Thesis
On

EXPERIMENTAL STUDY AND EFFECTS OF PROCESS PARAMETERS OF LM24 ALUMINIUM ALLOY IN COLD CHAMBER HIGH PRESSURE DIE CASTING

Submitted In partial fulfillment of the requirement of the requirement for award of the degree
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Submitted by

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CERTIFICATE

I hereby declare that the thesis entitled "**Experimental study and effects of process parameters of LM24 aluminum alloy in cold chamber High Pressure Die casting** " is an authentic record of my study carried out as requirement for the award of degree of **Master of Engineering** in **Production engineering at Thapar University**, **Patiala**, under the guidance of **Dr.V.P Agrawal**, Visiting Professor and **Mr. Lalit Kumar**, Thapar University, Patiala during February 2014 to July 2014.The matter embodied in this thesis has not been submitted in part or full to any other University or institute for the award of any degree.

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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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Lastly, and most importantly, I wish to thank my parents & my wife . They supported me and loved me. To them I dedicate my thesis.

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ABSTRACT

Cold Chamber High Pressure Die Casting is a process by which a molten non-ferrous material is forced under high pressure into reusable tool steel moulds. These moulds called dies can be designed to produce intricate shapes with a high degree of accuracy and repeatability and surface finish with smooth or textured surfaces. High Pressure Die Casting is best suited for mass production runs and can produce the least expensive parts. A variety of materials are available for the High Pressure Die Casting process. The materials and process charts can be used to help determine which are best suited for a specific application.

Experiments in industrial environment were conducted producing wire clamp using commercially treated LM24 alloy. The different process parameter were varied such as injection pressure, pouring temperature, coating type, cooling type to understand their effect on the final product.

The objective of this study is to evaluate the main effects i.e. thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (Oil + graphite coating, Dycote + graphite coating, Dycote coating), and the type of cooling (air cooling, water cooling and oil cooling) on impact strength of material, density of the material, hardness of the material and the surface roughness of the material. In the experiments I used transformer oil for coating and cooling because of high heat dissipation energy. The methodology used to calculate the effect of various parameters will also be studied using parameterization approach in design of experiment is Taguchi approach. Taguchi's approach provides a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. This approach allows quality considerations to be included at an early stage of any new venture; in the design phase for a product, during routine maintenance or during installation of a manufacturing process. Analysis of Variance (ANOVA) was performed for all the responses and the effect of the factors was explained with the help of main effect plots. Micro structural analysis for all the trials was done.

The major finding and conclusion of this research is that control of various parameter such as pouring temperature, injection pressure, coating type, cooling type enhances the quality of product and suggest the different combination of process parameter which helps the product to sustain in the market.

Some limitation of numerical modelling and metallurgical analysis were also identified during this research and recommendations were made to improve the impact strength, surface roughness, hardness & density of aluminium alloy wire clamps.

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

High pressure die casting is a process in which molten metal of ferrous and non-ferrous alloys is forced under high pressure by plunger into the reusable mould cavity (i.e die), can be designed to produce intricate shapes, complex shapes with good surface finish and repeatability [1]. It is best suited for the mass production and least expensive parts can also be produced. We can make many parts from high pressure die casting process like engine housings, transmission cases, engine heads, laptop housings, mobile housings etc. can be manufactured very precisely. The roughly temperature of molten metal is 695^{0}C.

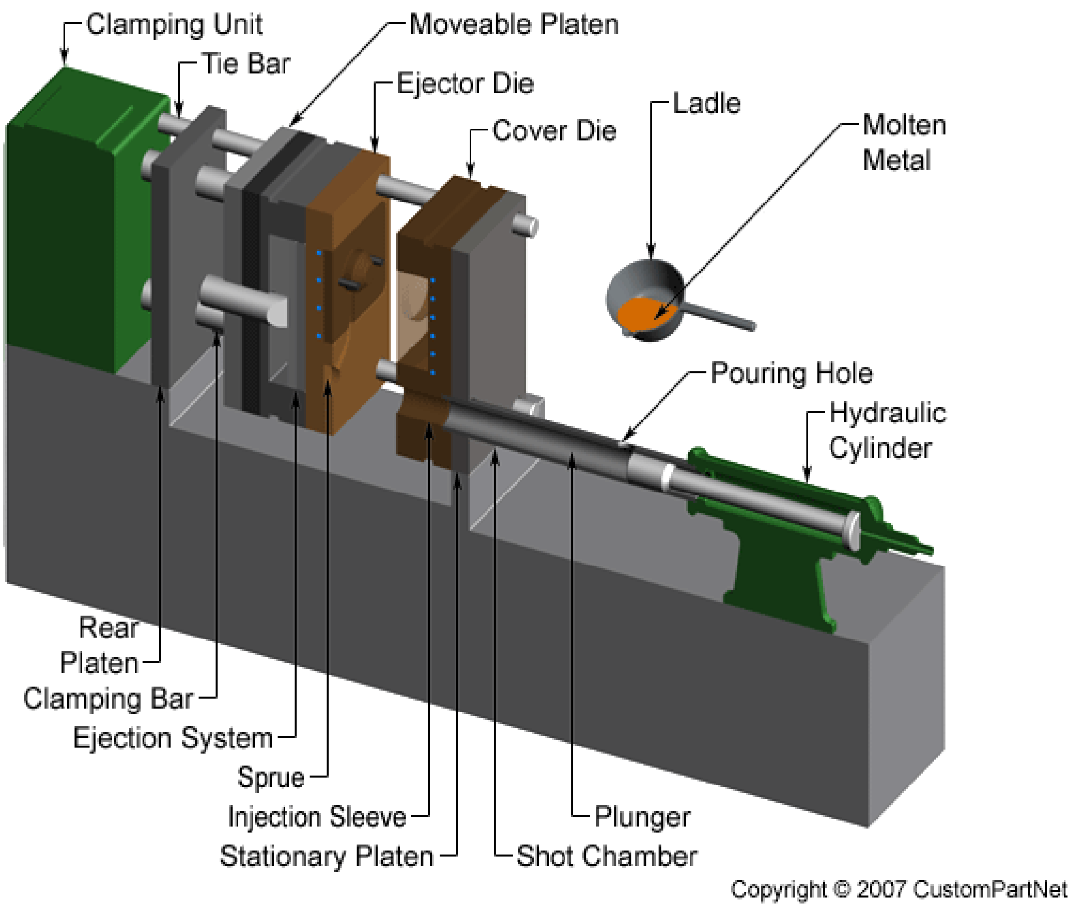

Fig.1.1 High pressure die casting machine (cold chamber die casting)

1.2 HISTORY

In 1800s examples of die casting by pressure injection-as opposed to casting by gravity by pressure occurred. Sturges patented first manually operated machine for casting printing type in 1849. The process was limited to printer's type for the next 20 years, but development of other shapes began to increase toward the end of the century. By 1892, commercial applications included parts for phonographs and cash registers, and mass production of many types of parts began in the early 1900s. Firstly the composition of die casting alloys were of tin and lead, but their use declined with the introduction of zinc and aluminium alloys in 1914.in that era magnesium and copper alloys were came into existence and were extremely successful. In 1930 some more modern alloys were came into existence and these are still available in market [3].

The die casting process has evolved from the original low-pressure injection method to techniques including high-pressure casting at forces exceeding 4500 pounds per square inch squeeze casting and semi-solid die casting. These modern processes are capable of excellent surface finish, fill the intricate shapes of the die casting dies and to increase the productivity.

1.3 ADVANTAGES OF DIE CASTING PROCESS [23]

1.3.1 High productivity

Die casting process has excellent surface finish and no machining is required for this process. Hundreds of casting can be produced simultaneously before going to required additional tooling.

1.3.2 Dimensional accuracy and stability

Die casting products are heat resistant and also produces parts that are dimensionally stable and durable. While maintaining close tolerances.

1.3.3 Strength and Weight

The strength of die cast parts is more than plastic injection molding having same dimensions. Intricate castings are lighter and stronger than other casting processes. Die casting does not consist of separate parts welded together.

1.3.4 Multiple finishing techniques

Die casting parts are easily finished and plated or these can be produced with smooth surfaces.

1.3.5 Simplified assembly

Integral fastening elements can be provided by die casing process. Holes can be cored and made to tap drill sizes, or external threads can be cast.

1.4 DIE CASTING PROCESS

Die casting is the manufacturing process in which geometrically complex metal parts can be produced with the use of metal dies which are reusable for mass production of the material. In the die casting process firstly we have furnace, crucible which is made from SiC, metal, dies (permanent mould) etc.. Metal is used for die casting machine i.e non-ferrous alloys like aluminium, magnesium, zinc, copper. Firstly these metals are melted in a furnace at the temperature of about 700^0C (aluminium alloy) and then injected into the dies of the die casting machine and after solidification of metal finished product is take out from the dies with help of ejectors. There are two types of die casting machines- gravity die casting machine and pressure die casting machine. We only consider pressure die casting machine. Pressure die casting machine further classified into two types- Hot chamber die casting machine and cold chamber die casting machine. Hot chamber die casting is used for ferrous alloys and cold chamber die casting is used for non ferrous alloys like aluminium and magnesium etc.. In hot chamber die casting furnace is integral part of the machine but in cold chamber die casting furnace is separate. The pressure at which the molten metal is filled into the mould cavity in cold chamber metal casting by about an order of magnitude. Pressure varies from 25Mpa to 300Mpa for cold chamber die casting process in industries. This process is suitable for high production applications. High pressure die casting have many other applications like transmission cases, mobile housings, laptop housings, motor housings, engine heads, cylinder heads, steering wheels, aircraft and marine.[1]

1.5 OPERATING SEQUENCE OF COLD CHAMBER DIE CASTING

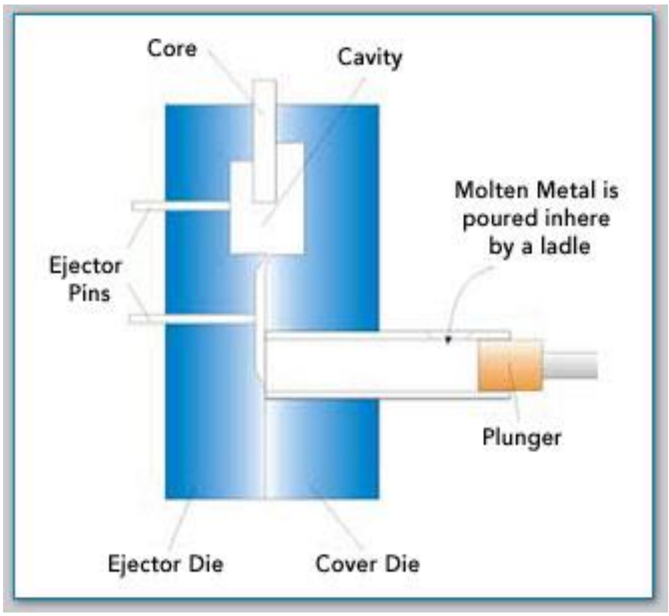

Fig1.2 [4]

1. firstly die is closed and molten metal is poured into the cold chamber shot sleeve

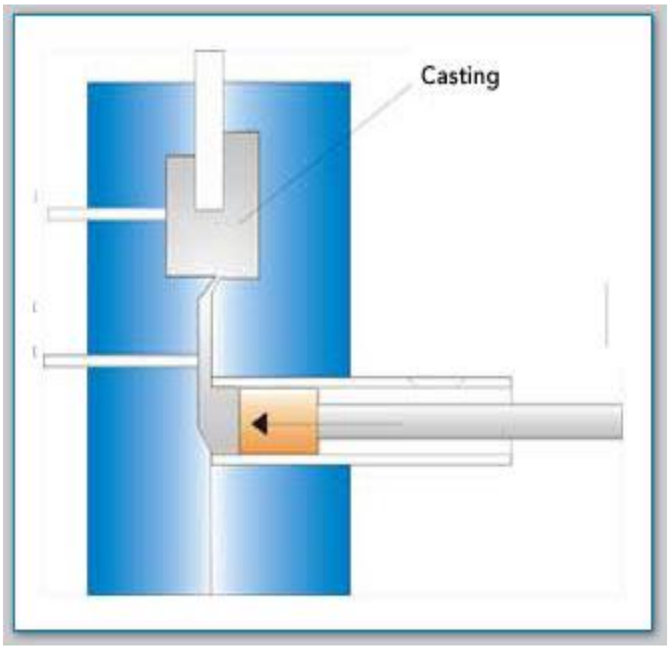

Fig1.3 [4]

2. The plunger pushes the molten metal into the die cavity where it is held under pressure until solidification

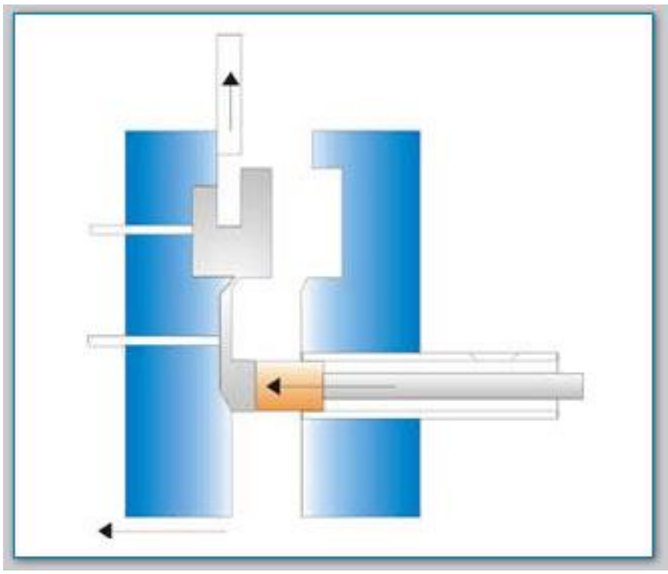

Fig1.4 [4]

3. The die opens and the plunger advances, to ensure that the casting remains in the injector die cores if any retract

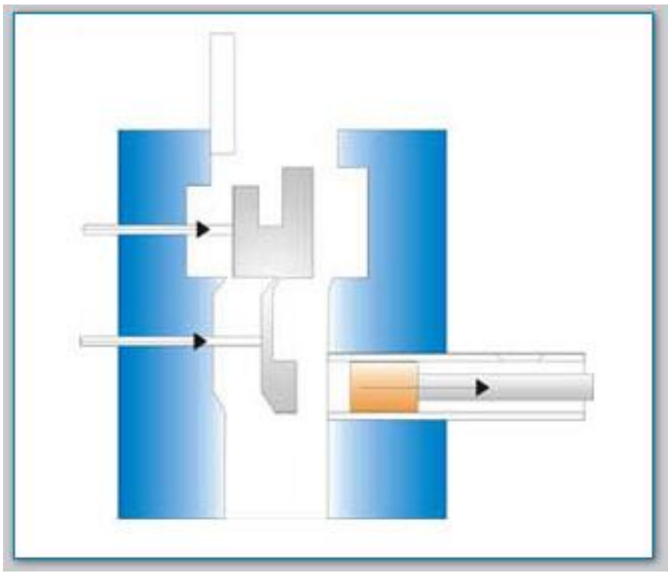

Fig1.5 [4]

5. Ejector pins push the casting out of the ejector die and the plunger returns to its original position

1.6 PROCESS CYCLE [2]

The process cycle for die casting consist of 5 main platforms. Which are given below. The cycle time is too short, generally 2 sec to 1 min.

1.6.1 Clamping

The clamping is necessary in the die casting process , without clamp the molten metal cannot be injected in the mould cavity. Each die half is first cleaned from the previous injection to simply ejection of next part. Lubrication time is dependent upon part size as the part size is increases lubrication time is also increases. Lubrication is required after 2 or 3 cycles depending upon the material. Adequate force is applied to the die to keep it clearly or safely closed during the injection of molten metal.

1.6.2 Injection

The molten metal which is maintained at particular temperature in the furnace is transferred in the chamber, where it can be injected into the die. The transfer method of molten metal is depend upon type of machine whether the hot chamber or cold chamber die casting machine. Typically the injection pressure is varied between 20Mpa to 300Mpa. The injection time is that time which is required to fill entire channels and cavities into the die. This time is too short typically less than or equal to 0.1 sec.

1.6.3 Cooling

The molten metal i.e injected into the die cavity will start to cool and solidify, once it enters the cavity. After solidification of molten metal the final casting will be formed. The die cannot be open until the cooling time has elapsed and the casting is solidified. Wall thickness will depend upon cooling time, as the thickness of the wall is greater then cooling time will also greater. The complex nature of the die also requires a longer cooling time. Because the extra resistance to the flow of heat.

1.6.4 Ejection

After the sufficient cooling time has passed, the die halves will be opened and ejection mechanism will work on the solidified metal means ejectors pushes the solidified metal out of the mould cavity. The ejection mechanism must apply some force to drawn out the solidified metal from the die cavity because while cooling the part shrinks and adhere to the die cavity. Once the solidified metal is ejected with help of ejectors pins, the die should be clamped shut for further injection.

