= Die casting =

Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mold cavity . The mold cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process . Most die castings are made from non @-@ ferrous metals , specifically zinc , copper , aluminium , magnesium , lead , pewter and tin @-@ based alloys . Depending on the type of metal being cast , a hot- or cold @-@ chamber machine is used .

The casting equipment and the metal dies represent large capital costs and this tends to limit the process to high @-@ volume production . Manufacture of parts using die casting is relatively simple , involving only four main steps , which keeps the incremental cost per item low . It is especially suited for a large quantity of small- to medium @-@ sized castings , which is why die casting produces more castings than any other casting process . Die castings are characterized by a very good surface finish (by casting standards) and dimensional consistency .

Two variants are pore @-@ free die casting , which is used to eliminate gas porosity defects ; and direct injection die casting , which is used with zinc castings to reduce scrap and increase yield .

= = History = =

Die casting equipment was invented in 1838 for the purpose of producing movable type for the printing industry . The first die casting @-@ related patent was granted in 1849 for a small hand @-@ operated machine for the purpose of mechanized printing type production . In 1885 Otto Mergenthaler invented the linotype machine , an automated type @-@ casting device which became the prominent type of equipment in the publishing industry . The Soss die @-@ casting machine , manufactured in Brooklyn , NY , was the first machine to be sold in the open market in North America . Other applications grew rapidly , with die casting facilitating the growth of consumer goods and appliances by making affordable the production of intricate parts in high volumes . In 1966 , General Motors released the Acurad process .

= = Cast metals = =

The main die casting alloys are : zinc , aluminium , magnesium , copper , lead , and tin ; although uncommon , ferrous die casting is also possible . Specific die casting alloys include : Zamak ; zinc aluminium ; aluminium to , e.g. The Aluminum Association (AA) standards : AA 380 , AA 384 , AA 386 , AA 390 ; and AZ91D magnesium . The following is a summary of the advantages of each alloy :

Zinc : the easiest metal to cast ; high ductility ; high impact strength ; easily plated ; economical for small parts ; promotes long die life .

Aluminium : lightweight ; high dimensional stability for complex shapes and thin walls ; good corrosion resistance ; good mechanical properties ; high thermal and electrical conductivity ; retains strength at high temperatures .

Magnesium : the easiest metal to machine ; excellent strength @-@ to @-@ weight ratio ; lightest alloy commonly die cast .

Copper : high hardness ; high corrosion resistance ; highest mechanical properties of alloys die cast ; excellent wear resistance ; excellent dimensional stability ; strength approaching that of steel parts .

Silicon tombac : high @-@ strength alloy made of copper , zinc and silicon . Often used as an alternative for investment casted steel parts .

Lead and tin : high density ; extremely close dimensional accuracy ; used for special forms of corrosion resistance . Such alloys are not used in foodservice applications for public health reasons . Type metal , an alloy of lead , tin and antimony (with sometimes traces of copper) is used for casting hand @-@ set type in letterpress printing and hot foil blocking . Traditionally cast in hand jerk moulds now predominantly die cast after the industrialisation of the type foundries . Around

1900 the slug casting machines came onto the market and added further automation , with sometimes dozens of casting machines at one newspaper office .

Maximum weight limits for aluminium , brass , magnesium and zinc castings are approximately 70 pounds (32 kg) , 10 lb (4 @.@ 5 kg) , 44 lb (20 kg) , and 75 lb (34 kg) , respectively .

The material used defines the minimum section thickness and minimum draft required for a casting as outlined in the table below . The thickest section should be less than 13 mm (0 @.@ 5 in) , but can be greater .

= = Equipment = =

There are two basic types of die casting machines : hot @-@ chamber machines and cold @-@ chamber machines . These are rated by how much clamping force they can apply . Typical ratings are between 400 and 4 @,@ 000 st (2 @,@ 500 and 25 @,@ 400 kg) .

