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Characterization & Optimization of Refinement of Aluminum-Silicon Alloy used for Die-casting

Krishna Pal Singh Chauhan
Head of the Department
Department of Mechanical Engineering,
Future Institute of Engineering and Technology,Bareilly (U.P.)

Abstract – The quality of the molten metal, from which the products are cast directly affects the quality of the cast products. One of the most crucial factors in the control and forecasting of desired casting properties in the cast components is to properly treat the melt. Melt treatment have direct impact on casting quality. The amount of an alloying element present and how the melt is treated have a considerable impact on the mechanical properties and, consequently, the quality of castings. Therefore, one of the most crucial steps in producing a product of the appropriate quality is the melt treatment. Aluminum casting alloys are frequently used to make high quality components due to their higher strength-to-weight ratio, superior wear resistance, and lower coefficient of expansion. The degree of microstructure and melt treatment refinement determines the quality of end products. Phosphorus addition in the aluminum alloy melt is a effective method to refine grain size of silicon and to improve mechanical properties. In this research paper the factors influencing the melt refinement are investigated and it was found that phosphorous addition in the molten metal affects silicon grain size and mechanical properties like hardness. The optimum conditions are ascertain through experimental work.

1. Introduction-

The faulty melt, if used for casting creates a number of defects, which finally leads to scrap and considerable financial losses to casting industries. The melt used for casting must need certain qualitative requirements. Melt quality indicates the main chemical composition of the aluminum alloy itself and impurity content in it. Thus the monitoring of chemical composition of melt, melting process and quality control of melt becomes the most important part for evaluation of product quality in foundries. Melt treatment is the process in which the different types of impurities like slag, inclusions, oxides and dissolved gases are removed before pouring in to the mould. These treatments purify the molten aluminium alloy; the objective is to provide more efficient separation of molten alloy and dross. The most important treatment processes are fluxing, grain refinement and degasification. The purpose of fluxing is to separate dross from molten alloy and to remove undesirable oxides and impurities. The objectives of grain refinement are to refine primary silicon grain size and to homogenize the distribution of Si, because for the smooth surface and good casting appearance homogeneous structure of extreme fineness is desired. Aluminum alloys absorbs hydrogen from its surroundings. The main sources of hydrogen are moisture present in atmosphere, oxides of aluminum and furnace atmosphere. This soluble hydrogen increases harmful defects as pinholes and micro porosity. The process of removing thes dissolved gases is called degasification. Degasification of aluminum alloy melt is done to remove the dissolved hydrogen.

2. Aluminum Casting Alloys-

Casting alloy designation system is based on 3-digit plus decimal designation XXX.X . The first digit represents main alloying element which has been added, second and third digits are arbitrary numbers given to identify specific alloy in that series. The number following the decimal point indicates weather alloy is casting (.0) or ingot (.1 or .2)

Some commonly used cast aluminum alloys are described in Table [1]

S.NO.	Alloy Series	Principal Alloying Elements	Main property & some applications
1	2xx.x Series	Cu (4-6) %	The strength and hardness is highest among all casting alloys Al 200.0 is used for cylinder heads, pistons and pumps, Al 208.0 is used general purpose castings.
2	3xx.x Series	Si (5-22)% Cu (0-4.5)% Mg	It is most widely used alloy. Al 319.0 is used for engine crankcase and oil pan and engine parts Al 332.0 is used for heavy duty pistons.
3	4xx.x Series	Si (5-12)%	It is a binary Al-Si system. Al 443.0 is used for carburetor bodies.
4	5xx.x Series	Mg	It has very good corrosion resistance. Al 514.0 is used for permanent mould casting. Al 518.0 is used for aircraft and marine castings.

5	7xx.x Series	Zn	Good finishing characteristics. Al 713.0 is used for automotive parts and mining equipments.
6	8xx.x Series	Tin (Apprx. 6%)	Very good bearing resistance. Al 850.0 is used for bushings, journal bearings and rollers.