1.6.5 Trimming:

When the molten metal is injected into the mould cavity under high pressure then the molten metal passes through the runner and after cooling the entire molten metal will solidified at their exist place. This extra material must be trimmed from the solidified casting either manually by cutting or sawing. The time required for trimming of the solidified casting will depend upon size of the casted part. After the cutting operation on extra material this extra material called scrap, this scrap can be discarded or reused for the casting

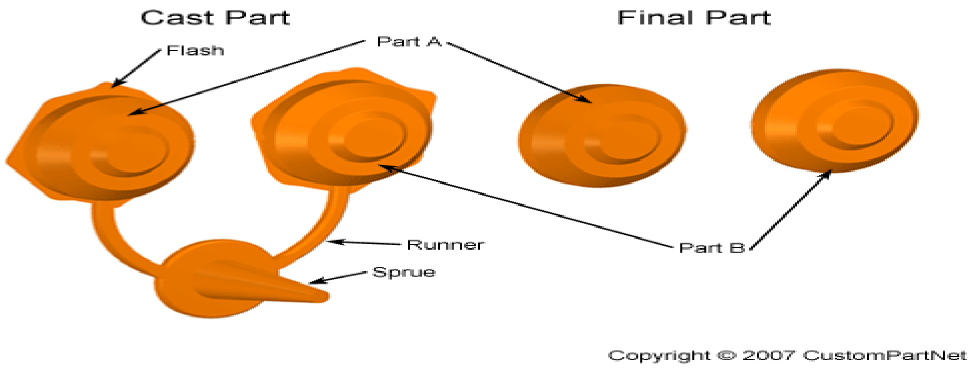

Fig1.6 [2]

1.7 EQUIPMENT

There are two types of die casting machines, which are given below:

1. Hot chamber die casting machine.
2. Cold chamber die casting machine.

1. **Hot chamber die casting machine:** Generally hot chamber die casting machines are used for those alloys which have low melting temperature such as lead, tin and zinc. The major difference between hot chamber die casting and cold chamber die casting machine is of the furnace, In hot chamber die casting machine the furnace is the integral part of the machine but in cold chamber die casting machine the furnace is split from the machine. In hot chamber die casting machine gooseneck is used for suck the molten metal. The pressure applied on the molten metal to fill the die cavity in this process is varies between 5Mpa to 35Mpa.Now I will show you how the hot chamber die casting machine works or we can say that operating sequence of hot chamber die casting machine.

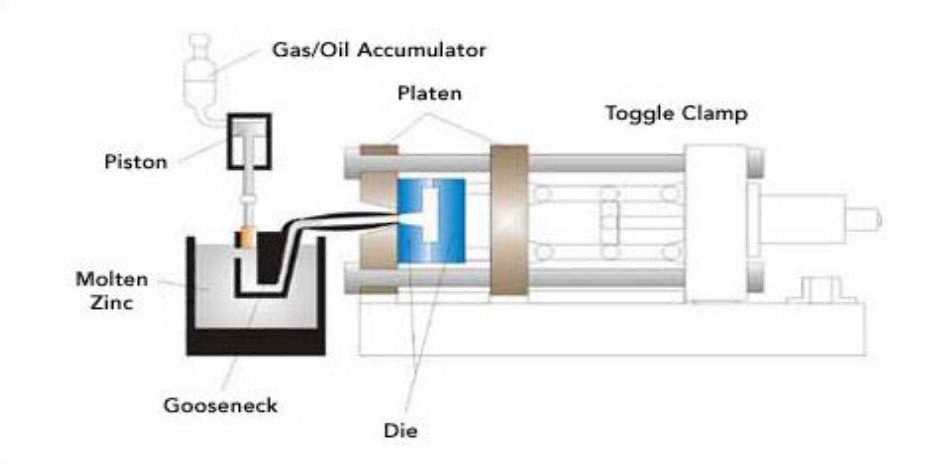

Fig1.7 (HOT CHAMBER DIE CASTING) [4]

WORKING OF HOT CHAMBER DIE CASTING MACHINE:

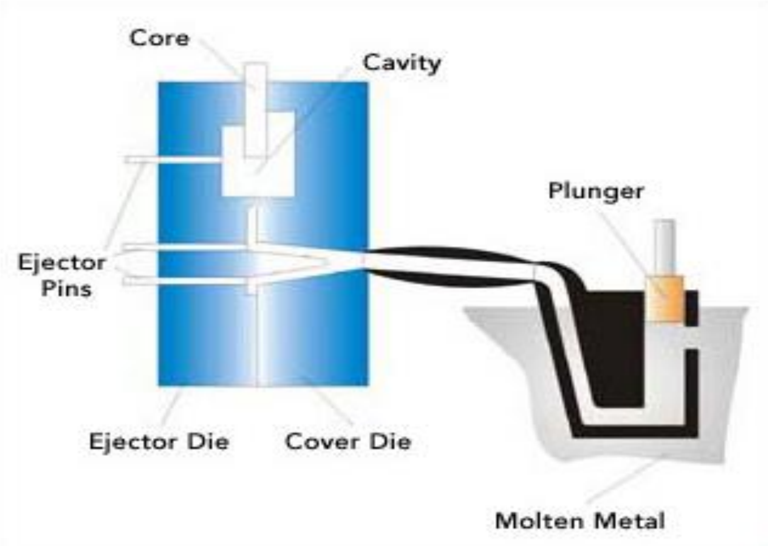

Fig1.8 [4]

I. Firstly the die is closed and the piston is at the extreme position, port is open and molten metal is entering into the cylinder.

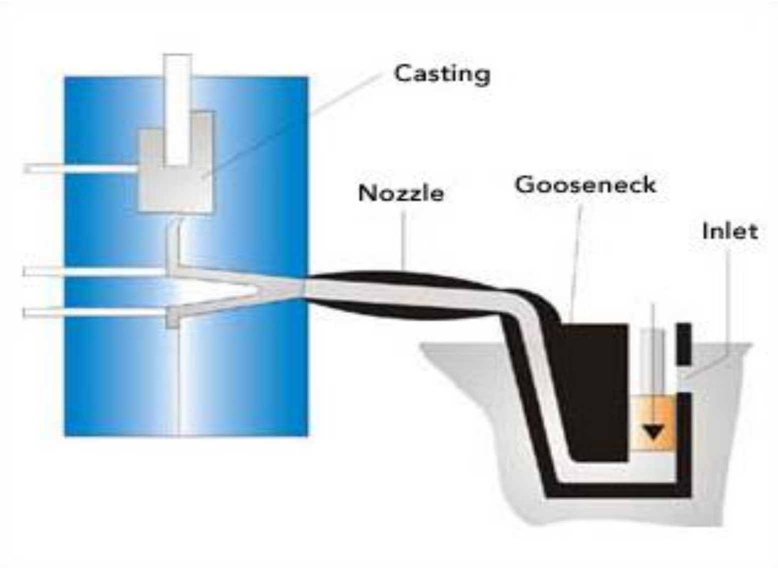

Fig1.9 [4]

II. The plunger moves down and it pushes the molten metal into the die cavity through the gooseneck and nozzle and it also seals the inlet port, this piston is at the same position until the molten metal get solidified.

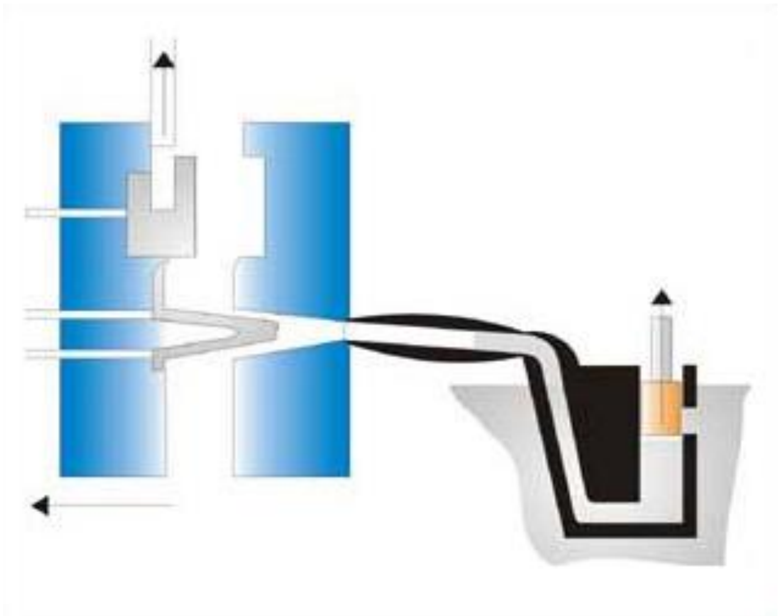

Fig1.10 [4]

III. After solidification the die opens and the cores, if any, retract the casting remains only on the ejector side, the plunger returned back allowing the residual molten metal back through the gooseneck and the nozzle.

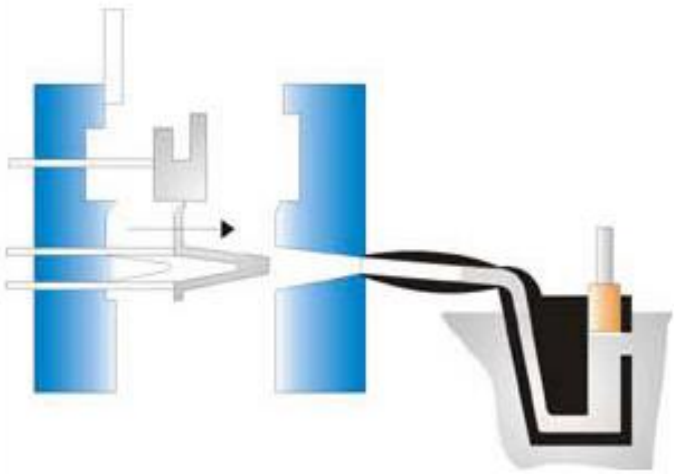

Fig1.11 [4]

IV. The ejector pins are ejecting the solidified metal from the ejector die, now the plunger is at the extreme position and the step 1 is repeating from here.

2. COLD CHAMBER DIE CASTING MACHINE: Cold chamber die casting process is excellent process to produce many products at the same time using different-different dies depend upon requirements of the customers. This process is used for high melting point alloys like aluminium, magnesium, copper, zinc etc... We cannot use these alloys in hot chamber die casting machines because these would damage the pumping system of the machines. In cold chamber die casting machining process firstly we prepare the furnace by using fire bricks, sand and the round container of mild steel, after that one crucible is used which is of silicon carbide or ceramics and coal is also used for melting purpose, coal are put in to the furnace and air blower is used to ignite the coal after that crucible is put into the furnace which is surrounded by coal, so that after 2 hours metal will be melted at particular temperature say for aluminium 660^0C. before going to start the casting, machine should be properly set like pressure regulator, injection pressure, die opening or closing etc… now the molten metal is take out from the crucible with ladle and pour into the shot chamber through the pouring hole, it does not include a gooseneck. Furnace is the separate part of machine.

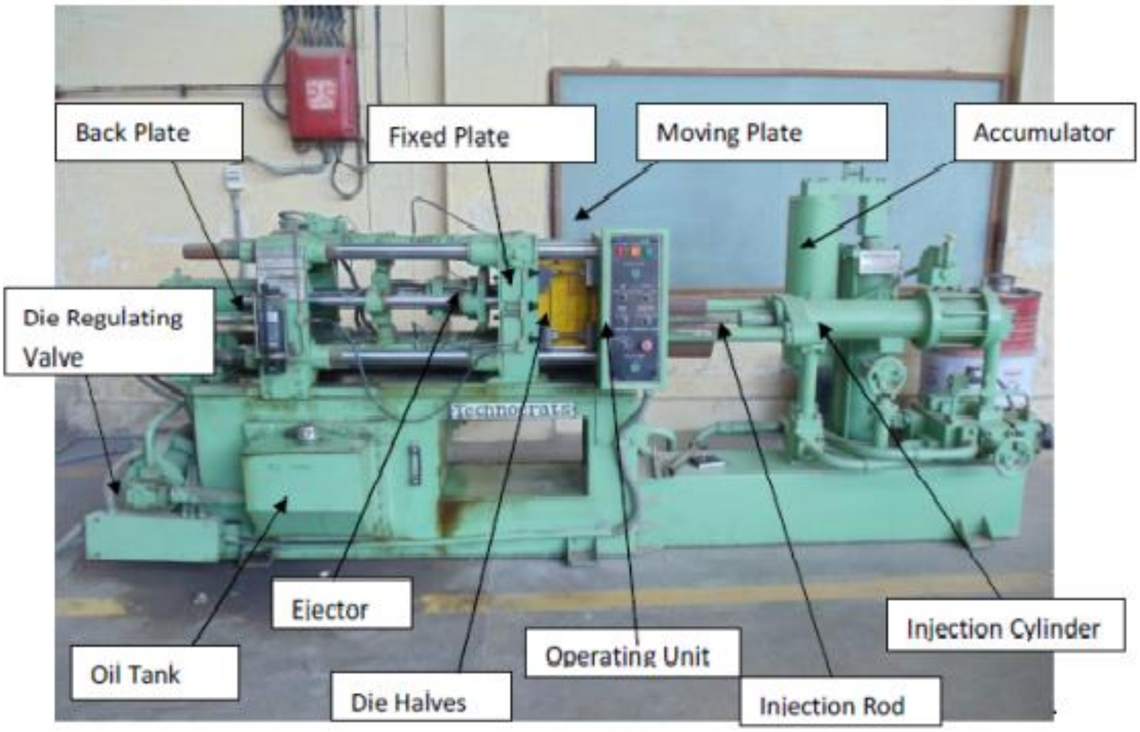

Fig1.12 (Cold Chamber Die Casting) [23]

1.8 COATING [5]

Coating of the die plays a vital role in the field of die casting. There are so many benefits to coat the die surface. These are given below:

a) It improves the quality of die casting.
b) It increases the life of die.
c) It improves cost competitiveness.
d) It reduces the downtime also.
e) It prevents the molten motel stick out on the die cavity surface.

We use dycote coating and we made this coating on our own with the use of silicate, soft stone powder and water. we took these three things together in a hemispherical bowl and after that stirring is required to mix properly.
Oil coating is also plays a great role in the die casting. Oil coating is also used for increase the die life. Oil used in cold chamber die casting process is transformer oil.

1.9 DIE CONSTRUCTION

Dies are plays a major role in the die casting machine, because without dies we can't produce finished products. These are made from alloy tool steel like H13 tool steel. Sprue hole is on the fixed die side that permits the molten metal into the die cavity. Runner is also on the fixed die and gate that routes the molten material to the die cavity.

Dies also have locking pins to protect the two halves, ejector pins helps to remove the cast part and opening for lubricant and coolant. When the die casting machine closes die halves are completely locked and maintain tight by the hydraulic pressure exerted by the machine. The surfaces where the fixed die halves of the dies are meeting are known as die parting line.

Basic functions of die casting dies are given below:

- We get desired casting to hold the molten metal in the die.
- Provides a mean for molten metal to get to a space where it will be held to the desired shape.
- Dies solidified the molten metal extracted heat from the molten metal.
- To provide means to exit out the casting.

1. **Single cavity die**

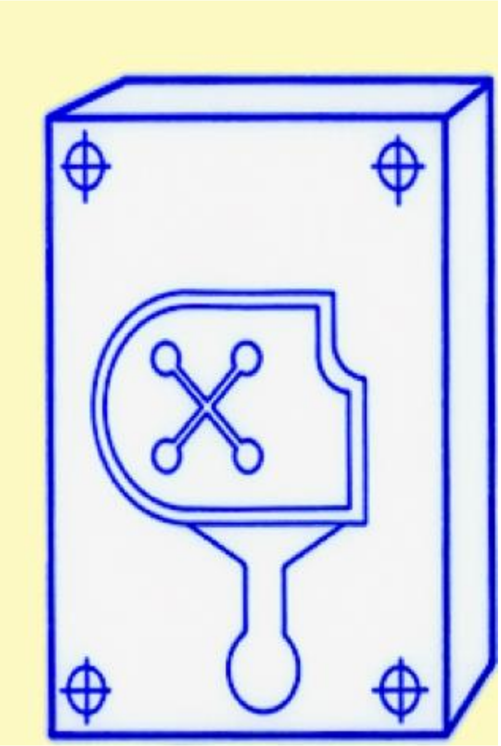

Fig1.13 [1]

2. **Multiple die cavity**

Fig1.14

Multiple cavity die can produce many identical parts at the same time.

3. **Unit die:**

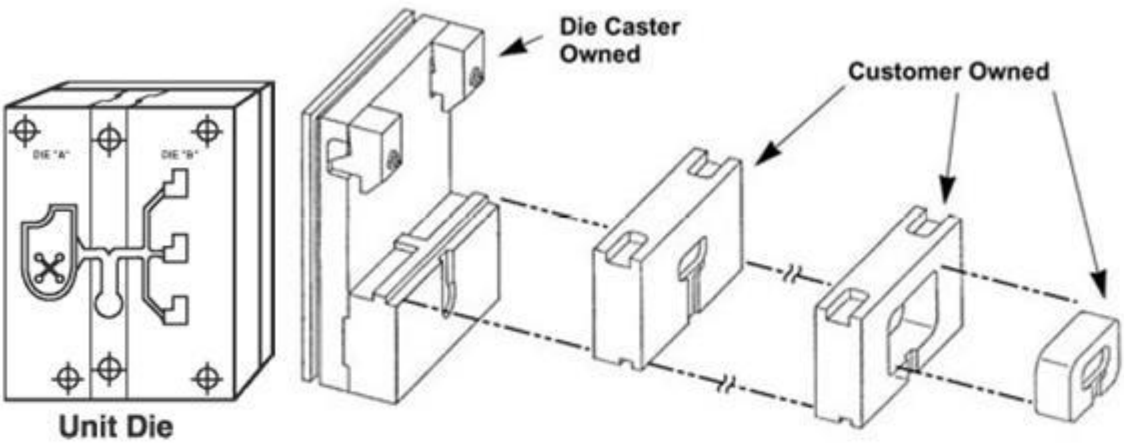

Fig1.15 [6]

Unit die is the die which can produce the different- different parts at a time.

CHAPTER 2 LITERATURE SURVEY

2.1 INTRODUCTION

The main aim of literature survey is as given below:

1) To investigate the influence of process parameters i.e. injection pressure, pouring temperature, cooling medium, coating type to minimize the defects in the cold chamber die casting.
2) To understand the relationship between the microstructure and the thermal condition of the casting.