= = = Hot @-@ chamber die casting = = =

Hot @-@ chamber die casting , also known as gooseneck machines , rely upon a pool of molten metal to feed the die . At the beginning of the cycle the piston of the machine is retracted , which allows the molten metal to fill the " gooseneck " . The pneumatic- or hydraulic @-@ powered piston then forces this metal out of the gooseneck into the die . The advantages of this system include fast cycle times (approximately 15 cycles a minute) and the convenience of melting the metal in the casting machine . The disadvantages of this system are that it is limited to use with low @-@ melting point metals and that aluminium cannot be used because it picks up some of the iron while in the molten pool . Therefore hot @-@ chamber machines are primarily used with zinc- , tin- , and lead @-@ based alloys .

= = = Cold @-@ chamber die casting = = =

These are used when the casting alloy cannot be used in hot @-@ chamber machines ; these include aluminium , zinc alloys with a large composition of aluminium , magnesium and copper . The process for these machines start with melting the metal in a separate furnace . Then a precise amount of molten metal is transported to the cold @-@ chamber machine where it is fed into an unheated shot chamber (or injection cylinder) . This shot is then driven into the die by a hydraulic or mechanical piston . The biggest disadvantage of this system is the slower cycle time due to the need to transfer the molten metal from the furnace to the cold @-@ chamber machine .

= = Mold or Tooling = =

Two dies are used in die casting ; one is called the " cover die half " and the other the " ejector die half " . Where they meet is called the parting line . The cover die contains the sprue (for hot @-@ chamber machines) or shot hole (for cold @-@ chamber machines) , which allows the molten metal to flow into the dies ; this feature matches up with the injector nozzle on the hot @-@ chamber machines or the shot chamber in the cold @-@ chamber machines . The ejector die contains the ejector pins and usually the runner , which is the path from the sprue or shot hole to the mold cavity . The cover die is secured to the stationary , or front , platen of the casting machine , while the ejector die is attached to the movable platen . The mold cavity is cut into two cavity inserts , which are separate pieces that can be replaced relatively easily and bolt into the die halves .

The dies are designed so that the finished casting will slide off the cover half of the die and stay in the ejector half as the dies are opened . This assures that the casting will be ejected every cycle because the ejector half contains the ejector pins to push the casting out of that die half . The ejector pins are driven by an ejector pin plate , which accurately drives all of the pins at the same time and with the same force , so that the casting is not damaged . The ejector pin plate also retracts the pins after ejecting the casting to prepare for the next shot . There must be enough

ejector pins to keep the overall force on each pin low , because the casting is still hot and can be damaged by excessive force . The pins still leave a mark , so they must be located in places where these marks will not hamper the casting 's purpose .

Other die components include cores and slides . Cores are components that usually produce holes or opening , but they can be used to create other details as well . There are three types of cores : fixed , movable , and loose . Fixed cores are ones that are oriented parallel to the pull direction of the dies (i.e. the direction the dies open) , therefore they are fixed , or permanently attached to the die . Movable cores are ones that are oriented in any other way than parallel to the pull direction . These cores must be removed from the die cavity after the shot solidifies , but before the dies open , using a separate mechanism . Slides are similar to movable cores , except they are used to form undercut surfaces . The use of movable cores and slides greatly increases the cost of the dies . Loose cores , also called pick @-@ outs , are used to cast intricate features , such as threaded holes . These loose cores are inserted into the die by hand before each cycle and then ejected with the part at the end of the cycle . The core then must be removed by hand . Loose cores are the most expensive type of core , because of the extra labor and increased cycle time . Other features in the dies include water @-@ cooling passages and vents along the parting lines . These vents are usually wide and thin (approximately 0 @.@ 13 mm or 0 @.@ 005 in) so that when the molten metal starts filling them the metal quickly solidifies and minimizes scrap . No risers are used because the high pressure ensures a continuous feed of metal from the gate .

The most important material properties for the dies are thermal shock resistance and softening at elevated temperature ; other important properties include hardenability , machinability , heat checking resistance , weldability , availability (especially for larger dies) , and cost . The longevity of a die is directly dependent on the temperature of the molten metal and the cycle time . The dies used in die casting are usually made out of hardened tool steels , because cast iron cannot withstand the high pressures involved , therefore the dies are very expensive , resulting in high start @-@ up costs . Metals that are cast at higher temperatures require dies made from higher alloy steels .