Table 1: Designation and Applications of casting aluminium alloys

Alloy series 1XX.X is almost pure alluminium (99.0%),series 6XX.X is unused series and in 9XX.X series other alloying elements are used therefore not included in this table. Alloying element as Si, Mg and Ni are added to get alloy of desired mechanical and metallurgical properties. In cast aluminium alloy silicon is added which provides the benefits of increasing fluidity, reducing cracking and improving feeding to minimize shrinkage and porosity.[2] This makes Al-Si alloy element as one of the most widely used material for casting of automobile components.the alluminium silicon alloy having silion percentage less than 11.6% (by weight) is called hypoeutectic and having more than 11.6 % silicon it is called hyper-eutectic alloy.Hyper-eutectic alloy have castability and improved fluidity[3]. In aluminum - silicon alloy other element are also added to improve mechanical properties. Addition of copper decreases shrinkage and provide basis for age hardening, which further improves hardness of the cast component after a certain time.The addition of Nickle increases the strength of alloy at elevated temperature [3]. In aluminum-silicon alloy the course silicon crystals creates harmful effects to the casting because silicon crystal are hard and brittle as a result this is the casting and machining of hypereutectic Silicon alloy provide poor surface finish[4] Thus the elimination of a large size silicon is very essential to get good quality castings.

The melting and alloying section of a casting plant is most important, since it is the starting point of casting production process. Just as the casting plant is dependent for production on a steady supply of water, gas and electricity. It is also and to same degree dependent upon a constant supply of suitable alloy. Failure of supply of any one of these items means complete shutdown in production plant.

3. Melt Treatment of Aluminum –Silicon Alloy

The melting and alloying of aluminum is done in induction furnace. These are the furnaces, in which the heating is performed by induced electric current within the metal being melted. These are the high frequency electric furnaces. The method of melting aluminum in electric induction furnace provides several advantages not obtained with other methods. First there is absence of any combustion products, which promote clean metal and absence of porosity. Second, the metal is continually stirred by the magnetic field which ensures uniformity of composition and prevents segregation of alloy constituents. Finally, due to lack of external heating the surroundings and operating conditions are cooler. Some other advantages are that the furnace atmosphere can be more closely controlled, losses by oxidation can be eliminated, alloying elements can be added without fear of their loss due to oxidation and composition of the melt and its temperature can be accurately controlled.[5]

A high frequency induction furnace consists of a refractory lining placed centrally inside water cooled copper coil. The high frequency induction furnace is used in lift coil type, in which the furnace shell, along with the coils, can be lifted up. Aluminum ingot and alloying elements in regulated quantity are placed in the furnace as metal charge. A high frequency current is passed through the water cooled copper coil which acts as the primary of a transformer and metal charges becomes the secondary. Heavy alternating secondary currents thus included in the metal charge by electromagnetic induction creates heat because the metal charge offers resistance to the secondary currents. The heat developed in the skin of metal charge reaches inside by conduction and melts the charge. The secondary current associates with a magnetic field which provides a magnetic stirring section on molten metal, speeds up the melting process and mixes up the metal charge uniformly[5]. It is very well known that the refinement is dependent largely on freezing rate [4] but modification with phosphorus addition is another method of controlling the refinement of primary silicon.[7] The purpose of this investigation is to examine the influence of phosphorus addition on the primary silicon grain size and mechanical properties of solidified component.

The quality of cast components also depends on casting process parameters. It is found through literature survey that the metal flow in the die castings is influenced by the pouring temperature, die temperature and the thermal conductivity of alloy. The nature of solidification in Al-alloys depends upon the specific gravity, thermal conductivity of liquid melt. Degasification, pouring temperature, velocity of pouring also influences the cast quality,[6] J.H Lee et al. [8] find the relation between turbulence of melt in holding furnace before pouring and degasification duration. They concluded that the design of degassing rotor have a huge impact on the generation of turbulence in the holding furnace before pouring. With the increase in the turbulence inside the furnace the time required for degassing is reduced which results in maintained flow-ability of the molten aluminum. Ottarwana et al [9], while investigating the effect of various parameters on quality of cast components, concluded that, the most important parameter which effects the quality of casting is Heat Transfer Coefficient of molten alloy. Diego et al [10] highlighted through their researches that casting of aluminum alloys have been a challenging task due to maximum shrinkage which occurs in this material. Therefore, the parameters that significant the casting method are rotation of impeller of degassing unit, maximum temperature of the aluminum alloy, the velocity of Pouring the molten metal and pre-heating of the dies. Thus from literature survey it is found that to create cast components of good quality the casting process variables like rate of pouring, temperature of melt, related humidity etc are some variables, which needs to controlled properly.