The literature survey has been divided into following sections:

1) Influence of pressure
2) Effect of coating and die lubricant
3) Microstructure
4) Effect of process parameters
5) Porosity
6) Effect of addition of material

Influence of pressure

Dargusch et al.[7] determined the influence of process variables on the quality of high pressure die casting machine with the help of in-cavity pressure sensors. They found that when the injection pressure was increases then the porosity of the part was decreases, and porosity was increases when the casting velocity was increases. There was no effect on porosity with respect to the delay time. They investigated the rapid solidification in particular sections of the castings resulting in shrink or gas porosity

Maleki et al. [8] examined the influence of pressure and die temperature on the microstructure of LM 13 aluminum alloy which is casted from squeeze casting. They find from their results the grain size will be decreases during solidification under the application of pressure. They also concluded that the microstructure of LM 13 aluminum alloy could be justified on the influence of applied pressure or modification of microstructure.

Abtan and Ghlaim [9] compared the squeeze casting process and pressure die casting process. They studied the effect of applied pressure to eliminate the porosities that formed during both the casting processes. Density, hardness and microstructure tests were performed to show the improvement in the samples of both processes. The results shows that the values of hardness and density in pressure die casting were lower than the squeeze casting samples. They conclude that the mushy zone of molten metal represents the optimum region to enhance the mechanical properties by injected pressure**.**

Effect of coating and die lubricant

Yucong Wang et al.[10] discussed about some applications of PVD coatings to enhance the die casting die life. They found out three main corrosion and erosion resistance coatings to molten aluminum such as TiN, TiAlN and CrN. They investigated the influence of coating on heat checking resistance was found from the coating variables and substrate material, Due to the coatings only H19 steel has appropriate reduction in heat checking resistance. They concluded from the experiments PVD coated HWM steels should be used if both corrosion/erosion resistance and heat checking resistance is required and low impact toughness is appreciable. Only heat checking resistance is required if H19 steel inserts should be used. Marlok steels or PVD coated H13 steel should be used if only erosion/corrosion resistance and impact toughness is required.

Heim et al.[11] studied about the hard coatings. They said that the steel surface of the casting tools can protect by hard coatings from the melted aluminum erosion and also enhance the thermal cracking resistance. They emphasizes the PACVD method which coated large moulds, this is the application of hard coatings in the area of aluminum die casting. They categorized the coating films with respect to their adhesion, micro hardness, thickness, microstructure and morphology. They found that the no tendency of soldering with all types of coatings.

Mitterer et al.[12] have discussed about the many parameters which affected the aluminum die casting dies such as erosion, corrosion, soldering, heat checking, gross cracking and oxidation**.** They found that the hard coatings based on carbides or nitrides of transition metals may protect the surface of the die steel erosion and soldering of the aluminum and also improve the thermal cracking resistance. They found from the results based on performance of coatings accumulated on to die casting dies by PACVD and magnetron sputtering. They concluded that TiN and Ti(C,N) showing a most feasible combination adhesion, hardness, soldering behavior, oxidation resistance and stress state.

Zhu et al. [13] studied the chemical element distribution of the soldering area in a failed die from die casting plant. Micro holes, micro cavities and cracks on the die surface exist. The smaller diameter of micro holes is 0.6μm and the bigger is more than 15μm, they also studied how the process parameters affect the soldering phenomena. They discussed about the WC-Co coating to prevent the soldering phenomena in the die casting, they said that when the number of die casting shots will increases then the soldering will also increases for a given die.

Salas et al.[14] have discussed about the coating on H13 steel substrates and try to improve the tribological performance of die casting dies for aluminium alloys. Aim of this study to design the multilayer coating system and to increase surface die performance and die life. Investigated coatings were CrN, CrC, ZrN, MoZrN, TiAlN, TiN/TiC, NiAl, NiAlN etc.. the characterization includes: microhardness, optical microscopy, X-ray diffraction, wear testing and scratch tesing. They concluded that the only some of the coatings had excellent wear and adhesion performance.

Rosso et al.[15] prepared old die manufactured by AISI H11 tool steel. Discussed about the thermal sprayed coating with various materials ZrO_2, WC-Co and WC-Co with silicon resin. They concluded that if the samples are coated with ZrO_2 and WC-Co with silicon resin reached 45000 cycles without any cracks any damage and their surface was still in excellent condition and increased roughness. If the samples are coated with WC-Co without an addition of slicon resin then substrate shown shorter duration i.e crack was appeared on 19000 cycles.

Microstructure

Song et al.[16] studied the corrosion of die casted AZ91D related to its microstructure. They discussed about the low purity magnesium and high purity magnesium. Corrosion was studied in three categories 1.Observing morphology of corrosion 2. Measurement of electrochemical polarisation curves 3.Measurement of hydrogen evolution rate and magnesium dissolution rate. They concluded that the casting method can affects the corrosion performance by its influence on the alloy microstructure.

Hajjari et al.[17] discussed about the 2024 aluminium alloy. If this alloy performs casting process greater no. of shrinkage porosities will be produced in its microstructure because of its long solidification range. They investigated the influence of squeeze pressure on the microstructure and tensile properties. They concluded that if the squeeze pressure is increases then the microstructure will be finer. If the squeeze pressure is increasing then the ultimate tensile strength will be improved.

Obiekea et al.[18] analysed the microstructure on the A1350 alloy die cast samples. This shows the structural changes occurred different morphology of grain size under the different pressures i.e coarse, lamellar and granular structure. Many other mechanical properties were also influenced by the applied pressure like tensile strength, impact strength and hardness. Hardness is increased from 77 to 86 HRN with applied pressure. Impact strength increased with applied pressures from 3.98 to 4.44 joules. They observed that the finer grain sizes under the pressure of 1400 kg/cm^2.

Zhang et al.[19] investigated the aluminium oxide particles(Al_2O_3) were to improve the microstructure of LM24 and also increase the tensile strength and yield strength of this kind of alloy. They found out the addition of in situ Al_2O_3 particles, the coarse primary Si phase was totally disappeared. They investigated that with the addition of 0.1%Sb in LM24/Al_2O_3 alloy then the tensile strength and yield strength are increased by 16 MPa and 52 MPa than that of LM24 alloy.

Hu et al.[20] simulated the temperature distribution, filling time, filling trace during the die casting process. They investigated phase distribution and surface microstructure in AZ91D magnesium component, which is casted on a hot chamber die casting machine by the use of scanning electron microscope and optical microscope. They concluded that the corrosion resistance is decreased along the filling trace.

Effect of process parameters

Syrcos [21] analysed the several important process parameters of $AlSi_9Cu_{13}$ aluminium alloy of the die casting method. Process parameters are as follows: metal temperature, piston velocity, filling time and hydraulic pressure. The effect of entire process parameters on the density and following optimal settings of the parameters have been dexterous using taguchi technique. The results show that the selected parameters importantly affect the density of $AlSi_9Cu_{13}$ aluminium alloy castings.

Penghuai Fu et al.[22] have studied about the influence of process parameters i.e pressure holding time, die temperature, holding pressure, filling time and casting temperature on microstructure, density and mechanical properties of low pressure die casting. They also determined these process parameters experimentally such as filling time 8-12s, die temperature 390-410^{0}C, holding pressure 0.08MPa and casting temperature 705-710^{0}C. They also concluded that when the filling time is increased then the grains become coarser and also leading to lower density and mechanical properties (yield strength, ultimate tensile strength and elongation), with increase in casting temperature then the grains become coarser and mechanical properties reduced. If die temperature and holding pressure both are high in combination then the structure will be fine and mechanical properties will also improve.

Lalit Kumar et al.[23] had investigated that the influence of injection pressure of the molten metal, cooling medium, coating type and pouring temperature on hardness of the material, density of the material and the surface roughness of the material. They have worked on material LM6 aluminum alloy on high pressure die casting machine.

Prabhu et al.[24] prepared lead samples in high pressure die casting D250 machine. They discussed about the parameters which affecting the defects in high pressure die casting process such as injection pressure, pouring temperature, cooling medium and pouring time. They used taguchi technique. Various parameters affecting defects i.e bubble, blow hole and flash defect shown by the signal-to-noise ratio graph. They concluded that the pouring temperature plays a major role in the blow hole defect but cooling medium, tool temperature and cooling time plays minor role in the blow hole defects. They also concluded that the tool temperature and cooling medium plays a major role in flash defect, when they increase the tool temperature then signal-to-noise ratio also increases.

El-Mahallawy et al.[25] studied the influence of velocity and pressure high pressure die casting on the thermal conditions and on the casting properties. Two gate velocities of the liquid 40 and 80 m/s were used for die filling and pressure 30 and 70 MPa. They concluded that the temperature distribution doesn't change importantly when varying velocity or pressure. They found from the results as the distance from the gate increases then the density will be found decrease.

Effect of porosity

Sabau and Viswanathan [26] studied the comprehensive methodology into solidification shrinkage, hydrogen precipitation and porosity evolution for the prediction of microporosity fraction and separation in aluminium alloy casting. They determined that the extent of gas and shrinkage porosity from this approach. The porosity profiles predictions are authorised by comparison with independent experimental measurements by many researchers on A356 aluminium alloy test casting design to capture a different solidification conditions.

Lee et al.[27] discussed the influence of process parameters on porosity distributions in HPDC. Process parameters are as follows: melt temperature, gate velocity and injection pressure. The amounts of gas porosity, total porosity, shrinkage porosity and pore size distributions can be measured by using novel digital image analysis. They concluded that the injection pressure importantly reduces the number density and area fraction of gas pores. They also concluded that if the gate velocity decreases the total porosity also decreases and gas porosity also decreases. They concluded that if the melt temperature decreases then the total amount of porosity decreases.

Zhao et al.[28] discussed about the entrapment of gas and induced final porosities during die casting process when liquid metal fills die cavity with high velocity. The maximum size of porosities were analysed quantitatively. They discussed the influence of size and fraction on the mechanical properties and critical porosity and size were suggested for ADC12 die castings. They compared with experimental analysis with simulation results.

Zhao et al.[29] discussed about the gas entrapment and gas porosity during the fill of the die cavity under the die casting process. They measured the mechanical properties of the specimen, which is of ADC12. They discussed influence of the fraction and the size on mechanical properties. They compared the experimental analysis with the simulation results. Thy found out how the porosity affects the mechanical properties. They investigated from the results that the maximum size and porosity fraction should be controlled not more than 171µm and 3.25% respectively.

Rejab et al.[30] evaluated the castability and porosity of titanium alloy, nickel-chromium and cobalt-chromium alloys. 30 samples were prepared for these tests. Hinman method was used to measure castability and Archimedes method was used to measure porosity. They found out from the results after conducting the experiments that the titanium alloy has the highest value of porosity percentage and castability is lowest, while cobalt-chromium alloys has moderate values. Nickel-chromium alloy has lowest value of porosity percentage and highest value for castabilty. They also concluded that the castability value depends upon the melting temperature, higher the melting temperature lesser the castability value.

Effect of addition of material

Dargusch et al.[31] investigated the influence of increasing level of silicon contents on the microstructure and creep properties of high pressure die cast Mg-Al-Si alloys. They concluded that if the silicon content is increased above the eutectic level it results increase in number of coarse faceted Mg_2Si particles in the microstructure. Creep rates are about 100 hrs found to decrease when increasing the silicon content in aluminium alloy. They also found from the results if silicon contents are upto 1.1 wt pct then the creep rate was decreased dramatically. Further addition of silicon upto 2.65wt pct then the creep rate was significantly decreases.

Zuki hu et al. [32] studied the effect of magnesium content on fatigue and mechanical properties of AlMgxSi2Mn, (where x value varies from 5.7% - 7.2%) to wide their applications and to improve the mechanical properties. The results comes from SEM, XRD, EDXS and optical microscope indicated that when we increases the magnesium content from 5.7% to 7.2% then the hardness and the yield strength will also be increases by 9% and 11% respectively. Elongation was decreased from 8.31% to 4.13%. They also concluded that with the increase of magnesium contents in AlMgxSi2Mn the fatigue limits was also increased (57 Mpa to 75 Mpa).

Farahany et al.[33] investigated the possible interaction between strontium and bismuth in ADC 12 die casting aluminium alloy. In this present work situ thermal analysis technique was used. They found out that with bismuth present in Al-Si alloy melt the efficiency of sr . The eutectic silicon was reduced. They found that if we get fully modified Si structure then we required Sr/Bi ratio of at least 0.5. The aluminum industries will most certainly benefit from this research work in terms of increased quality, costing and productivity and time savings, because the use of aluminum based secondary alloys are increases.

2.2 Summary of Literature

A lot of work has been done in the field of high pressure cold chamber die casting process in different type of process parameters, different type of thermal control factors such as type of cooling, metal temperature, gas entrapment, porosity. Alloy composition and its condition influence the wear rate .With increase in temperature hardness and wear rate resistance also increases. Increase in pressure in HPDC enhances the density of aluminum alloy. The influence of process parameters i.e. pressure holding time, die temperature, holding pressure, filling time and casting temperature on microstructure, density and mechanical properties of low pressure die casting. Effect of process parameters helps in predicting the micro porosity at various stage of casting. Die coating and lubrication maintain a thermal balance with in the part and helps in improving the mechanical properties of aluminum alloy. If the silicon content is increased above the eutectic level it results increase in number of coarse faceted Mg_2Si particles in the microstructure.

2.3 PROBLEM FORMULATION

Based on the literature survey and the subsequent analysis of gaps the present work aims to investigate the effect of various parameters in a High Pressure Die Casting Process on the properties of aluminium alloy and find out the properties using ANOVA. The experiments have been conducted using aluminium alloy LM24. The process parameters varied were the thermal characteristics (temperature of the molten metal), the injection pressure of molten metal, Coating thickness and solidification rate. The properties and quality of die cast components are directly related to the microstructure of die cast component. This research study has been carried out on the High Pressure Die Casting Machine available at S.L Casting &Allied Industries, D-217 Focal point, Patiala.

2.4 OBJECTIVES

- To evaluate the effect of process parameter (pouring temperature, injection pressure, coating thickness and cooling rate) on the properties of the final product.

- To evaluate the significant interactions between the above factors.
- To analyze the machined surface for microstructure and hardness to study the change in material properties as a result of the experimentation.

This has been done by factorial analysis of variance (ANOVA). The factor analysis parameterization approach has been used to study the effect of various factors at appropriate levels. After studying the effect of parameters using a parametric approach a study on material properties and effect of process parameters has been completed.

2.5 WORK PLAN

Following activity have been carried out to complete the project

1. Preparatory work
   (a) Selection of die casting alloy.
   (b) Procurement of material to make the required alloy and preparation of samples.
   (c) The samples will be cut by Power hack saw and filing has been done. Cut the final product into the pieces as per the requirement of experimentation and polished by the emery papers of 100,120,180,360,600 of Sic, this was fixed on hand made wood board.

2. After finalization of the significant process parameters detailed experiments were carried out with all possible variations, included in the study.
3. Measurements were taken for each process variable and results were analyzed using ANOVA to arrive at a method which satisfies the requirement of the cast product.
4. Study of material properties.

CHAPTER 3 DESIGN OF EXPERIMENT

3.1 INTRODUCTION

High pressure die casting is an excellent process for producing several types of engineered materials by injected molten metal forcibly into the steel moulds. Moulds are also known as dies. Dies are designed in such a way that the complex shape castings can get. High pressure die casting process has excellent surface finish and accuracy. Dies of this process can reuse back to back that's why this process is suitable for mass production. The influence of several process parameters has been studied after the machining of die cast parts. Various parameters are as follows*: injection pressure of molten metal*, *pouring temperature of molten metal*, *type of coating*, *type of cooling* was studied using taguchi technique.

The full factorial design is referred as the technique of finding and investigating all favorable conditions in experiment involving multiple factors investigate only fraction of all the combinations. Where there are advantages there are disadvantages also. These techniques are widely used but there are some demerits like this technique is so time consuming if the no. of variables is large. They must need strict mathematical treatment in the design of experiment and to analyse the results. In this design contribution of each factor is determined and generally this is not permitted so that's why to simplify and to standardize the fractional factorial design taguchi technique has been proposed to overcome the limitations.

3.2 OBJECTIVE FUNCTION

The main aim of the study is to evaluate the main effects i.e injection pressure of the molten metal, pouring temperature of molten metal, type of coating(oil+ Graphite coating, Dycote + graphite coating, dycote coating) and type of cooling(oil cooling, water cooling, air cooling) on substrate, material impact strength, material density, material surface roughness, material hardness.

3.3 FACTORS SELECTION

The selection of factors is very important phenomena. To find out the factors which affect the responses of interest? Those factors which affect the responses were investigated from fish bone diagram analysis. The list of factors with their levels are given below in the table 3.1

FACTOR	Level-1	Level-2	Level-3
Injection pressure of the molten metal kg/cm^2 (A)	170	180	190
Pouring temperature of the molten metal (B)	725^0	750^0	775^0
Type of coating (C)	Dycote+graphite	Oil + graphite coating (transformer oil)	Dycote coating
Type of cooling (D)	Air cooling	Water cooling	Oil cooling

Table 3.1 Factors of interest and their levels for work material LM 24

3.4 DEGREE OF FREEDOM (dof)

The total no. of factors and their interactions and levels find the total degree of freedom need for whole experimentation. The degree of freedom of each factor of entire degrees of freedom for experiment is given by table 3.2. The number of levels minus one gives the degree of freedom for each factor.

dof for each factor: k-1

i.e k is the no. of levels for each factor

Factors	**A**	**B**	**C**	**D**	**TOTAL**
Degree of freedom	2	2	2	2	8

Table 3.2 Degree of freedom

3.5 ORTHOGONAL ARRAY

Orthogonal array plays a great role in reaching the high efficiency of the taguchi technique. This array is derived from factorial design of experiment by a series of very sophisticated mathematical algorithms like finite fields, geometry and error correcting codes combinatorics. Orthogonal array has to be constructed in statistically independent manner that each and every level has an equal no. of occurrences with in the each column and for each level with in the each column, each level with in the other column will occur an equal no. of times then the columns are known as orthogonal to each other. Orthogonal array is available with several factors and levels in taguchi method. Since each and every column is orthogonal to each other.