The main failure mode for die casting dies is wear or erosion . Other failure modes are heat checking and thermal fatigue . Heat checking is when surface cracks occur on the die due to a large temperature change on every cycle . Thermal fatigue is when surface cracks occur on the die due to a large number of cycles .

= = Process = =

The following are the four steps in traditional die casting , also known as high @-@ pressure die casting , these are also the basis for any of the die casting variations : die preparation , filling , ejection , and shakeout . The dies are prepared by spraying the mold cavity with lubricant . The lubricant both helps control the temperature of the die and it also assists in the removal of the casting . The dies are then closed and molten metal is injected into the dies under high pressure ; between 10 and 175 megapascals (1 @,@ 500 and 25 @,@ 400 psi) . Once the mold cavity is filled , the pressure is maintained until the casting solidifies . The dies are then opened and the shot (shots are different from castings because there can be multiple cavities in a die , yielding multiple castings per shot) is ejected by the ejector pins . Finally , the shakeout involves separating the scrap , which includes the gate , runners , sprues and flash , from the shot . This is often done using a special trim die in a power press or hydraulic press . Other methods of shaking out include sawing and grinding . A less labor @-@ intensive method is to tumble shots if gates are thin and easily broken ; separation of gates from finished parts must follow . This scrap is recycled by remelting it . The yield is approximately 67 % .

The high @-@ pressure injection leads to a quick fill of the die , which is required so the entire cavity fills before any part of the casting solidifies . In this way , discontinuities are avoided , even if the shape requires difficult @-@ to @-@ fill thin sections . This creates the problem of air entrapment , because when the mold is filled quickly there is little time for the air to escape . This problem is minimized by including vents along the parting lines , however , even in a highly refined

process there will still be some porosity in the center of the casting .
Most die casters perform other secondary operations to produce features not readily castable , such as tapping a hole , polishing , plating , buffing , or painting .

= = = Inspection = = =

After the shakeout of the casting it is inspected for defects . The most common defects are misruns and cold shuts . These defects can be caused by cold dies , low metal temperature , dirty metal , lack of venting , or too much lubricant . Other possible defects are gas porosity , shrinkage porosity , hot tears , and flow marks . Flow marks are marks left on the surface of the casting due to poor gating , sharp corners , or excessive lubricant .

= = = Lubricants = = =

Water @-@ based lubricants , called emulsions , are the most commonly used type of lubricant , because of health , environmental , and safety reasons . Unlike solvent @-@ based lubricants , if water is properly treated to remove all minerals from it , it will not leave any by @-@ product in the dies . If the water is not properly treated , then the minerals can cause surface defects and discontinuities . There are four types of water @-@ based lubricants : oil in water , water in oil , semi @-@ synthetic , and synthetic . Oil in water is the best , because when the lubricant is applied , the water cools the die surface by evaporating while depositing the oil , which helps release the shot . A common mixture for this type of lubricants is thirty parts water to one part oil , however in extreme cases a ratio of 100 : 1 is used .
Oils that are used include heavy residual oil (HRO) , animal fats , vegetable fats , and synthetic fats . HROs are gelatinous at room temperature , but at the high temperatures found in die casting , they form a thin film . Other substances are added to control the emulsions viscosity and thermal properties ; these include graphite , aluminium , and mica . Other chemical additives are used to inhibit rusting and oxidation . Emulsifiers are added to water @-@ based lubricants , so that oil based additives can be mixed into the water ; these include soap , alcohol esters , and ethylene oxides .
Historically , solvent @-@ based lubricants , such as diesel fuel and kerosene , were commonly used . These were good at releasing the part from the dies , but a small explosion occurred during each shot , which led to a build @-@ up of carbon on the mold cavity walls . However , they were easier to apply evenly than water @-@ based lubricants .

