METAL CASTINGS IN CARS

By Frank Jensen 07/30/2024

More metal castings are produced for cars, trucks, and buses than any other market.

The primary metals used for these castings are alloys of aluminum, iron, some copper (i.e. brass and bronze), and a little zinc.

Pure metals are not suitable for casting because:

1. They have limited strength and hardness and bend easily since they freeze with a crystal structure that disforms easily.
2. They freeze at a single temperature with no ability to feed the non-uniform section thickness of the typical casting as it shrinks during solidification.

Metal alloys were invented to solve these problems by:

1. Slightly distorting the crystal structure with atoms of another metal of slightly different atomic structure and introducing other metal elements to add strength and harness through heat treatment after casting.
2. Causing the alloy to freeze over a range of temperature so that it can be fed by gravity or pressure as it freezes.
3. Here's video simulation of 4 ductile iron crankshafts solidifying in a sand mold - **Filling & Solidification of Sand Cast Ductile Iron Crank Shafts** **(What is Ductile Iron)**

Casting Methods

A. Sand Casting
B. Investment Casting (lost wax and lost foam)
C. Permanent Mold Casting
D. Die Casting

Because they differ in melting temperature, not all metals can be cast with all the above methods. Melting temperatures are listed below with the casting methods that can be used.

Melting temperatures:		Casting methods
Zinc	787 F	Sand, Investment, Perm Mold, Die
Aluminum	1220 F	Sand, Investment, Perm Mold, Die
Copper	1983 F	Sand, Investment
Iron	2200 F	Sand, Investment

Sand castings in cars:

Cast iron and aluminum engine blocks, heads, and intake manifolds

Cast iron disc brake rotors (Highly automated vertical parted sand casting with sand cores)

Ductile Iron crankshafts

Investment castings in cars:

carburetor housing (lost wax), heads, camshafts, engine blocks (lost foam)

Permanent mold castings in cars:

Cast aluminum wheels, Brake master cylinders

Die castings in cars:

Pump housings, covers, trim, engine blocks(?)

Casting history and characteristics:

A. Sand Casting – Around 1300 BC, the Shang Dynasty in China were the first to utilize bonded sand molds for metal casting.

Small to very large casting sizes are possible, all the above metals can be cast, each mold is used only once and is broken to retrieve the part, lower accuracy, good detail, partial net shape, good surface finish possible, low-cost tooling, parts relatively expensive.

B.1 Investment Casting (lost wax) – The earliest use for investment casting was in the creation of idols, ornaments and jewelry, around the year 3,700BC. Natural beeswax was used for the patterns, clay for the molds and manually operated bellows stoked the furnaces. The Egyptians later created intricate metalwork for their tombs and temples.

Limited to small - medium size castings, all the above metals can be cast, each mold used only once and is broken to retrieve the part, excellent accuracy and cast detail, near net shape, excellent surface finish, good - excellent casting strength, expensive tooling and expensive parts.

B.2 Investment Casting (lost foam) – Developed as a high volume process around 1970's. Styrofoam patterns are coated with a refractory coating then invested in a fluidized bed of unbonded sand. Molten metal is poured into the mold to vaporize the foam pattern yielding a metal casting. This produces accurate castings at low cost if the vaporization of the foam pattern can be controlled properly by venting the combustion byproducts through the refractory coating. Uses I'm aware of are to produce aluminum heads and steel/ductile iron camshafts for GM Saturn cars and aluminum heads for OMC outboards.

C. Permanent Mold Casting (Gravity/Tilt Pour/Low Pressure) – Permanent mold casting originated earlier than the Bronze Age, using open stone molds to cast lead, gold, and copper. Examples of such casts are found in Mesopotamia, Egypt, and China. Greek and Roman metallurgy made use of processes that are considered predecessors to modern permanent mold casting.

Small - medium casting sizes are possible, only aluminum or zinc alloys can be cast, reusable mold, medium accuracy, very good detail, near net shape, good surface finish, bonded sand cores and pullbacks in the mold possible, excellent mechanical properties, moderate cost tooling and parts.

D. Die Casting – The die casting process was invented. 1849- Patent for die casting was approved. 1890s- Up until this point the only use was for typewriters and portable print. As the technology gained traction over time, people began using it for different products including aluminum alloys.

