any sand present in the casting gets removed and the voids on the surface get opened. After this, the casting is sent for primary inspection. If the defects are workable, only then the casting is sent for further processing or else it is rejected.

## 12. MACHINING/FETTLING/GRINDING

The excess material remained on the casting after powder cutting and rod gouging is removed by machining or fettling. The casting is machined to desired dimensions with the help of various machining tools. The feet and flanges of the involute casing are machined to desired dimensions and finish. This is usually done for the castings that are to be exported. The casting is given a smooth, shiny surface finish by grinding operations.

Then, the dimensions of the casting obtained are compared with the expected dimensions. Any dimension greater than the desired one is reduced by rod gouging and dimensions smaller than the desired ones are increased by welding. Then, the affected area is again given a smooth finish by grinding.

## 13. ACID PICKLING

It is a surface treatment used to remove impurities such as stains, inorganic contaminants, rust or scale (oxide layer formed during hot working processes), etc. These are removed by reactions with mineral acids. As the damaged metal layer gets removed, a properly alloyed steel surface gets exposed providing a good corrosion resistant performance. Commonly used acids for pickling are sulphuric acid, hydrochloric acid, nitric acid, hydrofluoric acid, phosphoric acid. Hydrochloric acid is used in steel castings. Even though it is more expensive than sulphuric acid, it pickles at a faster rate while minimizing base metal loss.

## 14. NON-DESTRUCTIVE TESTING (NDT)

Here, the casting goes through a number of quality tests without actually damaging or wasting the casting unlike tensile test, Brienell hardness test, etc.

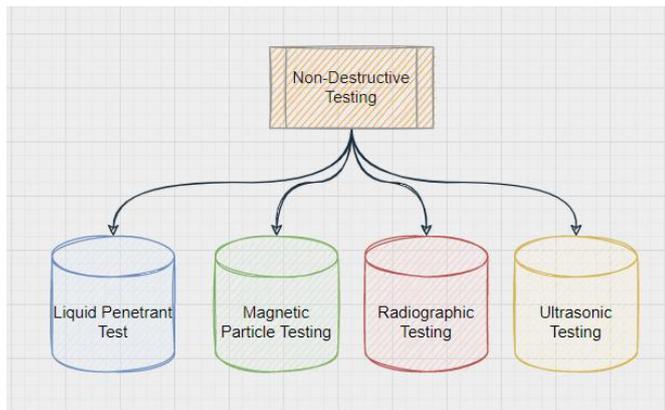


Fig-7: Types of NDT

### 14.1 Liquid Penetrant Test

The casting is first cleaned with red fluorescent paint. The paint is then allowed to settle and enter the surface pores and cracks for about 15 minutes. Then the entire casting is washed using water and solvent based cleaner and dried using air blower. A developer solution is sprayed on the casting which turns the entire casting white after sometime and exposes the fluorescent paint at locations where there are defects. Based on the severity of the defects, a decision is made upon which defects to ignore and which ones to fix. Then the entire casting is washed and the defective locations are marked. The paint penetrated in the cracks and holes is removed by a water washable penetrant.

### 14.2 Magnetic Particle Test

It is used for detection of surface and near-surface flaws in ferromagnetic materials and is primarily used for crack detection. The workpiece is magnetized and the magnetic flux is present predominantly inside the material. If there is any surface breaking flaw, the magnetic field is distorted, causing local magnetic flux leakage around the flaw. This leakage flux is displayed by covering the surface with very fine iron particles suspended in diesel. The particles accumulate at the regions of flux leakage, producing a build-up which can be seen visually even if the crack is very small and narrow. Thus, a crack is indicated as a visible line of iron powder or magnetic particles on the surface.

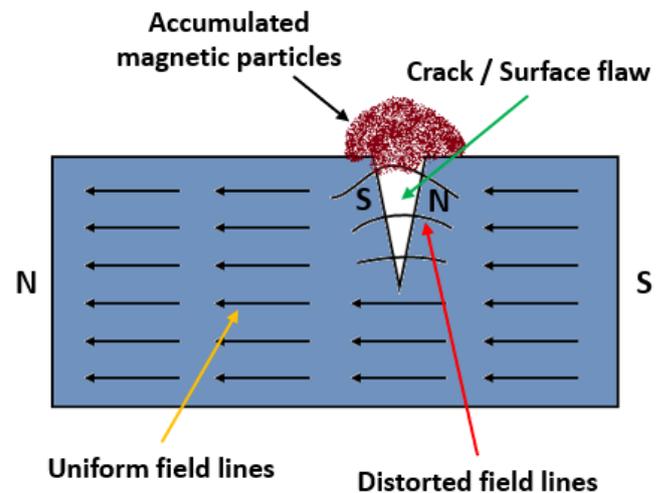


Fig-8: Magnetic particle testing

Magnetization can be produced by any of the following ways:

- By applying a permanent/electromagnet to the surface which is termed as magnetic flow

- By passing a large current through the overall specimen or it can be done locally by means of current prods

- By putting the component/specimen inside a current carrying loop

- By threading a current carrying bar through a hollow specimen

The method of magnetization should produce a magnetic field such that the lines of force are at large angles to the expected direction of cracks to be detected. So, magnetization is done more than once in different directions. This can also be done using a combination of two magnetic fields so that a swinging or rotating magnetic field can be produced which will detect a crack in any direction/orientation

### 14.3 Radiographic Testing

Ionizing radiations are used to penetrate the cross-sectional area of a casting and a piece of radiographic film is exposed. When discontinuities like cracks, gas, shrinkage or unfused chills or chaplets are present in a casting, the casting absorbs less radiation and more radiation reaches the film. This increased film exposure of the radiation ultimately produces an image of the discontinuity on the film. X-rays or Gamma rays are used to pass ionizing radiations through the casting.