= = = Advantages and disadvantages = = =

Advantages of die casting :
Excellent dimensional accuracy (dependent on casting material , but typically 0 @.@ 1 mm for the first 2 @.@ 5 cm (0 @.@ 005 inch for the first inch) and 0 @.@ 02 mm for each additional centimeter (0 @.@ 002 inch for each additional inch) .
Smooth cast surfaces (Ra 1 ? 2 @.@ 5 micrometres or 0 @.@ 04 ? 0 @.@ 10 thou rms) .
Thinner walls can be cast as compared to sand and permanent mold casting (approximately 0 @.@ 75 mm or 0 @.@ 030 in) .
Inserts can be cast @-@ in (such as threaded inserts , heating elements , and high strength bearing surfaces) .
Reduces or eliminates secondary machining operations .
Rapid production rates .
Casting tensile strength as high as 415 megapascals (60 ksi) .
Casting of low fluidity metals .
The main disadvantage to die casting is the very high capital cost . Both the casting equipment required and the dies and related components are very costly , as compared to most other casting processes . Therefore , to make die casting an economic process , a large production volume is

needed . Other disadvantages are that the process is limited to high @-@ fluidity metals , and casting weights must be between 30 grams (1 oz) and 10 kg (20 lb) . In the standard die casting process the final casting will have a small amount of porosity . This prevents any heat treating or welding , because the heat causes the gas in the pores to expand , which causes micro @-@ cracks inside the part and exfoliation of the surface . Thus a related disadvantage of die casting is that it is only for parts in which softness is acceptable . Parts needing hardening (through hardening or case hardening) and tempering are not cast in dies .

= = Variants = =

= = = Acurad = = =

Acurad was a die casting process developed by General Motors in the late 1950s and 1960s . The name is an acronym for accurate , reliable , and dense . It was developed to combine a stable fill and directional solidification with the fast cycle times of the traditional die casting process . The process pioneered four breakthrough technologies for die casting : thermal analysis , flow and fill modeling , heat treatable and high integrity die castings , and indirect squeeze casting (explained below) .

The thermal analysis was the first done for any casting process . This was done by creating an electrical analog of the thermal system . A cross @-@ section of the dies were drawn on Teledeltos paper and then thermal loads and cooling patterns were drawn onto the paper . Water lines were represented by magnets of various sizes . The thermal conductivity was represented by the reciprocal of the resistivity of the paper .

The Acurad system employed a bottom fill system that required a stable flow @-@ front . Logical thought processes and trial and error were used because computerized analysis did not exist yet ; however this modeling was the precursor to computerized flow and fill modeling .

The Acurad system was the first die casting process that could successfully cast low @-@ iron aluminum alloys , such as A356 and A357 . In a traditional die casting process these alloys would solder to the die . Similarly , Acurad castings could be heat treated and meet the U.S. military specification MIL @-@ A @-@ 21180 .

Finally , the Acurad system employed a patented double shot piston design . The idea was to use a second piston (located within the primary piston) to apply pressure after the shot had partially solidified around the perimeter of the casting cavity and shot sleeve . While the system was not very effective , it did lead the manufacturer of the Acurad machines , Ube Industries , to discover that it was just as effective to apply sufficient pressure at the right time later in the cycle with the primary piston ; this is indirect squeeze casting .

= = = Pore @-@ free = = =

When no porosity is allowed in a cast part then the pore @-@ free casting process is used . It is identical to the standard process except oxygen is injected into the die before each shot to purge any air from the mold cavity . This causes small dispersed oxides to form when the molten metal fills the die , which virtually eliminates gas porosity . An added advantage to this is greater strength . Unlike standard die castings , these castings can be heat treated and welded . This process can be performed on aluminium , zinc , and lead alloys .

= = = Heated @-@ manifold direct @-@ injection = = =

Heated @-@ manifold direct @-@ injection die casting , also known as direct @-@ injection die casting or runnerless die casting , is a zinc die casting process where molten zinc is forced through a heated manifold and then through heated mini @-@ nozzles , which lead into the molding cavity . This process has the advantages of lower cost per part , through the reduction of scrap (by the

elimination of sprues , gates and runners) and energy conservation , and better surface quality through slower cooling cycles .

= = = Semi @-@ solid = = =

Semi @-@ solid die casting uses metal that is heated between its liquidus and either solidus or eutectic temperature , so that it is in its " mushy region " . This allows for more complex parts and thinner walls .