Small - medium casting sizes are limited by the high pressure to fill and feed the casting during solidification (1000-20,000 psi) requiring massive hydraulic clamping force (up to 1800+ tons!), only aluminum and zinc alloys can be cast, reusable mold, excellent accuracy, very good detail, near net shape, very good surface finish, pullbacks in the die possible, high skin strength, high velocity injection filling causes turbulence resulting in internal porosity and poor machinability, high cost tooling and lowest cost parts.

Casting Process Details:

Sand Casting: Molds are made by mixing a controlled fineness sand with a binder and compacting the sand around a pattern to form a cavity in the shape of the desired part. The cavity is then filled with molten metal and after allowing the metal to freeze, the mold is broken open to remove the part. Lowest tooling cost casting method but you must make a mold for each casting produced. The lower the metal melting point and the thinner the casting section is, the finer the sand can be and still be permeable enough to vent the hot gases created during pouring. Finer sand produces a smoother cast surface finish. So thin wall aluminum castings can use a finer sand than a heavy section cast iron part.

Binder systems include:

1. Clay and water (called green sand molding because it's not baked in an oven). Pros - Low-cost materials, only require compaction to form the mold, the sand can be reused by simple remixing, breaks up easily to remove the solidified casting, can be automated for high production. Cons – requires constant sampling and control to maintain molding sand properties, large sand storage tank to allow sand cooling before reuse. Here's some videos (Iron casting with

shell sand cores),(Aluminum Navarro Head casting with solid sand core assembly for the combustion chambers and cooling water passages) Here's an extreme high volume production line animation video using a Disamatic vertical parted molding machine making disc rotors in WI (Cast iron brake rotors with a solid sand core) Note that, an operator or a robot loads the two sand cores in a "core setter fixture while the mold is being made. Then the machine sets the cores in the mold while the next mold is being made. This one molding machine consumes around 50 tons of prepared sand each hour. I saw this foundry in the mid nineties they had 13 of these machines, some in smaller sizes than this one. They shipped out the back in bins loaded on rail cars!

2. Heat cure resin bonding. Pros – high bond strength allows thin (shell) molds and cores to minimize material cost, tighter tolerance near net shape castings. Cons – poor permeability mold requiring more venting, sand not recycled, slower molding process, tooling and parts are more expensive than clay bonded sand castings. Many cast iron cylinder liners cast into cast aluminum engine blocks are made this way. This process is also used to make hollow sand cores. Here's some videos (Shell mold casting), (Making Shell (Hollow) Cores)
3. No bake (Resin and Catalyst) Bonding. Pros – high mold strength, best way to make molds for large, complicated shapes with more accurate castings. Cons – poor permeability mold requiring more venting, expensive chemicals, slow bond curing, must use sand once and pay for its disposal or buy and use expensive equipment for thermal reclaiming to reuse sand. Here's a video (No bake molding).
4. Chemical bonding with catalyzing gas. Pros – like #3 above but with instant bond curing, can be automated. Cons - poor permeability mold requiring more venting, more capital equipment for catalyzing gas, similar sand disposal/reuse issues.
5. Cosworth process. A while ago, the Cosworth V8 was popular on the Indy race circuit. Cosworth patented an aluminum casting process they used to cast the Cosworth V8 block. Recently, several car companies licensed the process to make cast aluminum engines and other parts. It uses the chemical sand bonding with catalyzing

gas in #4 directly above. However, they used more expensive ground zircon as a molding sand because it conducts heat better than the silica sand normally used. This makes the casting freeze faster with fine grain structure resulting in higher strength while also saving weight. Their other innovation was to seal the mold on top of an aluminum holding furnace and pull the metal up into the mold by vacuum. The mold fills with no turbulence and reduced oxide formation resulting in higher strength also. Here's a video of a highly automated Cosworth Process to make cast aluminum engine blocks [Aluminum engine block with cast iron cylinder liners cast with automated Cosworth Process]

Investment casting: Lost wax method - A replica of the part is made by injecting wax into a metal mold. The mold may include multiple sections that pull back after the wax solidifies to form a complex shape. Multiple wax replicas are usually heat bonded to a central pouring sprue or stalk that is then dipped in a ceramic refractory slurry to form a ceramic shell around the wax assembly. After the ceramic shell dries and cures, the assembly is then baked at high temperature to harden the shell and melt out the wax for reuse. Metal is then poured into the cavity. After the parts cool, the ceramic shell is broken, and the cast parts are retrieved and cut loose from the stalk.