The selection of OA depends upon:

- The no. of levels for the factors of interest.
- The no. of factors and interaction of interest.

Taguchi's orthogonal array requires only a fraction of the full factorial combination. The arrays are designed to handle most of factors as possible in a particular no of runs compared to those dictated by full factorial design. The columns and arrays are orthogonal and balanced. It means all factor combinations occurs same no. of times. Once the degree of freedom of particular level is known, further step which is selecting the orthogonal array is easy. The total no. of treatment conditions is equal to the no. of rows in orthogonal array and should be equal to or greater than degrees of freedom. Once the accurate OA has been selected then the factors can be assigning to the various columns. The total degree of freedom must be calculated for selecting appropriate orthogonal array for experiments. The degree of freedoms are defined as the no. of comparisons between process parameters that must be made to find which level is best and how much best it is. For example a two level process parameter counts for one degree of freedom. The interaction between two process parameters associated with degree of freedom these are given by the product of degrees of freedom for the two process parameters. In this study the correlation between die casting parameters is neglected. In this study four process parameters have taken in cold chamber die casting process. For the four sets of input parameters there are eight degrees of freedom. Once the degree of freedom is known, the next step is to select the particular orthogonal array to fit the specific task. The degrees of freedom should be greater than or less than equal to those process parameters for orthogonal array. L9 orthogonal array with nine rows and five columns was used in this study. Each cold chamber die casting parameter which was assigned to a column and nine cold chamber die casting parameters were tested. Therefore by using orthogonal array only nine experiments are requires analyzing the entire casting parameters. The experimental layouts for the cold chamber die casting parameters by using L9 orthogonal array is shown in table 3.3

Trial No.	Pouring temp. ^0C	Injection pressure Kg/cm^2	Coating type	Cooling medium
1	725	170	Oil+Graphite	Air
2	725	180	Dycote+Graphite	Water
3	725	190	Dycote	Oil
4	750	170	Dycote+Graphite	Water
5	750	180	Dycote	Oil
6	750	190	Oil+Graphite	Air
7	775	170	Dycote	Oil
8	775	180	Oil+Graphite	Air
9	775	190	Dycote+Graphite	Water

Table 3.3 L9 orthogonal array

3.6 Description of Cold Chamber Die Casting Machine

The experiments have been conducted on high pressure die casting machine of technocrats model TDC-120 available at S.L castings D-217, focal point, Patiala. The machine which is available at thapar university workshop is 80 ton but machine is available at focal point, Patiala is 120 ton, but looks wise these both machines are same. The main parts of the machine are moving plate, fixed plate, control box panel, back plate, accumulator, injection cylinder, injection rod, ejector mechanism, oil tank, pressure regulating valve, die regulating valve. Injection pressure can be varying during operation through the pressure regulating valve. Control panel is provided on the machine for die opening and die closing and ejector for the casting parts. The machine can be operated on manual as well as automatic mode both. Important specifications of the machine are given in table 3.4

Injection force	13 tons
Hydraulic ejection force	6 tons
Locking force	120 tons
Space between tie bars	380 x 410 (mm)
Die moulding plates	555 x 600 (mm)
Max. die height	450 mm
Min. die height	150 mm
Tie bar diameter	65 mm
Die opening stroke	375 mm
Injection plunger stroke	275 mm
Ejection stroke	65 mm
Distance between center and bottom injection	85 mm
Electric motor capacity	11 kw
Working pressure	170/210 kg/cm^2
Hydraulic pump (vane type)	70 ltr./min
Oil tank capacity	350 lit.
Machine weight	4 tons
Shot capacity	950 gm

Table 3.4: Specification of Cold Chamber Die Casting Machine

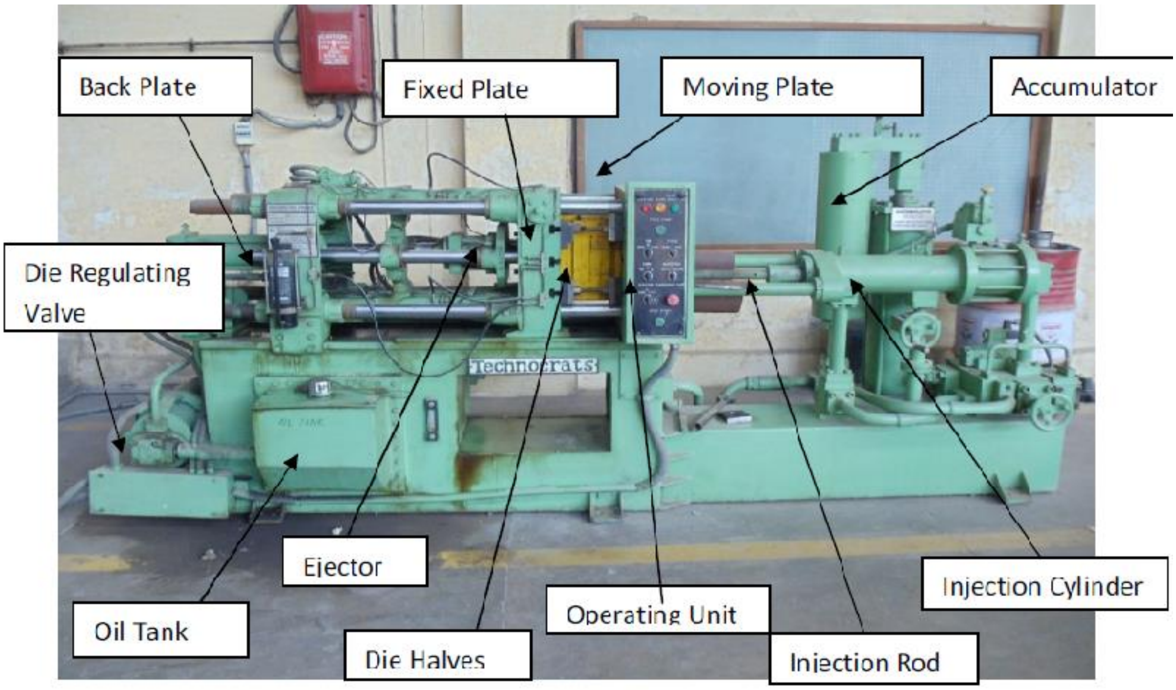

Fig 3.1 80 tons High Pressure Die Casting Machine at Thapar University Workshop

3.6.1 Operating mode

In operating mode three modes are exists

- **Manual Mode:** In this mode operation directions totally depends upon the operator decision and machine is not under the casting programme.
- **Automatic made:** In this mode entire process is automatic which is control by the control panel mounted on front of the machine. In this mode machines operations can be programmed i.e. die opening time, die closing time, casting ejection time can be controlled.
- **Stop button:** If we pushed the stop button then the entire process will be stop.

3.6.2 Display indication

- **Pressure gauge:** These gauges are used to show the injection pressure of the molten metal and also to show the accumulator pressure.

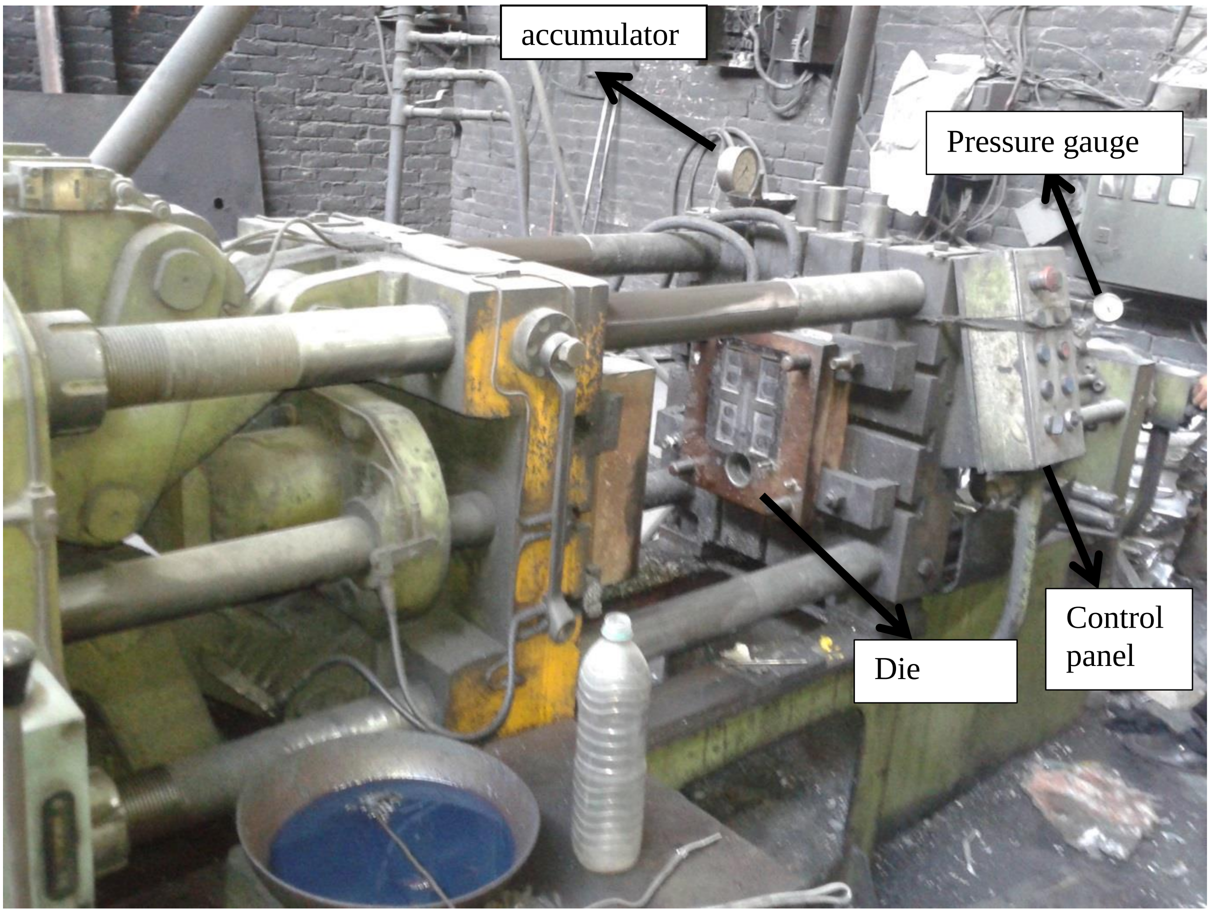

Fig 3.2 High Pressure Die Casting Machine (120 tons) at Focal Point (D-217), Patiala.

3.7 DESCRIPTION OF PIT FURNACE

Before going to conduct the experiment, Raw material (LM 24) was put in to the crucible and leave for melting at up to **665^{0}C** for about **1**hour **30** minutes. Pit furnace achieved maximum temperature of about 1100^{0}C. The pit furnace which was used for melting metal is available at S.L Castings & Allied industry Focal Point, Patiala (shown in fig 3.3). The temperature of the molten metal can be varied and these variations in the melting temperature can be measured by the pyrometer indicator (shown in fig 3.4).

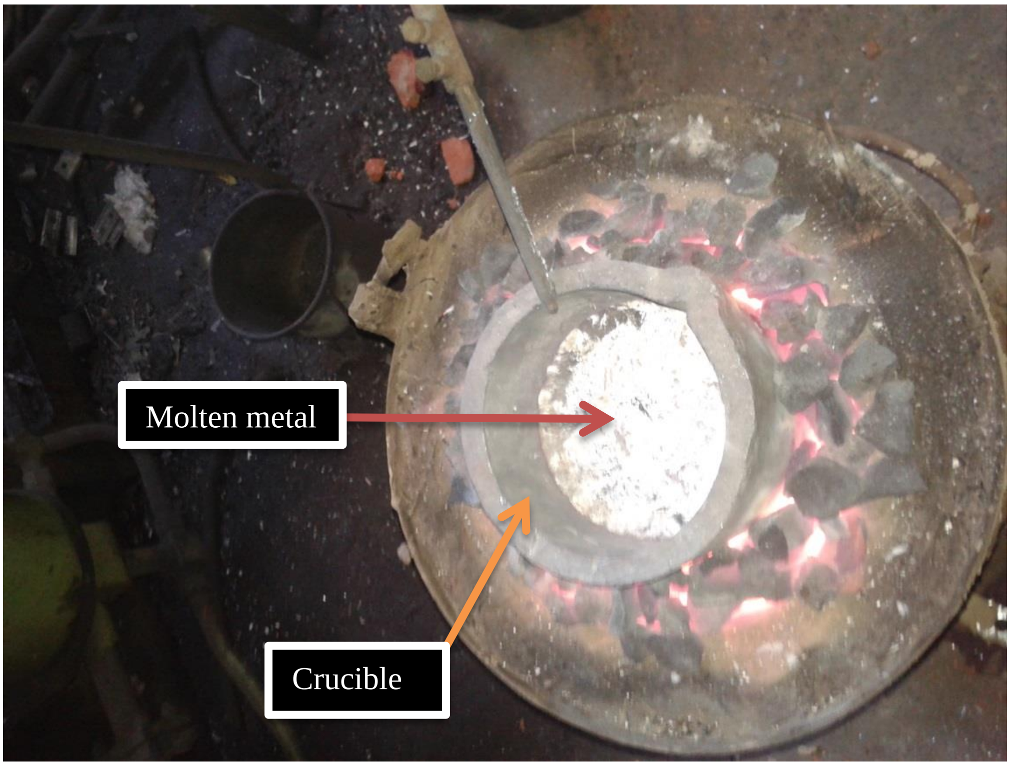

Fig 3.3 Pit Furnace

Fig 3.4 Pyrometer indicator

3.8 EXPERIMENTAL SET UP

We have conducted experiments on the raw material LM 24 aluminium alloy. Raw material was melted in the crucible on temp. 665^0C which was made up of Sic. Metal was ready for pouring after 1 hour 30 minutes. Firstly machine was started empty without any pouring of metal to heat up the dies for better accuracy of dimensions. The entire machine set up was operated on standard conditions except injection pressure, because the injection pressure was varied at 170, 180, 190 kg/cm^2 as per experimental design. Some other factors were also varied as per experimental design, which is given below:

a) Pouring temperature of the molten metal.
b) Cooling medium of the cast product (oil [transformer] cooled, water cooled, air cooled).
c) Coating type (oil +graphite, dycote +graphite, dycote coating). Dycote was made up from silicate, soft stone powder and water.

Fig 3.5 dycote (handmade)

Experiments were conducted on different pouring temperature of the molten metal i.e (725^{0}C, 750^{0}C, 775^{0}C).The molten metal was poured into the injection chamber in the shot sleeve with the help of pouring ladle. After pouring the molten metal into the injection chamber the plunger pushes the molten metal in the direction of dies and after applied some force like 170 kg/cm^2 the plunger comes back to its original position. After few seconds dies were opened by the operator to push the button of die open on control panel. When the dies were open then after solidification of metal the ejectors were ejects the casted part, and after that casted part was drop in air or water or oil as per the experimental requirements. We were repeating this process again and again as per the orthogonal array table requirements. We had done this entire work on the basis of L9 orthogonal array as shown in table 3.3. This entire experimental process was conducted at the D-217, S.L Castings and Allied industry, Focal point, Patiala.

3.8.1 Dies used for experiment

Dies plays a most vital role in the high pressure die casting machine. Without dies we are not able to do the castings on high pressure die casting machine. The dies which were used for the casting of LM 24 aluminium alloy made of H13 die steel. Dies were divided into two sections, one was moving die half and another was fixed die half or also known as ejector die half because in this side ejectors are mounted to allow the removal of casting. Sprue hole was in the fixed die side that permit the molten metal to enter the die and fill the mould cavity. The fixed die contains the runner and gates that route the molten metal to die cavity.

Moving die with solidified casted part when die opened as shown in fig 3.5

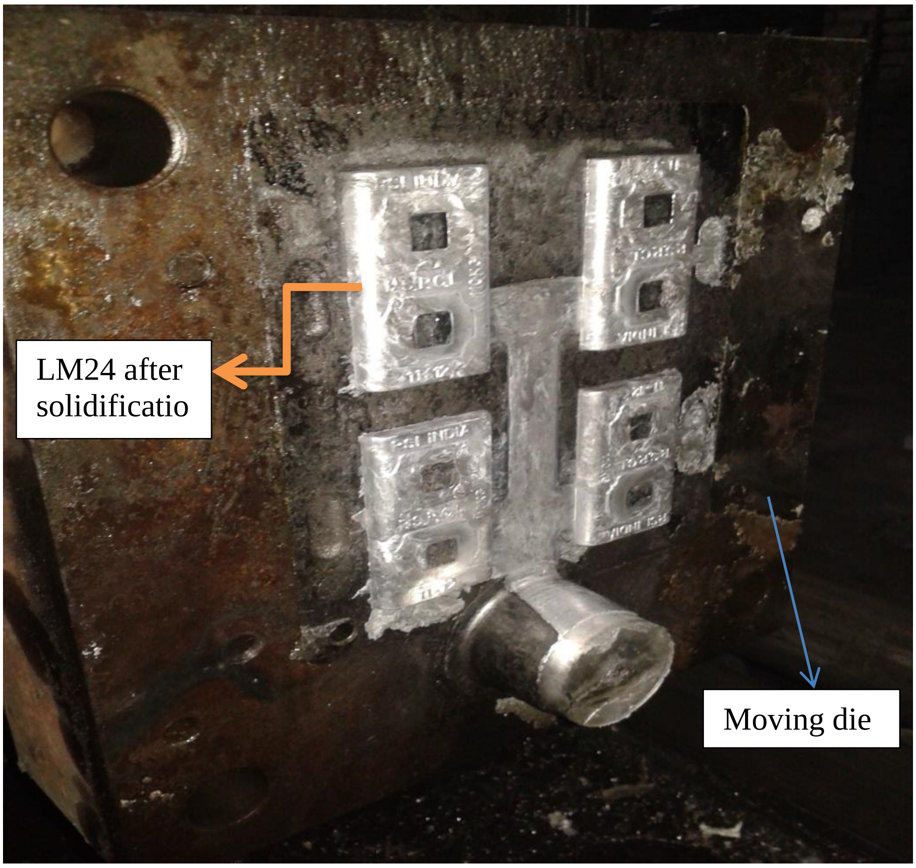

Fig 3.6 moving die

3.9 MEASURING AND TEST EQUIPMENTS USED AFTER EXPERIMENTS

Impact test, surface roughness test and Rockwell hardness test was conducted on all the samples of LM 24 aluminium alloy, produced after each of the 9 trials. Density was also measured using weighing machine. The entire detail of test equipment used in experimental study is given below:

3.9.1 Impact test

Impact test was performed on charpy impact tester machine available at solid mechanics lab, Thapar University, Patiala, and Punjab.