4. Experimental work and Test Procedure-

Aluminum silicon hyper eutectoid alloy (Si 17%) is used for piston. Before proceeding for refinement of silicon alloy, fluxing is done. The melt temperature is increased and maintained between 700-750 degree Centigrade .At this temperature dirt, inclusion, insoluble material and slag floats on the top surface of molten metal. At this stage sodium and potassium chloride fluxes 200 gram per 100 kg of melt are sprinkled on the top surface of molten alloy. Duration of 5-10 min. is provided to react fluxes with the melt. Now the flux is thoroughly mixed with the floating slag with the help of dross cleaning tool. This results in liquid melt trickle down, leaving behind the black powder, known as dross. The dross available of top surface is skimmed off with the help of skimming spoon. After this cleaning process the melt is ready for refining process.

4.1 Influence of Phosphorus addition on Silicon Grain Size-

Molten alloy (Al-Si alloy) having Si 17% is taken as a raw material (500kg) and fix amount of phosphorus is added to melt with the help of plunger. In this method the entire refinement process is divided in to five stages. In each the treatment is done for the duration of 3 minutes. The procedural steps of grain refinement are:

Step 1- First of all the unrefined and without addition of phosphorus, the molten metal is solidified and after turning the silicon grain size is measured.

Step 2- Add 20 gm of grain refiner (phosphorus) in the molten alloy and provide treatment for duration of 3 min. After this process solidify the test sample from this melt. After turning one side of test sample and doing chemical treatment, microstructure is observed under microscope and average grain size is measured.

Step 3- Step 2 is repeated for stage 2(more 20 gm phosphorus addition), stage 3(more 20 gm phosphorus addition), stage 4(more 20 gm phosphorus addition) and stage 5(more 20 gm phosphorus addition), keeping treatment time for every step 3 min.

Thus the total refinement time 15 min. At every stage there is a addition of 20gm phosphorus in 50kg melt. So the amount of phosphorus increases from 20gm to 100gm.After each stage the silicon grain size is measured and every grain size is calculated and recorded. After each stage a sample is taken and solidified to check the hardness.

4.2 Influence of Phosphorus addition on Hardness-

To find the influence of phosphorus addition and treatment time on hardness, following steps are taken:

Step 1- First of all unrefined and having no phosphorus, the molten metal is solidified and hardness is measured on Rockwell Hardness tester.

Step 2- After stage 1 treatment the molten alloy is solidified and the hardness of test piece is tested through Rockwell Hardness Tester and average value of hardness is listed.

Step 3- The hardness is tested after second, third and fourth stage as per method stated in step 2 and the average value are tabulated as under.

Initial observations for unrefined melt sample

1. Average grain size of silicon=160 micrometers

2. Hardness=20 Rc

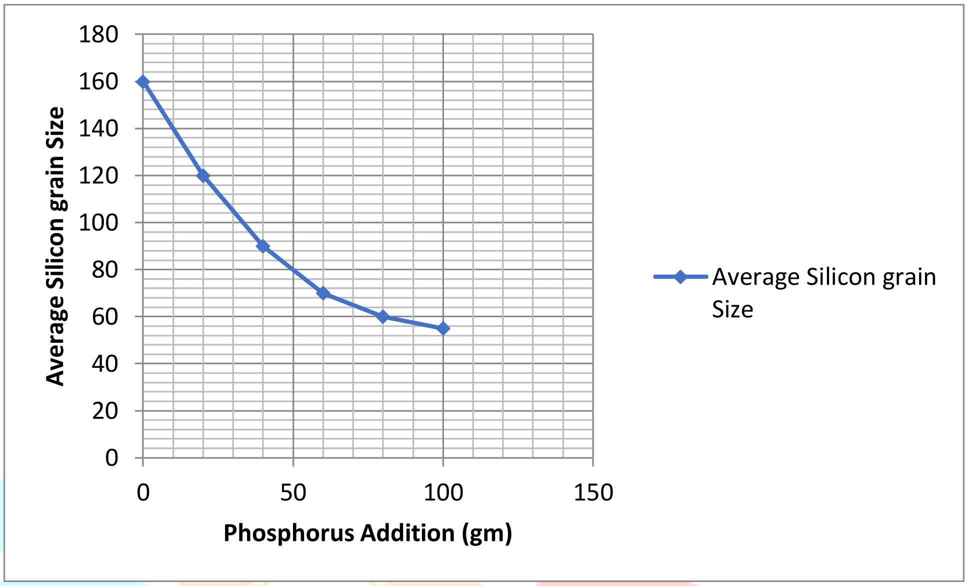
Test conditions – holding time for each stage = 3 min