Investment castings have excellent accuracy, smooth surfaces, and near net shape. Complex shapes are possible. Their size is limited by the ability to handle and assemble the wax replicas without distortion. They are expensive to produce for their size, but, in the right application, their near net shape as cast can result in the lowest net cost compared to other methods. For volume production, many steps of the process can be automated. Here's a video [Investment (lost wax) Casting]

Lost foam method-A replica of the part is made by blow molding Styrofoam like making a disposable coffee cup. Multiple foam parts can be glued together to make a complex shape. The foam replicas are glued to a foam stalk that serves as a down sprue. The foam assembly is dipped in a thin refractory slurry and dried at low heat. The assembly is lowered into an air fluidized bed of unbonded sand inside of a cylindrical open top metal container. When the air is shut off, the assembly is held tightly in the unbonded sand. Molten metal is poured into the mold burning out the Styrofoam and replacing its shape with solidifying metal. The gases generated during pouring pass through the refractory coating and vent into the sand. The process can be highly automated to produce inexpensive castings with low cost and very good accuracy. This process is difficult to control but very cost effective if you can master it. I saw this in operation at the GM Saturn plant in TN. They were casting aluminum heads and ductile iron camshafts with it. If you see a casting that looks like the surface of a foam coffee cup on your car or outboard motor that's how it was made. Here's a video Investment (Lost foam) Casting

Permanent Mold Casting: Permanent molds can be used to produce aluminum castings. The mold is usually made in two vertically parted halves and is most often made from cast iron that has been machined to the final cavity shape. It includes the channels (called the gating system) that deliver molten aluminum to the part cavity and to feed the casting with liquid metal as it shrinks during solidification. The mold is heated and painted with a refractory coating to protect it from chemical attack by the molten aluminum. If needed to form an internal passage in the casting, a bonded sand core can be inserted into the mold cavity before pouring. The mold can also be built with a cast iron section(s) that can be pulled back before the part is removed from the mold to form an undercut.

Molten aluminum is poured into the mold, the part is allowed time to freeze, the mold is opened, and the part is removed. Because of the individual part shape, ejector pins are often used to assist casting removal as the mold is opened. The mold is then closed, and the cycle is repeated to produce additional castings.

To reduce the turbulence caused by pouring molten aluminum into a vertically parted metal mold, the "Tilt Pour" process was invented. The mold is mounted in a machine that holds it closed in the horizontal position. The appropriate amount of aluminum is poured into a pouring cup attached to the entrance of the mold. The machine rotates the mold to the vertical position in a controlled manner causing the metal to slowly flow to fill the cavity. This is similar to pouring beer into a tilted glass to minimize the head. This process with a sand core is used to make cast aluminum master brake cylinders. Here's a video Investment (Lost foam) Casting

A separate process called "Low Pressure Permanent Mold" was developed to cast aluminum wheels for cars. The permanent mold sits horizontally on top of a holding furnace full of aluminum held at the necessary pouring temperature. Low air pressure is applied above the molten aluminum in a controlled manner that forces the metal to enter the bottom of the mold at the hub of the cast wheel. The pressure stays on to force feed metal into the casting while it solidifies. Next multiple parts of the mold that form the outside air cavity for the tire to mount pull back so that the casting can be removed, and the cycle is repeated. Here's a video Low pressure permanent mold casting aluminum wheels

Die Casting: Molten aluminum is injected under high pressure into the cavity of a steel die (the mold). The die is made up of two halves, and after the molten aluminum has solidified, they are separated to eject the cast aluminum part from the die. The die is sprayed with a mist lubricant before every cycle to protect the die from chemical attack from the molten aluminum and to facilitate ejection.

The die casting machine holds the die closed with multiple tons of hydraulic force (up to 100 tons) because of the pressure exerted on the metal to feed the casting as it freezes and the hot gases due to the molten metal filling the die. The metal squirts into the die at high velocity through small ingate passages and mixes with the air in the die, creating turbulence, aluminum oxides and small voids resulting in unsound internal structure. The surface skin of the die casting freezes fast because the die is externally cooled. This gives the part its strength via small grain structure. A shearing die is usually used to separate the part from the gating system. The cycle time is fast resulting in low cost, near net shape parts. Here's some videos Die Casting Slide show, Die cast engine block Semisolid aluminum die casting

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2 **What is Ductile Iron**

3 **Iron casting with shell sand cores**

4* **Aluminum Navarro Head casting with solid sand core assembly for the combustion chambers and cooling water passages**

5 **Cast iron brake rotors with a solid sand core**

6 **Shell mold casting), (Making Shell (Hollow) Cores**

7 **No bake molding**

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