Fig.3.7 Material after impact test

3.9.2 Surface roughness tester

Surface roughness was measured by using the mitutoyo model SJ-400 available in metrology lab at Thapar University, Patiala, Punjab. The stylus method of measurement was used has profile resolution of 12 nm and roughness measurement limit upto 100µm. a tracing length of 4.8 mm was used for analysis. Surface toughness tester used for conducting test is shown in fig 3.8

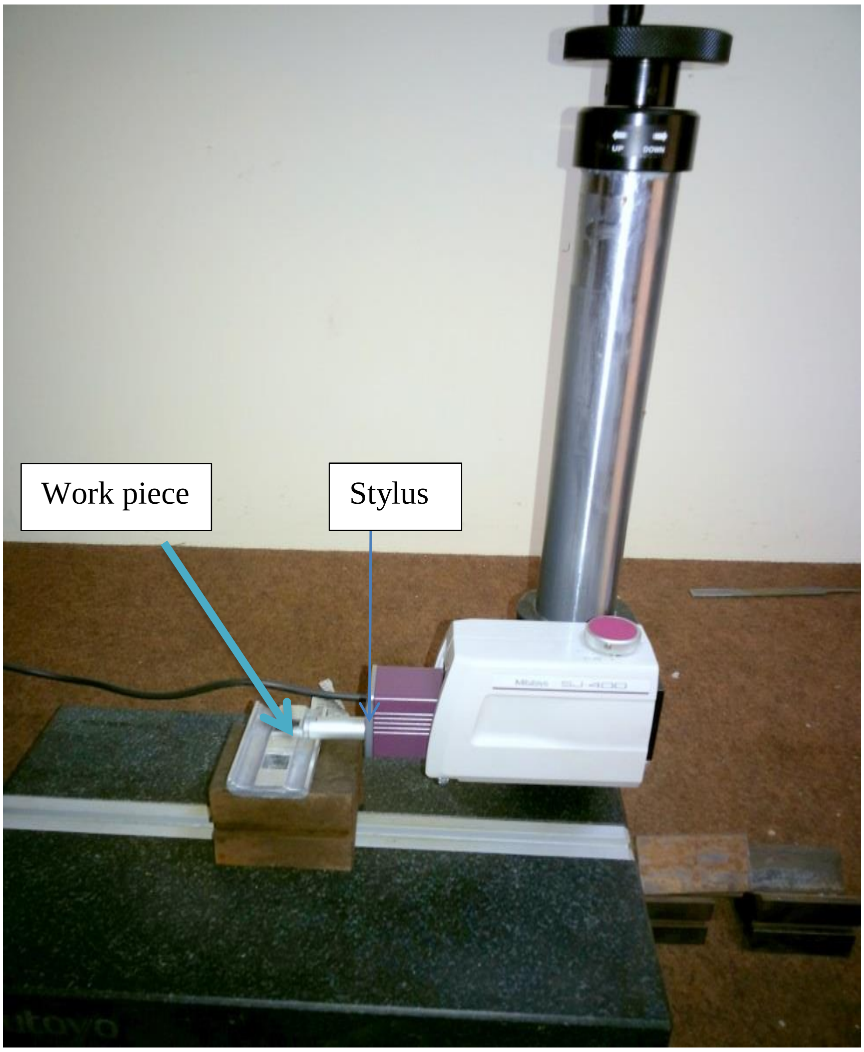

Fig 3.8 Surface roughness tester

3.9.3 Rockwell Hardness Tester

Hardness of the material was measured on Rockwell hardness tester machine (model AVERY 6402) England, available at strength of Material, Thapar university, Patiala. The measurement of the hardness is depends upon the indentation diameter on the samples. Pyramid shaped steel ball indenter was used for measuring the hardness on B scale with minor load 10 kg for 15 sec.

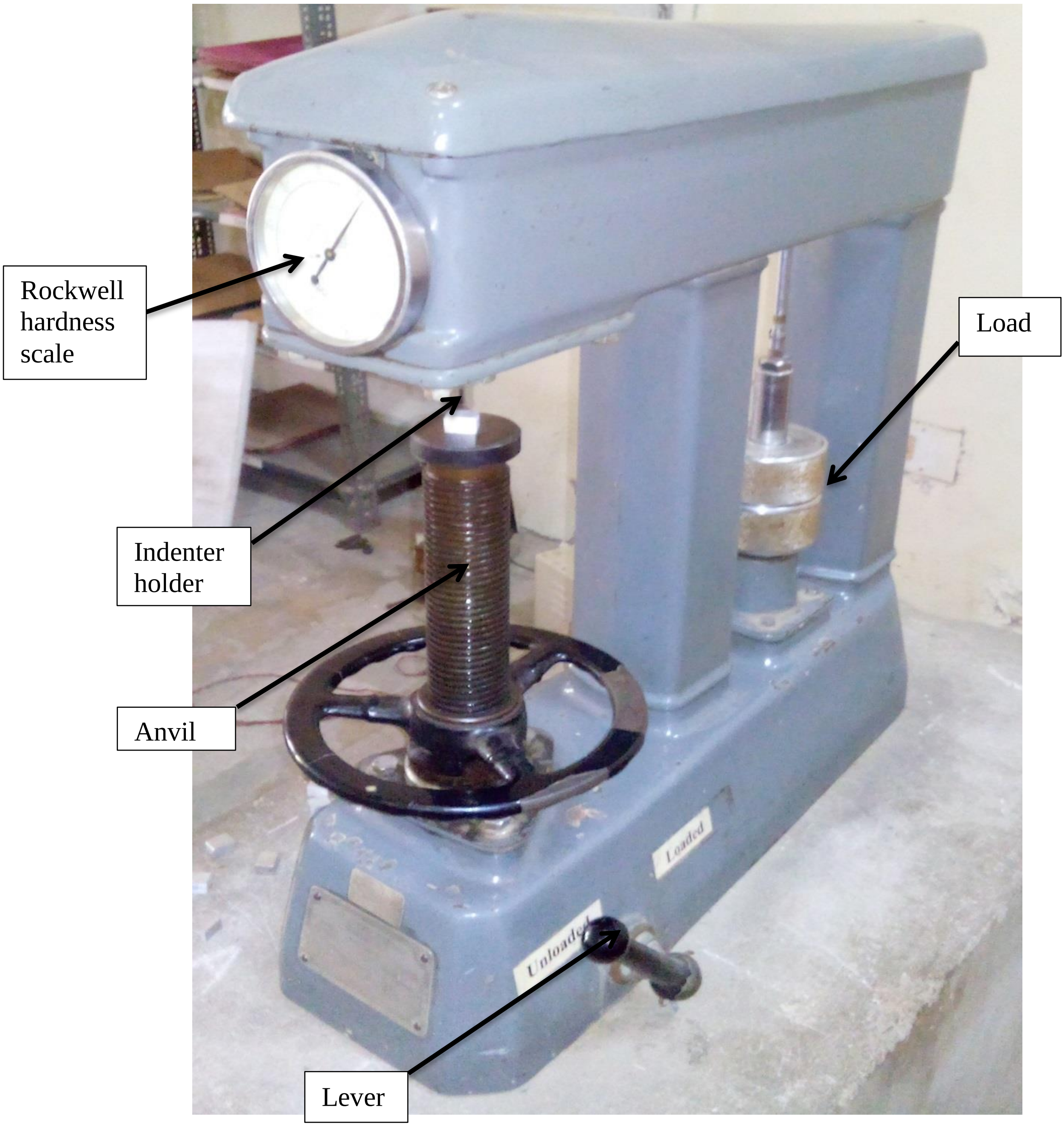

Fig 3.9 Rockwell hardness Testing Machine

3.10 COMPOSITION OF WORK MATERIAL

LM 24 Aluminium alloy was used as a work piece material. The entire percentage composition of the work piece is shown in table 3.5. The Raw material is shown in fig 3.9 and work pieces after castings as of final samples are shown in fig 3.10

Fig 3.10 Raw material of LM 24 prior to castin

	% Composition of aluminum alloy LM 24														
	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Ni**	**Zn**	**Ti**	**B**	**Ca**	**Co**	**Na**	**P**	**Pb**
Value	6.50%	0.590%	2.41%	0.234%	0.157%	0.0118%	0.00795%	0.161%	0.0565%	0.00036%	.00068%	.00510%	.00079%	.00040%	.00727%
	Sb	**Sn**	**Sr**	**V**	**Zr**	**Al**									
Value	.00010%	.0158%	.00111%	.00905%	.00279%	89.80%									

Table 3.5 Chemical Composition of work piece material

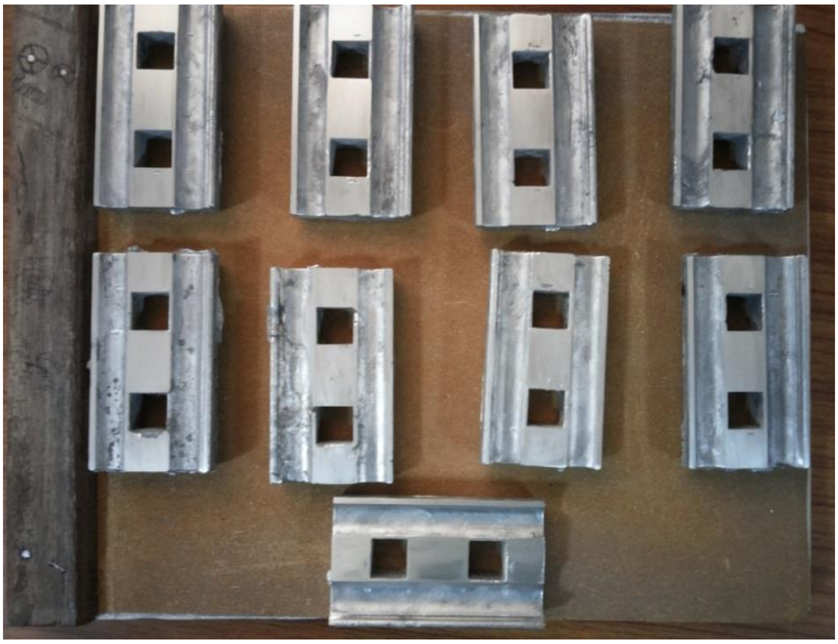

Fig 3.11 Final samples of LM 24 after die casting

3.11 ANALYSIS OF RESULT

The results of impact test, surface roughness, density and hardness after each of the 9 trials conducted with repetition are given below in table: 3.6

Sample No.	Pouring Temp ^0C	Injection Pressure Kg/cm^2	Coating type	Cooling medium	Impact Strength (joules)	Mean Surface Roughness R_a (μm)	Mean density	Mean hardness
1	725	170	Oil+graphite	Air	0.98	0.59	2.621	95.66
2	725	180	Dycote+graphite	Water	5.88	0.74	2.652	100.66
3	725	190	Dycote	Oil	11.77	0.58	2.681	104
4	750	170	Dycote+graphite	Oil	6.86	0.60	2.626	102.66
5	750	180	Dycote	Air	5.88	0.62	2.662	103.16
6	750	190	Oil+graphite	Water	3.23	0.47	2.688	102
7	775	170	Dycote	Water	5.88	0.58	2.624	102.83
8	775	180	Oil+graphite	Oil	7.85	0.55	2.654	101.66
9	775	190	Dycote+graphite	Air	4.96	0.52	2.689	99.66

Table 3.6 Analysis of result for LM 24 aluminium alloy

3.11.1 Analysis of Variance

The knowledge of the contribution of individual factors is critically important for the control of the each response. The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. It calculates parameters known as sum of squares (*SS*), pure *SS*, degree of freedom (dof), variance, F-ratio and percentage contribution of each factor. Since the procedure of ANOVA is a very complicated and employs a considerable of statistical formula, only a brief description of is given as following.

The Sum of Squares (SS) is a measure of the deviation of the experimental data from the mean value of the data.

Let '*A*' be a factor under investigation

$$SS_T = \sum_{i=1}^{N} (y_i - \overline{T})^2$$

Where N = Number of response observations, $\overline{T}$ is the mean of all observations y_i is the i, *th* response

Factor Sum of Squares (SS_A) - Squared deviations of factor (*A*) averages from overall average

$$SS_A = \left[\sum_{i=1}^{k_A} \left(\frac{A_i^2}{n_{Ai}} \right) \right] - \frac{T^2}{N} \qquad \text{(Equation 3.1)}$$

Where

$\overline{A}_i$ =Average of all obseravtions under A_i level = A_i / n_{Ai}

T = sum of all observations

$\overline{T}$ = Average of all observations = T / N

n_{Ai} = Number of obsernations under A_i level

Error Sum of Squares (SS_e) - Squared deviations of observations from factor (A) averages

$$SS_e = \sum_{j=1}^{k_A} \sum_{i=1}^{n_{Ai}} \left(y_i - \overline{A}_j \right)^2 \qquad \text{(Equation 3.2)}$$

$$SS_A^{/} = SS_A - (V_e)(v_A) \qquad \text{(Equation 3.3)}$$

$SS_A^{/}$ is expected sum of squares due to factor A, and the percent contribution to the total variation can be calculated as:

$$P = \frac{SS'_A}{SS_T} \times 100 \qquad \text{(Equation 3.4)}$$

3.10.2 Signal-to-Noise Ratio

The parameters that influence the output can be categorized into two classes, namely controllable (or design) factors and uncontrollable (or noise) factors. Controllable factors are those factors whose values can be set and easily adjusted by the designer. Uncontrollable factors are the sources of variation often associated with operational environment. The best settings of control factors as they influence the output parameters are determined through experiments. From the analysis point of view, there are three possible categories of the response characteristics explained below.

r is the number of tests in a trial (noise of repetitions regardless of noise levels)

$\sum_{i=1}^{r} y^2{}_i$ = summation of all response values under each trial

MSD = Mean square deviation

y_j= Observed value of the response characteristic

y_o= nominal or target value of the results

The three different response characteristics are given by the following.

1) Higher is Better. The S/N for higher the better is given by:

$(S/N)_{HB} = -10 \log (MSD_{HB})$

Where $MSD_{HB} = \frac{1}{r}\sum_{j=1}^{r}\left(\frac{1}{y_j{}^2}\right)$

(Equation 3.5.)

MSD_{HB} = Mean Square Deviation for higher-the-better response.

2) Nominal is Better. The S/N for nominal is better is:

$(S/N)_{NB} = -10 \log (MSD_{NB})$

Where $MSD_{NB} = \frac{1}{r}\sum_{j=1}^{r}(y_j - y_0)^2$

(Equation 3.6.)

Lower is Better. In this design situation, the surface roughness and hardness is the type of ‘‘lower is better’’, which is a logarithmic function based on the mean square deviation (MSD), given by

$$S/N_{LB} = -10\log(MSD) = -10\log[(\frac{1}{r}\sum_{i=1}^{r} y^2{}_i)$$

(Equation 3.7.)

Where $MSD_{LB} = \frac{1}{r}\sum_{j=1}^{r}\left(y_j{}^2\right)$

3.10.3 Signal to noise ratio for response characteristics

The parameters that influence the output can be categorized in two categories, controllable factors and uncontrollable factors. The control factors that may contribute to reduced variation can be quickly identified by looking at the amount of variation present in response. The uncontrollable factors are the sources of variation often associated with operational environment. For this experimental work, response characteristics have given in the Table 3.7.

Table 3.7: Response Characteristics

Response name	**Response type**	**Units**
Impact test	Higher is better	Joules
Density	Higher is better	gm/cm^3
Hardness	Higher is better	HRB
Surface Roughness	Lower is better	Microns

3.10.4 Measurement of F-value of Fisher’s F ratio

The principle of the *F* test is that the larger the *F* value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. *F* value is defined as:

$$F = \frac{MS\ for\ the\ term}{MS\ for\ the\ error\ term}$$

(Equation 3.8)

Depending on F-value, percentage contribution is calculated of each factor and interaction.