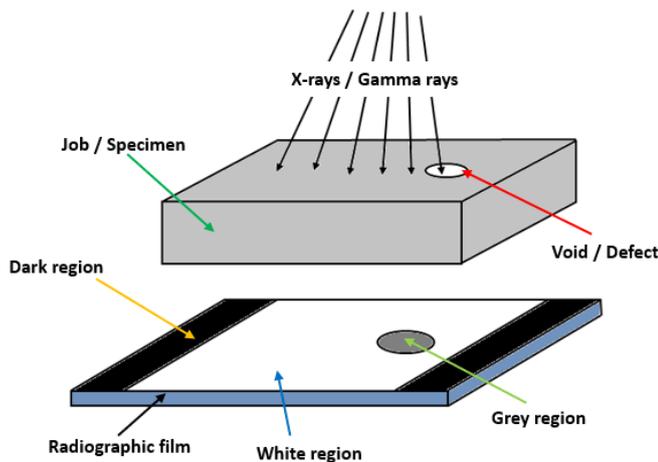


Fig-9: Radiographic testing

#### 14.4 Ultrasonic Testing

This method uses high frequency sound waves to detect surface and subsurface discontinuities in castings. It can also measure the thickness of the casting at locations where the human hand or mechanical devices cannot reach. Here, an ultrasonic transducer transforms electrical energy into mechanical energy in the form of sound pressure waves and the sound pulse thus, generated initiates at the transducer, travels through the casting and is reflected by both the back wall of the casting and any discontinuities that may be present. The transducer senses the reflected sound wave and converts it to an electrical signal. The properties of the sound wave like transit time, amplitude and shape give an idea about any defects present.

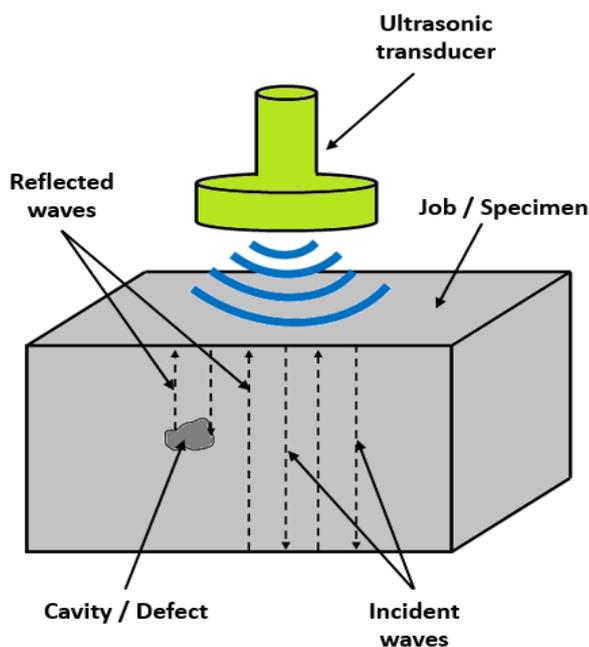


Fig-10: Ultrasonic testing

Once the defective locations are marked, they are entirely removed by rod gouging and then welded. The excess of weld bead is removed by grinding and then the casting is sent for post weld heat treatment to relieve the stresses developed in the weld. After the post weld heat treatment (PWHT), the casting is again sent for shot blasting (for carbon steels) or grit blasting (for stainless steels). The material used for grit blasting is aluminium. The NDTs are performed again to ensure whether the defects have been fixed or not. Final finishing and acid pickling is done once again after all the defects have been removed.

#### 15. Punching

Large castings usually have heat numbers, pattern numbers and material grades embossed/extruded on them along with the casting itself. However, some small castings need to be punched using metal stamping technique. The stamp has a specific dimension and has a letter or number embossed/extruded at its tip. The stamp of the correct size and letter must be chosen for punching. Holding the stamp vertically and hammering it 2-3 times creates a punch of the desired letter or number on the casting. After all the above processes, the casting is finally ready for dispatch.

#### 16. CONCLUSIONS

This paper explains most of the processes involved in sand casting of steels. It takes into account not only the basic foundry processes of molding, scrap melting and pouring but also the additional steps taken to ensure a good quality of the overall casting. The properties of the casting highly depend on the quality of the mold and hence, a number of steps are taken to strengthen the mold and remove any voids or moisture contained within it. Moreover, the process of scrap melting needs to be done carefully wherein additional alloying elements need to be added to obtain the desired composition of the material.

This study also explains the basics of heat treatment of steel castings. However, more research needs to be done in order to obtain detailed information about the various physical phases and the corresponding microstructures of steel obtained during heat treatment. A number of transformations take place during heat treatment (martensite, austenite, bainite, pearlite, etc.) resulting in different mechanical properties of the component.

A number of machining and finishing processes have been mentioned in the paper. However, the importance of each of them highly depends on the type of the component and the desired finish. Also, the availability of resources can affect the application of any process in a foundry. Many organizations, due to unavailability of space and resources, have to outsource in order to complete a given process. Also, the materials, tools and equipment used for different processes vary from company to company leading to

different quality of finished products. Moreover, the quality and volume of production also depend upon the extent to which manual labour and automation are implemented.

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