S.No.	Stage	Phosphorus addition (gm)	Average Si grain size micrometers	Rockwell Hardness(Rc)
1	Initial stage	00	160	20.0
2	First stage	20	120	30.0
3	Second stage	40	90	34.0
4	Third stage	60	70	34.5
5	Fourth stage	80	60	35.0
6	Fifth stage	100	55	35.0

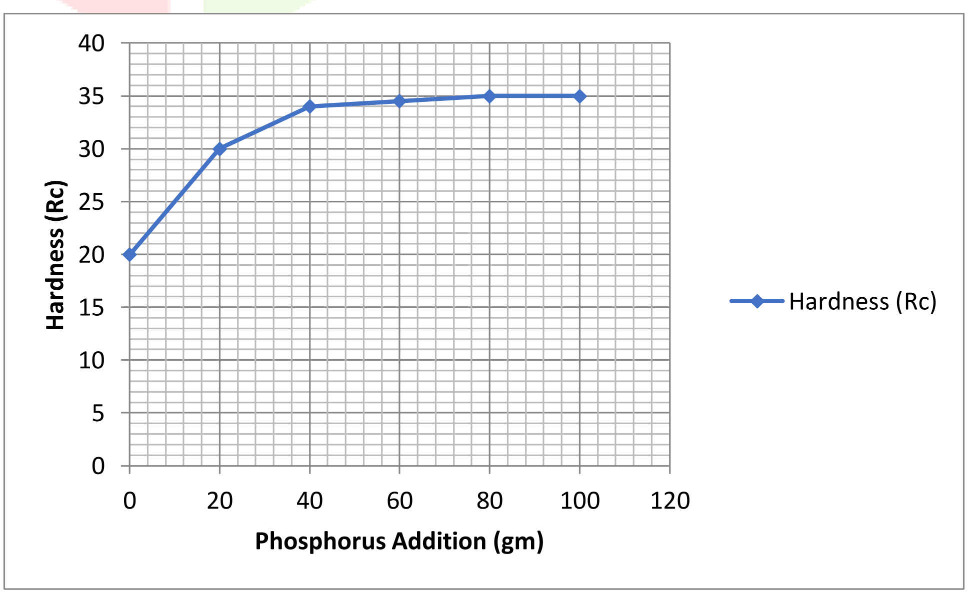
Table-2 Observations of experimental work

5-Results and Discussions-

Various test result are plotted on the graph. Figure 1 shows variation of silicon grain size with respect to phosphorus addition.



There is exponential reduction in grain size from 160 micrometers to 55 micrometers. In initial stages the grain size reduces rapidly and after that the value of gradient reduces. It is observed that the rate of change in hardness is more in initial stage, where reduction in grain size is from 120 to 90 micrometers. During intermediate stage, where reduction in grain size is from 90 to 70 micrometers, the rate of change of hardness is less. During the third stage, where the silicon grain size is reduced from 70 to 60 micrometers the rate of change of hardness is very low. Figure 2 shows variation of Hardness with respect to phosphorus addition.



There is slight increment in hardness value from 20 Rc to 35 Rc. In initial stages the hardness increases with comparatively more rate. It is observed that the rate of change in hardness is more in initial stage and after that there is very low increment .During last stage no further changes takes place in hardness values. After that no appreciable changes takes place. The optimum conditions for refinement of Silicon grain size is at 100 gm Phosphorous addition in melt which is equivalent to 200 PPM.

6. CONCLUSION-

It has been determined from the experimental work that adding phosphorus to the melt of an alloy of aluminum and silicon results in a superb refining of primary silicon. Primary silicon is refined as a result of the nucleation of aluminum phosphide. This results in a homogenous structure that is incredibly fine. Through experimental work, the ideal value of the process parameters is obtained. Due to its fine, homogenous structure and ability to provide a highly smooth surface, the uniform dispersion of fine silicon crystals improves the machining characteristics of aluminum–silicon alloy.

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