Computation of average performance:

Average performance of a factor at certain level is the influence of the factor at this level on the mean response of the experiments

CHAPTER 4 RESULTS AND ANALYSIS

4.1 INTRODUCTION

The effect of various input parameters i.e. thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (oil+ graphite coating, dycote + graphite coating, dycote coating), and the type of cooling (air cooling, water cooling and oil cooling). The four responses were selected for experimentation namely, surface roughness, density, hardness and impact strength. The experiment was conducted using LM 24 aluminium alloy. The assignment of factor was carried out using statistical software MINITAB 17. All the factors were varied at three levels. The degree of freedom required for the experiment was calculated to be 8, thus orthogonal array that can be used should have degree of freedom (DOF) less than or equal to 8. L9, which can accommodate factors with 3-levels, was thus used for conduct of experiments to measure four responses namely the surface roughness, density and hardness and impact strength. After conducting the 9 trials the mean value for all the above factors are tabulated. For the analysis of result Analysis of Variance (ANOVA) was performed.

4.2 RESULTS OF IMPACT STRENGTH

Impact strength was measured using charpy impact testing machine available at solid mechanics lab, Thapar University, Patiala. Impact strength can be measured in joules. The results of the impact strength for each of the 9 experiments in table 4.1

Table 4.1 Results of impact strength

Sample No.	Pouring Temp ^0C	Injection Pressure Kg/cm^2	Coating type	Cooling medium	Impact Strength (joules)	SNRA1	Mean
1	725	170	Oil+graphite	Air	0.98	-0.1755	0.98
2	725	180	Dycote+graphite	Water	5.88	15.3875	5.88
3	725	190	Dycote	Oil	11.77	21.4155	11.77
4	750	170	Dycote+graphite	Oil	6.86	16.7265	6.86
5	750	180	Dycote	Air	5.88	15.3875	5.88
6	750	190	Oil+graphite	Water	3.23	10.1841	3.23
7	775	170	Dycote	Water	5.88	15.3875	5.88
8	775	180	Oil+graphite	Oil	7.85	17.8974	7.85
9	775	190	Dycote+graphite	Air	4.96	13.9096	4.96

4.3 ANALYSIS OF VARIANCE- IMPACT STRENGTH

The results were analysed using ANOVA for identifying the significant factors affecting the impact strength. ANOVA results for the impact strength at 95% confidence interval are given in Table 4.1. The variation data for each factor was tested for F value to find significance of each factor. The principle of F-test is that the larger the F values for a particular parameter, the greater the effect of performance characteristics due to the change in that process parameter. ANOVA analysis showed that Cooling (F value 6.54547) was the only factor that significantly affects the impact strength. All other factors, namely, pouring temperature, Injection pressure and coating were found to be insignificant. Table 4.3 shows the rank of various factors in the term of their relative significance. Cooling has the highest rank; signifying highest contribution to impact strength and the pouring temperature has the lowest rank and was observed to be insignificant in affecting impact strength. Main effect plot for the mean surface roughness is shown in the Figure 4.1 which shows the variation of impact strength with the input parameters. As can be seen impact strength improves with oil (Transformer) cooling.

Table 4.2 Analysis of variance for means of impact strength

Factors	DOF	Seq SS	Adj MS	F	P
Pouring Temperature	2	1.6086	0.8043		
Injection Pressure	2	8.1947	4.0973		
Coating	2	21.9288	10.9644		
Cooling	2	39.6650	19.8325	6.54547	75.25
Total	8	71.3971			

Table 4.3 Response table for impact strength

Level	pouring temp	injection pressure	Coating	cooling
1	6.210	4.573	4.020	3.940
2	5.323	6.537	5.900	4.997
3	6.230	6.653	7.843	8.827
Delta	0.907	2.080	3.823	4.887
Rank	4	3	2	1

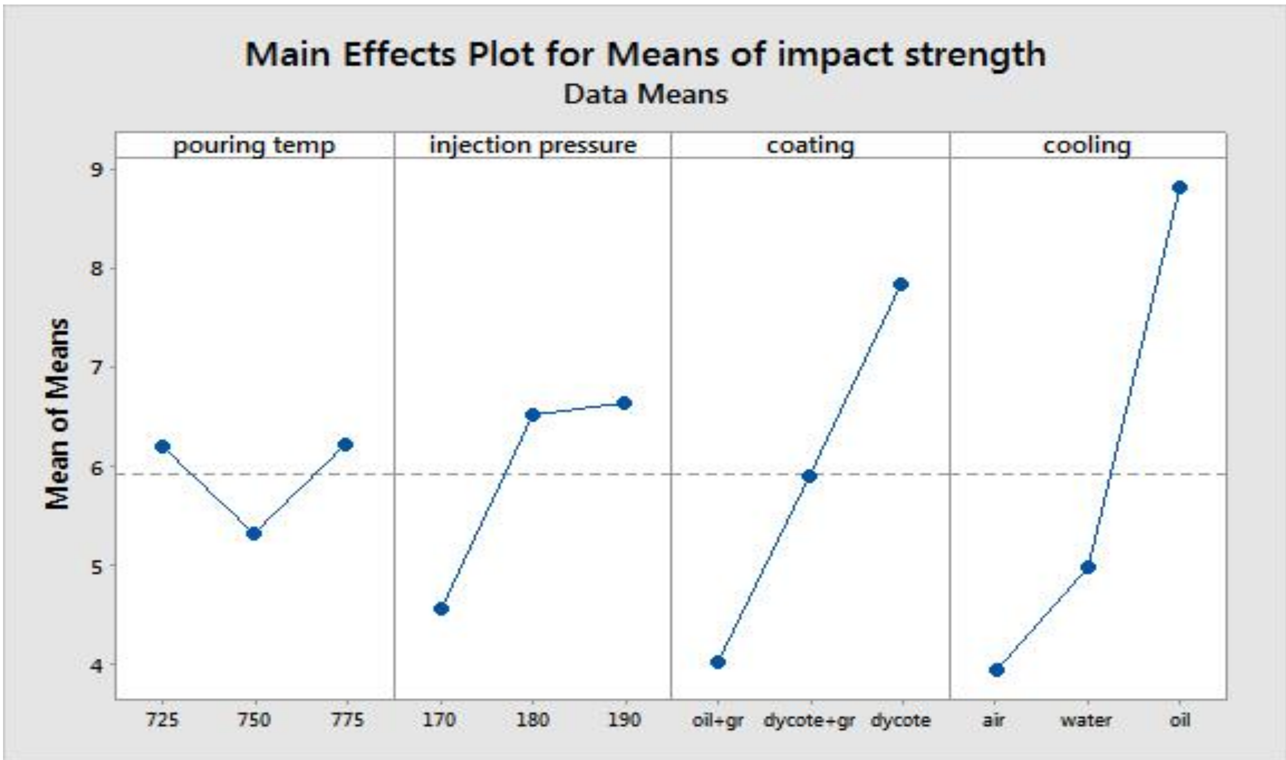

Figure 4.1 Main effect plot for impact strength

4.4 RESULTS FOR S/N RATIO- IMPACT STRENGTH

The S/N ratio consolidated several repetitions into one value and is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors and interactions that cause variation in impact strength. Impact strength is a "Higher the better" type response and is given by a logarithmic function based on the mean square deviation (MSD),

$$S/N_{HB} = -10\log(MSD) = -10\log[(\frac{1}{r}\sum_{i=1}^{r} y^2{}_i)$$

Where $MSD_{HB} = \frac{1}{r}\sum_{j=1}^{r}\left(y_j{}^2\right).$

Table 4.4 shows the ANOVA results for S/N ratio of impact strength at 95% confidence interval. Other than pouring temperature, all other factors, namely coating, cooling and injection pressures were found to be significant in affecting impact strength. According to F-test, Cooling was observed to be the most significant factor affecting the impact strength, followed by Coating and Injection Pressure according to F-test. Main effect plot of S/N ratio for impact strength as shown in the Figure 4.2.

Table 4.4 Analysis of variance results for S/N ratio of impact strength

Source	DOF	Seq SS	Adj MS	F	P
Pouring Temperature	2	18.643	9.3217	1	2.54
Injection Pressure	2	52.688	26.3441	2.345	10.265
Coating	2	106.225	53.1126	2.5478	14.1542
Cooling	2	121.345	60.6723	6.54547	75.2355
e-pooled	2	2.6479	1.3135		
Total	8	300.902			

Table 4.5 Response table for S/N ratio of impact strength

Level	Pouring Temperature	Injection Pressure	Coating Type	Cooling Type
1	12.209	10.646	9.302	9.707
2	14.009	16.224	15.341	13.653
3	15.732	15.170	17.395	18.680
Delta	3.522	5.578	8.095	8.973
Rank	4	3	2	1

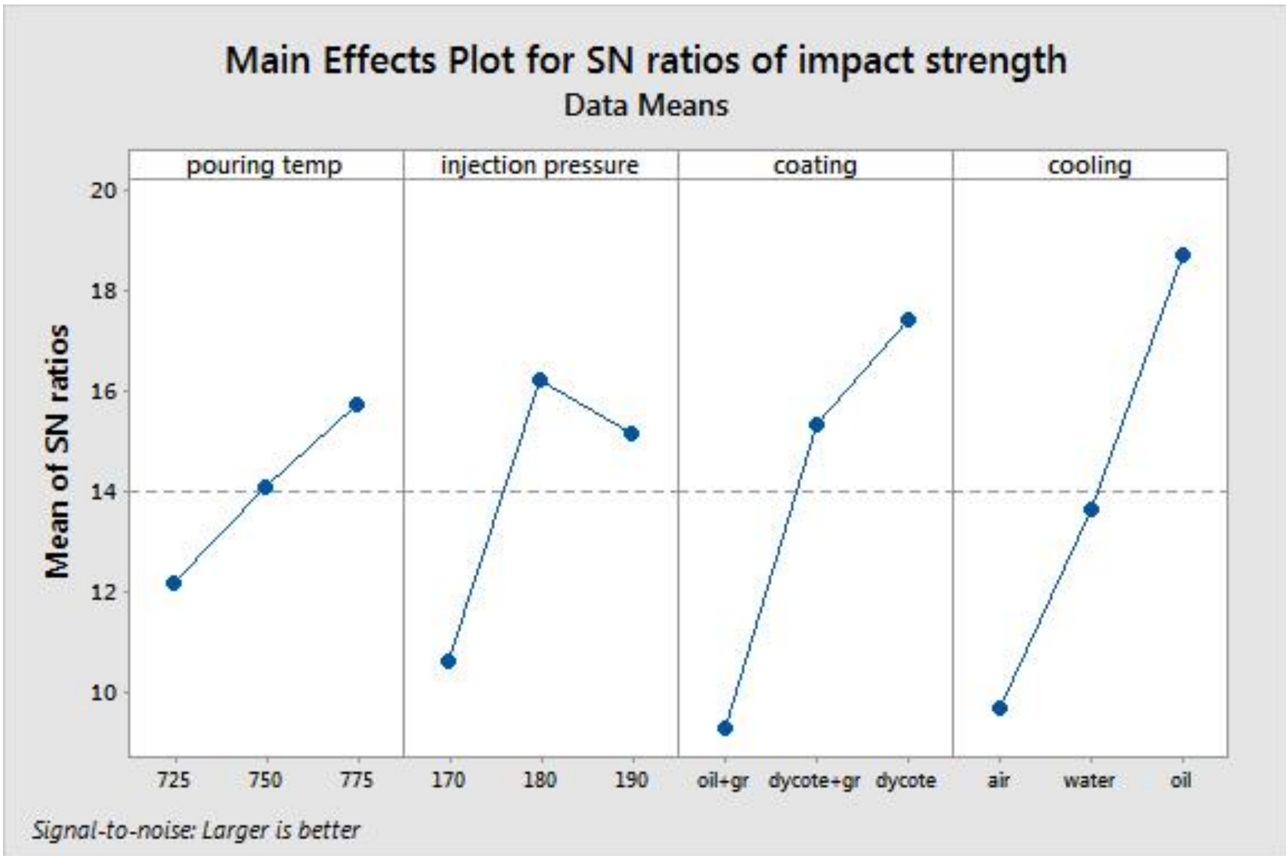

Figure 4.2 Main effect plot for S/N ratio of impact strength

4.5 OPTIMAL DESIGN FOR IMPACT STRENGTH

The same level of all the significant factors provide a higher mean value and reduced variability so nothing has to be compromised. The level of factors which improves average and uniformity may conflict, so a compromise may have to be reached. Also a compromise has to occur when multiple responses are considered and the same factor level may cause one response to improve and other to deteriorate. In this experimental analysis, the main effect plot in Figure 4.1 and estimate the impact strength. From the, Table 4.6 it is concluded that Highest impact strength was observed when cooling type Oil is used and pressure was kept at 180 kg/cm^2 .In S/N ratio highest impact strength was observed when coating type dycote was used and pressure was kept at 190 kg/cm^2.

Table 4.6 Significant factors and their levels

Factor	Affecting mean		Affecting variation	
	Contribution	Best level	Contribution	Best level
Pouring Temperature, A	insignificant	-	insignificant	Level -3 ,(7705ºC)
Injection Pressure, B	insignificant	Level-3	significant	Level-2, (180kg/cm^2)
Coating, C	insignificant	-	significant	Level-3 (Dycote)
Cooling, D	significant	Oil	significant	Level-3 (Oil)

Estimating the mean

In experimental analysis, impact strength is a higher average response is better (HB) characteristic. Depending on the characteristic, different treatment combinations has chosen to obtain satisfactory results. After conducting the experiments the optimum treatment condition within the experiments determined on the basis of prescribed combination of factor levels is determined to one of those in the experiment [30].

Mean value impact strength

$$\mu_{B_1 C_1 D_2} = \overline{B_1} + \overline{C_1} + \overline{D_2} - 2\overline{T}$$

$$= 4.573 + 4.020 + 4.997 - 2 \times 3.451 = 3.676\ microns$$

Confidence Interval around the Estimated Mean

The confidence interval is a maximum and minimum value between which the true average should fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment. Statistically this provides a 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ.

Confidence Interval around the estimated impact strength mean

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$

Where $F_{\alpha v_1 v_2} = F\ ratio$

$\alpha = risk$ (0.05) $\qquad confidence = 1-\alpha$

$v_1 = dof\ \ for\ mean\ which\ is\ always = 1$

$v_2 = dof\ \ for\ error = v_e$

$$V_e = \frac{\text{Total pooled variation}}{\text{Total pooled DOF}}$$

$$n_{eff} = \frac{\text{No of Experiments}}{\text{1+Total DOF assosiated with μ.}}$$

$$n_{eff} = \frac{N}{1 + dof_{B,C,D}} = \frac{9}{1+2+2+2} = 1.28$$

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{6.23 \times 0.5487}{1.28}} = 1.6342$$

So, the confidence interval around the impact strength is given by 3.676±1.6342microns.

4.6 RESULTS OF SURFACE ROUGHNESS (R_a)

Surface roughness was measured using the Mitutoyo Surftest model SJ-400 available in the Metrology laboratory at Thapar University, Patiala. The result of surface roughness for each of the 9 experiments is given in Table 4.7.

Table 4.7: Results for Surface Roughness (R_a) for LM 24 Alloy.

Trial No.	Pouring temp.	Injection pressure	Coating type	Cooling type	Mean surface roughness	S/N ratio
1	725	170	Oil+graphite	Air	0.59	2.61537
2	750	180	dycote+Graphite	Water	0.74	4.73144
3	775	190	Dycote	Oil	0.58	4.43697
4	750	170	dycote+Graphite	Oil	0.60	4.15217
5	775	180	Dycot	Air	0.62	6.55804
6	725	190	Oil+ graphite	Water	0.47	4.73144
7	775	170	Dycot	Water	0.58	5.19275
8	725	180	Oil+ graphite	Oil	0.55	5.67993
9	750	190	dycote+Graphite	Air	0.52	4.58296

4.7 ANALYSIS OF VARIANCE- SURFACE ROUGHNESS

The results were analysed using ANOVA for identifying the significant factors affecting the surface roughness. ANOVA results for the mean surface roughness at 95% confidence interval are given in Table 4.8. The variation data for each factor was tested for F value to find significance of each factor. The principle of F-test is that the larger the F values for a particular parameter, the greater the effect of performance characteristics due to the change in that process parameter. ANOVA analysis showed that injection pressure (F value 9.55395) was the only factor that significantly affects the surface roughness. All other factors, namely, pouring temperature, coating and cooling were found to be insignificant. Table 4.9 shows the rank of various factors in the term of their relative significance. Injection pressure has the highest rank, signifying highest contribution to surface roughness and the cooling has the lowest rank and was observed to be insignificant in affecting surface roughness. Main effect plot for the mean surface roughness is shown in the Figure 4.3 which shows the variation of surface roughness with the input parameters. As can be seen surface finish improves with injection pressure of 190 kg/cm^2.

Table 4.8 : Analysis of Variance for means of surface roughness (R_a)

Factors	DOF	Seq SS	Adj MS	F	P
Pouring Temperature	2	0.013067	0.006533	3.5455	25.6821
Injection Pressure	2	0.019467	0.009733	9.55395	56.9575
Coating	2	0.010867	0.005433	2.02554	11.6249
Cooling	2	.000800	.000400	1.85892	8.3844
Total	8	.044200			
E pooled	2	0.006109	0.24854		

Table 4.9: Response Table for Means in Surface Roughness For LM 24 Alloy (R_a)

Level	**Pouring Temperature**	**Injection Pressure**	**Coating Type**	**Cooling Type**
1	0.6367	0.5900	0.5367	0.5767
2	0.5633	0.6367	0.6200	0.5967
3	0.5500	0.5233	0.5933	0.5767
Delta	0.0867	0.1133	0.0833	0.0200
Rank	2	1	3	4

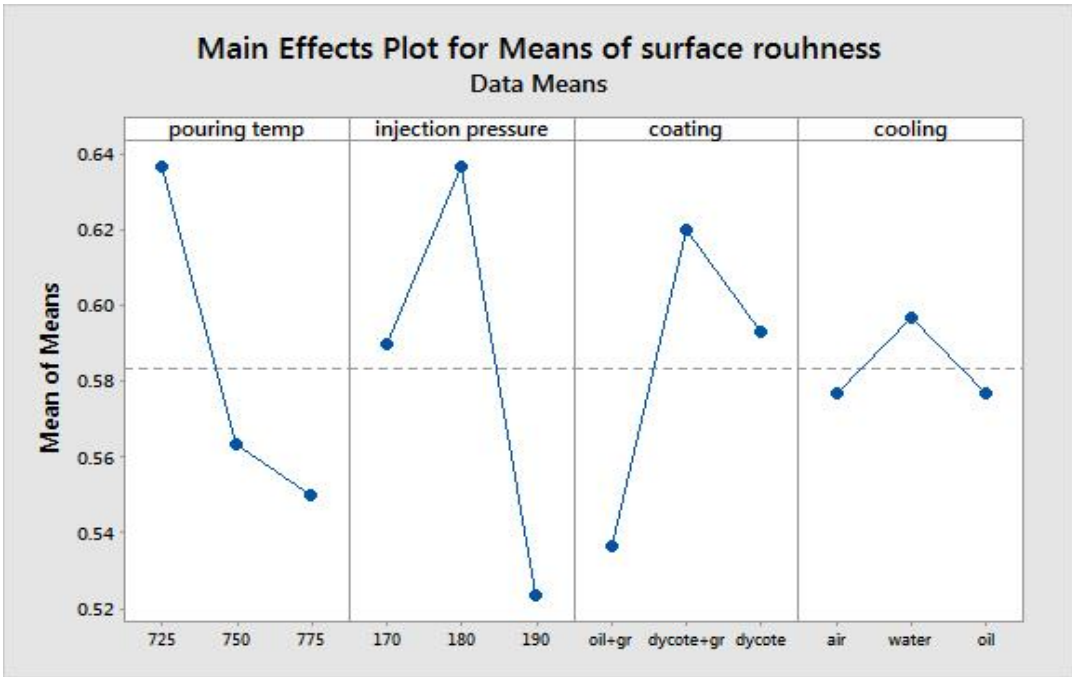

Figure 4.3 Main effect plot for surface roughness

4.8 RESULTS FOR S/N RATIO – SURFACE ROUGHNESS

The S/N ratio consolidated several repetitions into one value and is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors and interactions that cause variation in surface roughness. Surface roughness is a "lower the better" type response and is given by a logarithmic function based on the mean square deviation (MSD),

$$S/N_{LB} = -10\log(MSD) = -10\log[(\frac{1}{r}\sum_{i=1}^{r} y^2{}_i)$$

Where $MSD_{LB} = \frac{1}{r}\sum_{j=1}^{r}\left(y_j{}^2\right)$

The S/N ratio values are given in the last column of Table 4.7. Table 4.10 shows the ANOVA results for S/N ratio of surface roughness at 95% confidence interval. Other than cooling, all other factors, namely coating, pouring temperature and injection pressures were found to be significant in affecting surface roughness (R_a). According to F-test, coating was observed to be the most significant factor affecting the surface roughness, followed by Cooling and Injection Pressure according to F-test. Main effect plot of S/N ratio for surface roughness are shown in the Figure 4.4.

Table 4.10: Analysis of Variance for S/N ratios of surface roughness

Source	DOF	Seq SS	Adj MS	F	P
Pouring Temperature	2	2.67349	1.33675	2.3658	20.2145
Injection Pressure	2	4.29503	2.14752	7.5698	65.2364
Coating	2	2.34903	1.17451	1.2365	10.2365
Cooling	2	0.05238	0.02619	1.02365	5.1254
e-pooled	2	0.6269	1.102		
Total	8	9.36994			

Table 4.11 Response Table for S/N Ratio of Surface Roughness

Level	Pouring Temperature	Injection Pressure	Coating Type	Cooling Type
1	3.977	4.584	5.445	4.805
2	5.049	3.987	4.244	4.635
3	5.201	5.656	4.538	4.787
Delta	1.225	1.670	1.200	0.170
Rank	2	1	3	4

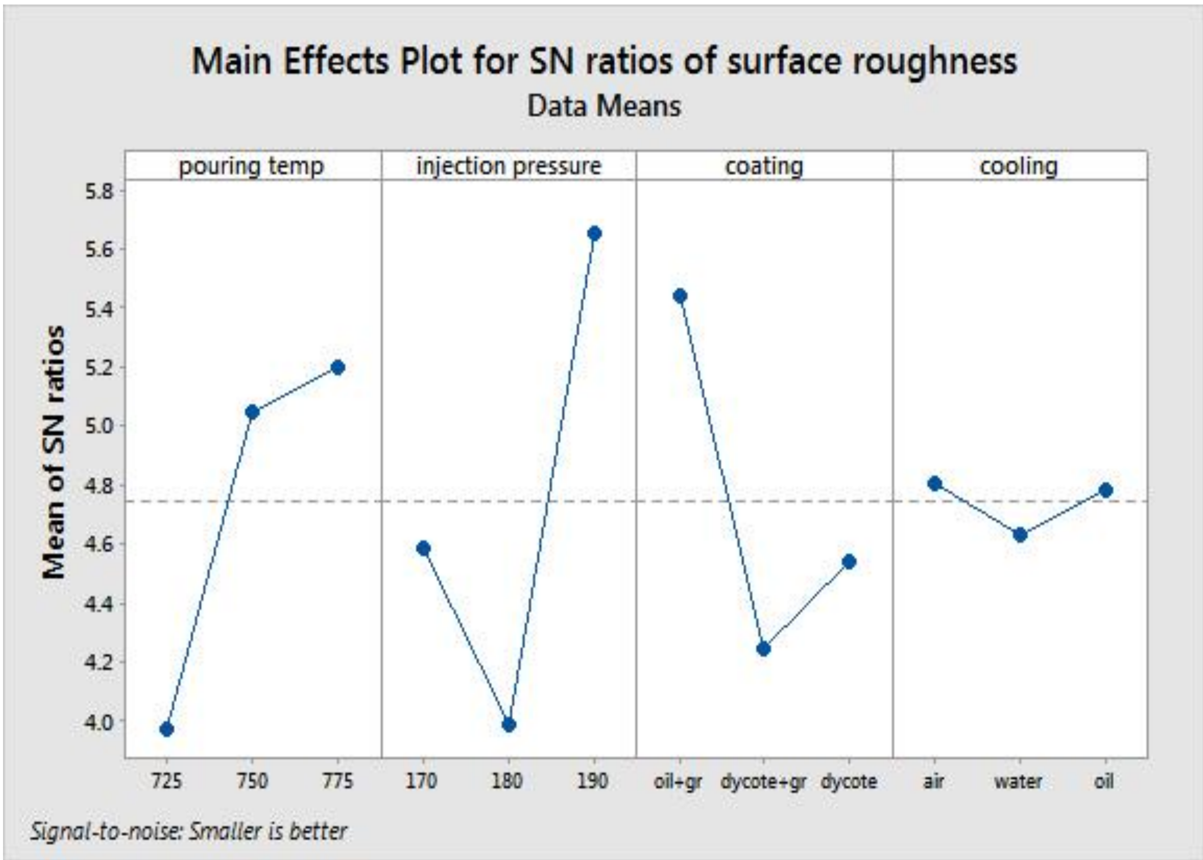

Figure 4.4 Main effects plot for S/N ratio of surface roughness

4.9 OPTIMAL DESIGN FOR SURFACE ROUGHNESS

The same level of all the significant factors provide a higher mean value and reduced variability so nothing has to be compromised. The level of factors which improves average and uniformity may conflict, so a compromise may have to be reached. Also a compromise has to occur when multiple responses are considered and the same factor level may cause one response to improve and other to deteriorate [29].In this experimental analysis, the main effect plot in Figure 4.3 and estimate the mean surface roughness. From the, Table 4.12 it is concluded that lowest roughness was observed when injection pressure was kept at 190 kg/cm^2 .In S/N ratio lowest roughness was observed when injection pressure was kept at 190 kg/cm^2, and cooling type air cooling was used as they reduce the variation and improve the surface finish.

Table 4.12 Significant Factors and Their Levels

Factor	Affecting mean		Affecting variation	
	Contribution	Best level	Contribution	Best level
Pouring Temperature, A	insignificant	-	significant	Level -3 (775ºC)
Injection Pressure, B	significant	Level-3 (190 kg/cm^2)	significant	Level-3 (190kg/cm^2)
Coating, C	insignificant	-	insignificant	-
Cooling, D	insignificant	-	significant	Level-1 (air)

Estimating the mean

In experimental analysis, surface roughness is a lower average response is better (LB) characteristic. Depending on the characteristic, different treatment combinations has chosen to obtain satisfactory results. After conducting the experiments the optimum treatment condition within the experiments determined on the basis of prescribed combination of factor levels is determined to one of those in the experiment [30].

Mean value for Roughness

$$\mu_{A_3\,B_3\,C_1} = \overline{A_3} + \overline{B_3} + \overline{C_1} - 2\overline{T}$$

$$= 0.5500 + 0.5233 + 0.5367 - 2 \times 0.6367 = 0.3366\, micron$$

Confidence Interval around the Estimated Mean

The confidence interval is a maximum and minimum value between which the true average should fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment. Statistically this provides a 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ [17].

Confidence Interval around the estimated roughness mean

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}}$$

Where $F_{\alpha v_1 v_2} = F\ ratio$

$\alpha = risk$ (0.05) $\quad$ $confidence = 1 - \alpha$

$$v_1 = dof \ \ for\ mean\ which\ is\ always = 1$$
$$v_2 = dof \ \ for\ error = v_e$$

$$V_e = \frac{\text{Total pooled variation}}{\text{Total pooled DOF}}$$

$$n_{eff} = \frac{\text{No of Experiments}}{\text{1+Total DOF assosiated with μ.}}$$

$$n_{eff} = \frac{N}{1 + dof_{B,C,D}} = \frac{9}{1+2+2+2} = 1.28$$

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2} V_e}{n_{eff}}} = \sqrt{\frac{1.56 \times 0.8754}{1.28}} = 1.066$$

So, the confidence interval around the Surface Roughness is given by 0.3366±1.066 micron.

4.10 RESULTS FOR DENSITY

The density of the cast material was obtained by using micrometer to conclude the volume and the weight was observed by using the electronic weighing scale available in Workshop at Thapar University, Patiala (Punjab). Density is denoted by $\rho = \frac{Weight}{volume}$ .The result for density for each of the 9 experiments is given in Table in 4.13.

Table 4.13: Results for Density

Trial No.	Pouring temp.	Injection pressure	Coating type	Cooling type	Mean density	S/N ratio
1	725	170	Oil+graphite	Air	2.621	8.36934
2	725	180	dycote+Graphite	Water	2.652	8.47147
3	725	190	Dycot	Oil	2.681	8.56594
4	750	170	dycote+Graphite	Oil	2.626	8.38589
5	750	180	Dycot	Air	2.662	8.50416
6	750	190	Oil+graphite	Water	2.688	8.58559
7	775	170	Dycot	Water	2.624	8.37928
8	775	180	Oil+graphite	Oil	2.654	8.478028
9	775	190	dycote+Graphite	Air	2.689	8.59182

4.11 ANALYSIS OF VARIANCE- DENSITY

The results were analysed using ANOVA for identifying the significant factor affecting the performance measures. ANOVA for the mean density at 95% confidence interval is given in

Table 4.14. ANOVA table shows that injection pressure (F value (35.541) is the only factor that significantly affects the density. All other factors, namely, Pouring temperature, Coating and cooling type were found to be insignificant. Table 4.15 shows the rank of various factors in the term of their relative significance. Pressure has the highest rank, signifying highest contribution to density and the Coating has the lowest rank and was observed to be insignificant. Main effect plot for the mean density is shown in the Figure 4.5 which shows the density increase with the increase in injection pressure.

Table 4.14: Analysis of Variance for Means density

Factors	DF	Seq SS	Adj MS	F	P
Pouring Temperature	2	0.000082	0.000041	3.2154	2.560521
Injection Pressure	2	0.005831	0.002915	35.54125	82.04531
Coating	2	0.000004	0.000002	1	7.805711
Cooling	2	0.000022	0.000011	2.54587	7.603973
e-pooled	2	.000001	0.000045		
Total	8	0.005983			

Table 4.15: Response Table for Means of Density

Level	**Pouring Temperature**	**Injection Pressure**	**Coating Type**	**Cooling Type**
1	2.651	2.624	2.654	2.657
2	2.659	2.656	2.656	2.655
3	2.656	2.686	2.656	2.654
Delta	0.007	0.062	0.001	0.004
Rank	2	1	4	3

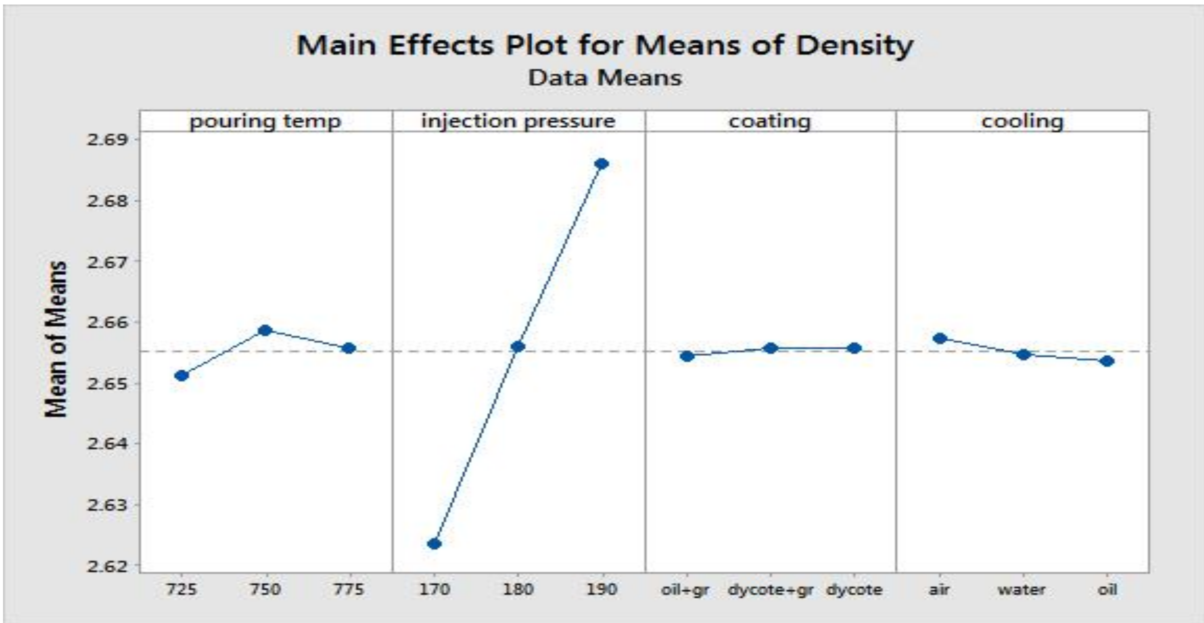

Figure 4.5 Main effect plot for mean density

4.12 RESULTS FOR S/N RATIO – DENSITY

The S/N ratios have been calculated to identify the major contributing factors and interactions that cause variation in density. Density a "Higher the better" type response is given by a logarithmic function based on the mean square deviation (MSD),

$$(S/N)_{HB} = -10 \log (MSD_{HB})$$

Where $MSD_{HB} = \frac{1}{r}\sum_{j=1}^{r}\left(\frac{1}{y_j^{\,2}}\right)$

MSD_{HB} = Mean Square Deviation for higher-the-better response.

Table 4.16 shows the ANOVA results for S/N ratio of density at 95% confidence interval. Except injection pressure all other factor namely Coating, Cooling and Pouring temperature are found to be insignificant. According to F-test injection pressure was observed to be the most significant factor affecting the density, followed at small level by temperature 775^{0}C.

Table 4.16: Analysis of Variance for S/N ratio for Density

Factors	DOF	Seq SS	Adj MS	F	P
Pouring Temperature	2	0.000871	0.000435	2.2356	12.57055
Injection Pressure	2	0.062427	0.031214	25.8741	70.4578
Coating Type	2	0.0000400	0.000020	3.2256	7.22356
Cooling Type	2	0.000225	0.000112	2.11542	9.5468
e-pooled	2	0.002654	0.00065		
Total	8	0.063562			

Table 4.17: Response Table for S/N Ratio for Density

Level	Pouring Temperature	Injection Pressure	Coating Type	Cooling Type
1	8.469	8.378	8.479	8.488
2	8.493	8.485	8.483	8.480
3	8.483	8.582	8.483	8.477
Delta	0.024	0.204	0.004	0.012
Rank	2	1	4	3

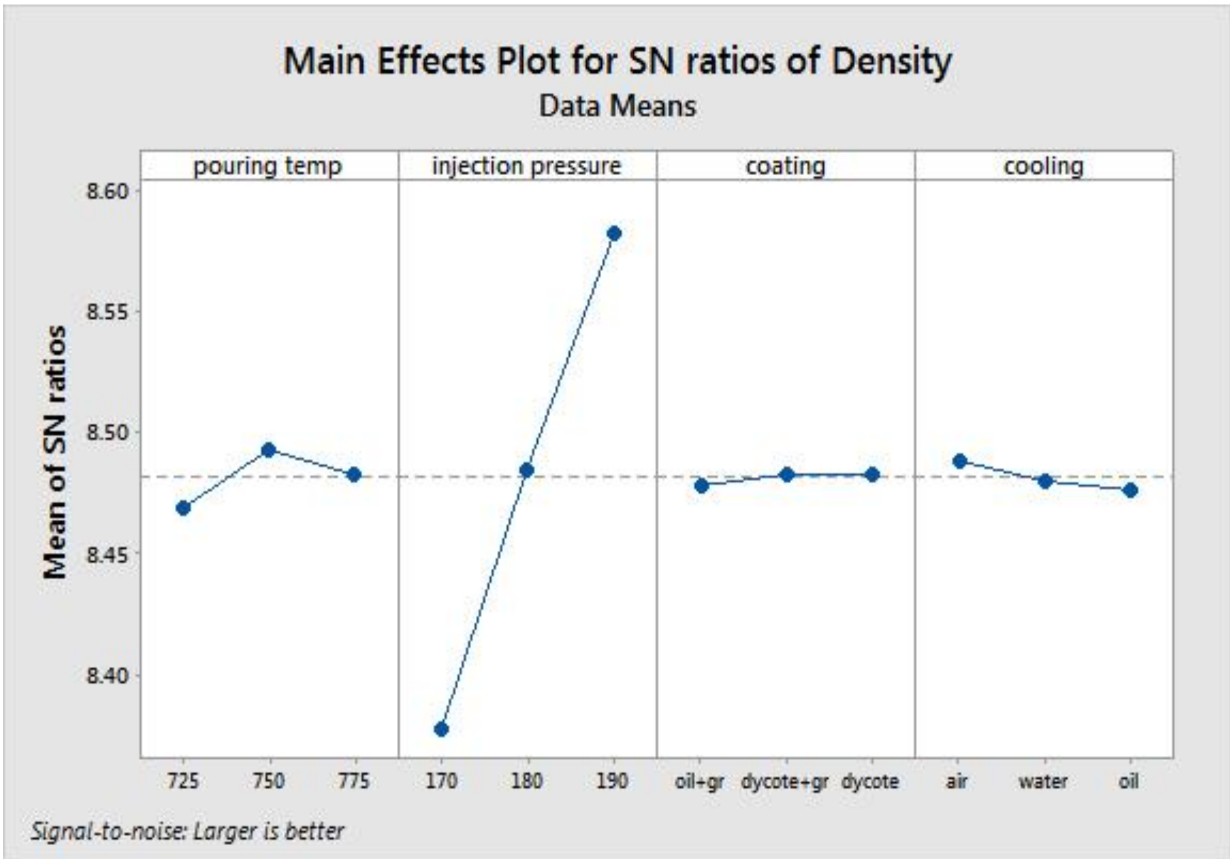

Figure 4.6 Main effects plot for S/N ratios of Density

4.13 OPTIMAL DESIGN FOR DENSITY

The same level of all the significant factors provide a higher mean value and reduced variability so nothing has to be compromised. In this experimental analysis, the main effect plot in Figure 4.17 and estimate the mean for density. From the, Table 4.18 it is concluded that highest density was observed when injection pressure was kept at 190 kg/cm^2 and Pouring temperature 775^{0}C is used. In S/N ratio plot 4.18 shows same result.

Table 4.18 Significant Factor and their Levels

Factor	Affecting mean		Affecting variation	
	Contribution	Best level	Contribution	Best level
Pouring Temperature, A	significant	Level-3 (775^{0}C)	significant	Level-2 (750^{0}C)
Injection Pressure, B	significant	Level-3, (190kg/cm^2)	significant	Level-3, (190kg/cm^2)
Coating, C	insignificant	-	insignificant	-
Cooling, D	insignificant	-	insignificant	-

Estimating the mean

In experimental analysis, density is a higher average response is better (HB) characteristic. After conducting the experiments the optimum treatment condition within the experiments determined on the basis of prescribed combination of factor levels is determined to one of those in the experiment

Mean value for Density

$$\mu_{B_3 A_3} = \overline{B_3} + \overline{A_3} + - \overline{T}$$

$$= 2.676 + 2.689 - 2.668 = 2.697 \text{ gms/mm}^3$$

Confidence Interval around the Estimated Mean

Confidence Interval around the estimated density mean

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}}$$

Where $F_{\alpha v_1 v_2} = F\ ratio$

$\alpha = risk$ (0.05) $\quad$ $confidence = 1 - \alpha$

$v_1 = dof\ \ for\ mean\ which\ is\ always = 1$

$v_2 = dof\ \ for\ error = v_e$

$n_{eff} =$ Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1 + dof_{A,B}} = \frac{9}{1 + 2 + 2} = 1.8$$

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}} = \sqrt{\frac{6.23 \times 0.000075}{1.8}} = 0.0509$$

So, the confidence interval around the Density is given by 2.697 ± 0.0509 gms/mm^3.

4.14 RESULTS OF HARDNESS

Hardness was measured on a Rockwell Hardness Tester, (model AVERY 6402) England, available at Mechanics of Solids lab, Thapar University, Patiala. The hardness measurement is dependent on the diameter of indentation on the samples. The indents formed in the pyramid shaped steel ball indenter were measured on B scale with a minor load of 10 kg for 10 Seconds. The result of hardness for each of the 9 experiments is given in Table in 4.19.

Table 4.19: Results of Hardness

Trial No.	Pouring temp.	Injection pressure	Coating type	Cooling type	Hardness	S/N ratio
1	725	170	Oil+graphite	Air	95.66	39.6146
2	725	180	dycote+Graphite	Water	100.66	40.0571
3	725	190	Dycot	Oil	104	40.3407
4	750	170	dycote+Graphite	Oil	102.66	40.2280
5	750	180	Dycot	Air	103.16	40.2702
6	750	190	Oil+graphite	Water	102	40.1720
7	775	170	Dycot	Water	102.83	40.2424
8	775	180	Oil+graphite	Oil	101.66	40.1430
9	775	190	dycote+Graphite	Air	99.66	39.9704

4.15 ANALYSIS OF VARIANCE- HARDNESS

The results were analysed using ANOVA for identifying the significant factor affecting the performance measures. The analysis of variance (ANOVA) for the mean hardness at 95% confidence interval is given in Table 4.20. ANOVA table shows that coating (F value 16.926) and cooling (F value 6.9568) are the factor that significantly affects the hardness, whereas pouring temperature and Injection pressure factor was found to be insignificant. Table 4.21 shows the rank of various factors in the term of their relative significance. Coating has the highest rank; signifying highest contribution to hardness and the injection pressure has the lowest rank and was observed to be insignificant in affecting hardness. Main effect plot for the mean hardness is shown in the Figure 4.7.

Table 4.20: Analysis of Variance for Mean Hardness

Factors	DF	Seq SS	Adj MS	F	P
Pouring Temperature	2	9.3764	4.68821	3.4487	10.71756
Injection Pressure	2	4.3468	2.17341	2.6548	4.5654
Coating	2	19.5983	9.79914	16.926	69.2366
Cooling	2	17.1083	8.55414	6.9568	16.2365
e-pooled	4	3.254	1.2785		
Total	8	53.6838			

Table 4.21: Response Table for Means for Hardness

Level	Pouring Temperature	Injection Pressure	Coating Type	Cooling Type
1	100.11	100.38	99.77	99.49
2	102.61	101.83	100.99	101.83
3	101.38	101.89	103.33	102.77
Delta	2.50	1.50	3.56	3.28
Rank	3	4	1	2

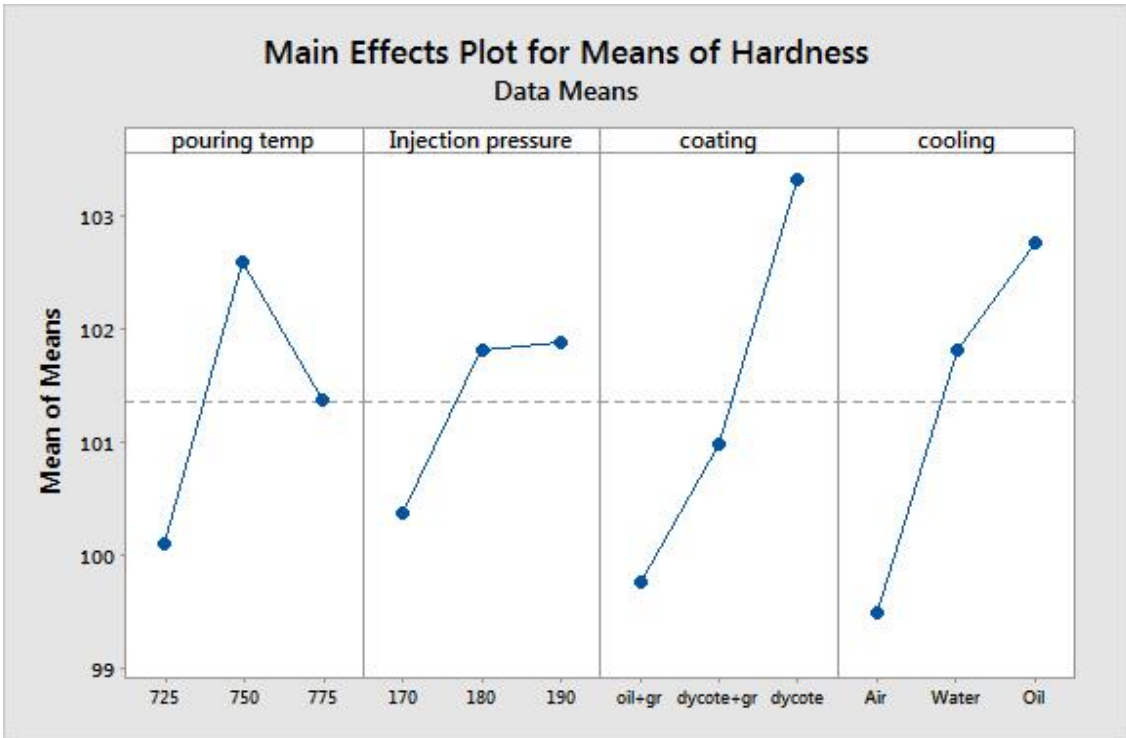

Figure 4.7 Main effects plot for means of hardness

4.16 RESULTS FOR S/N RATIO – HARDNESS

The S/N ratio consolidated several repetitions into one value and is an indication of the amount of variation present in the process. The S/N ratios have been calculated for hardness to identify the major contributing factors and interactions that cause variation in hardness. Hardness is a "Higher the better" type response is given by a logarithmic function based on the mean square deviation (MSD),

$$(S/N)_{HB} = -10\log(MSD_{HB})$$

$$Where\ MSD_{HB} = \frac{1}{r}\sum_{j=1}^{r}(\frac{1}{y_{j^2}})$$

MSD_{HB} =Mean square Deviation for higher-the-better response

Table 4.22 shows the ANOVA results for S/N ratio of hardness at 95% confidence interval. Except pouring temperature and injection pressure, all other factors are significant. According to F-test coating was observed to be the most significant factor affecting the hardness, followed by cooling according to F-test. Table 4.23 shows the rank of various factors in the term of their relative significance. Coating has the highest rank; signifying highest contribution to hardness and the injection pressure has the lowest rank and was observed to be insignificant in affecting hardness. Main effect plot of S/N ratio for hardness are shown in the Figure 4.

Table 4.22: Analysis of Variance for S/N Ratio of Hardness

Factors	DF	Seq SS	Adj MS	F	P
Pouring Temperature	2	0.072173	0.036086	3.54245	8.564789
Injection Pressure	2	0.034122	0.017061	2.5478	4.54895
Coating	2	0.146299	0.073149	14.21547	69.23654
Cooling	2	0.130109	0.065054	8.45785	19.25487
e-pooled	4	0.56478	0.41256		
Total	8	1.382702			

Table 4.23: Response Table for S/N Ratio of Hardness

Level	Pouring Temperature	Injection Pressure	Coating Type	Cooling Type
1	40.00	40.03	39.98	39.95
2	40.22	40.16	40.09	40.16
3	40.12	40.16	40.28	40.24
Delta	0.22	0.13	0.31	0.29
Rank	3	4	1	2

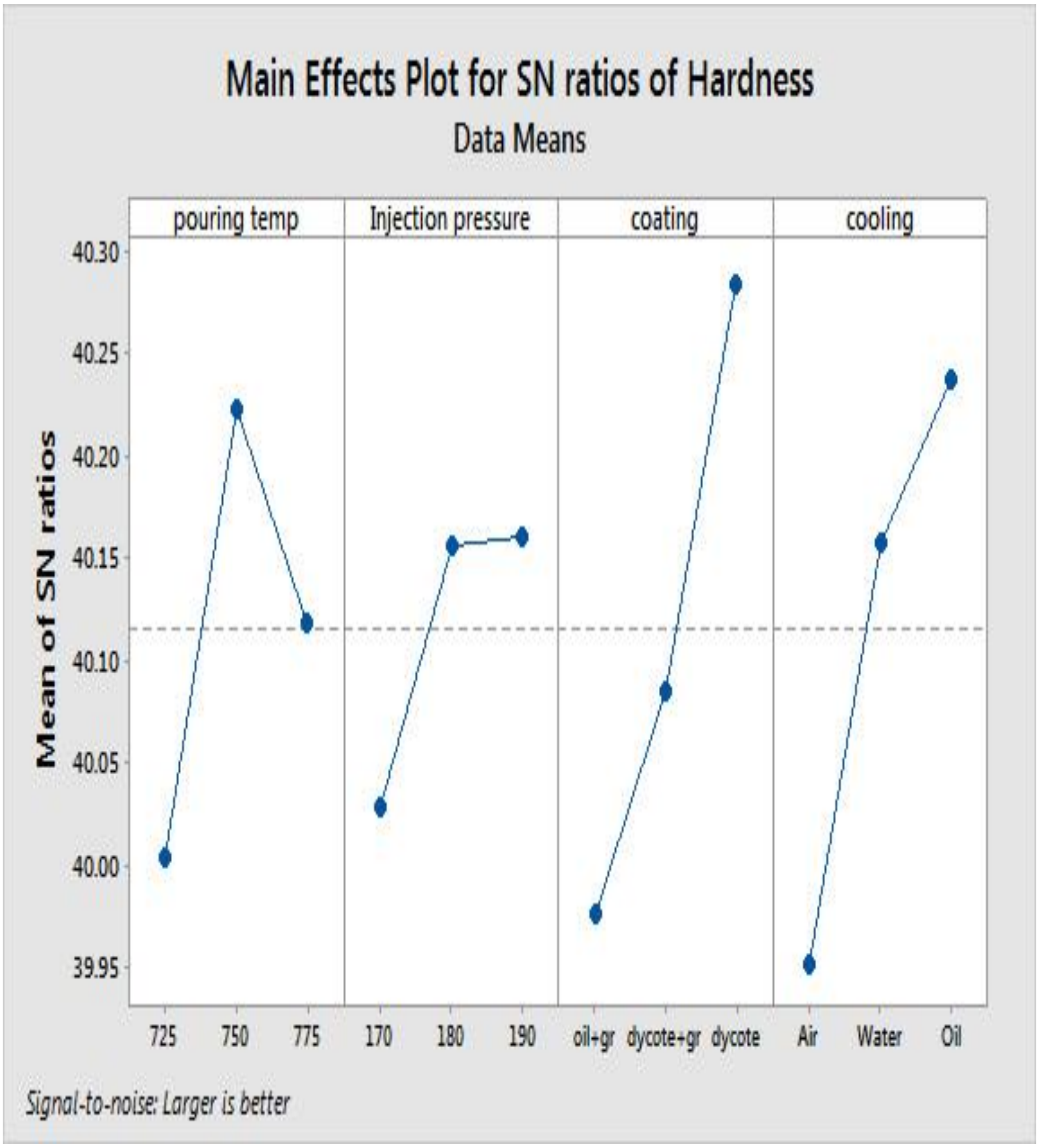

Figure 4.8 Main effects plot for S/N ratios of Hardness

4.17 OPTIMAL DESIGN FOR HARDNESS

In this experimental analysis, the main effect plot in Figure 4.8 and estimate the mean Hardness. From the, Table 4.24 it is concluded that Higher hardness was observed when Coating Type Dycote was used and pouring temperature was kept at 775^0C and for cooling oil cooling was used during casting because these decrease variation.

Table 4.24 Significant Factors and Their Levels

Factor	Affecting mean		Affecting variation	
	Contribution	Best level	Contribution	Best level
Pouring Temperature, A	significant	Level 3 (775^0C)	significant	Level 3 (775^0C)
Injection Pressure, B	Insignificant	-	Insignificant	-
Coating, C	significant	Level-3, (Dycote)	significant	Level-3, (Dycote)
Cooling, D	significant	Level 3 (Oil)	significant	Level 3 (Oil)

Estimating the mean

Mean value for Hardness

$$\mu_{A_3C_3D3} = \overline{A_3} + \overline{C_3} + D_3 - 2\overline{T}$$

$$=104+102.66+102 - 2*101.5=105.66\text{HRN}$$

Confidence Interval around the Estimated Mean

Confidence Interval around the estimated hardness mean

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}}$$

Where $F_{\alpha v_1 v_2} = F\ ratio$

$\alpha = risk$ (0.05) $confidence = 1-\alpha$

$v_1 = dof\ \ for\ mean\ which\ is\ always = 1$

$v_2 = dof\ \ for\ error = v_e$

n_{eff} = Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1+dof_{B,C}} = \frac{9}{1+2+2} = 1.8$$

$$CI_1 = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}} = \sqrt{\frac{0.987\times 5.458}{1.8}} = 1.7299$$

So, the confidence interval around the hardness is given by 105.66±1.7299 HRN.

CHAPTER 5 ANALYSIS OF MICROSTRUCTURE

5.1 INTRODUCTION

LM 24 has an excellent die soldering property. The aluminium-silicon alloys possess exceptional casting characteristics; LM24 aluminium alloy is better than LM 6 aluminium alloy in terms of anti -soldering. We also see the microstructure of LM 6 material to differentiate between the properties of both these materials. We compare the microstructure of real life product used by P.S.P.C.L, Punjab with our product which is LM 24. Microstructure of all the finished samples of LM 24 and one sample of LM 6 are shown below:

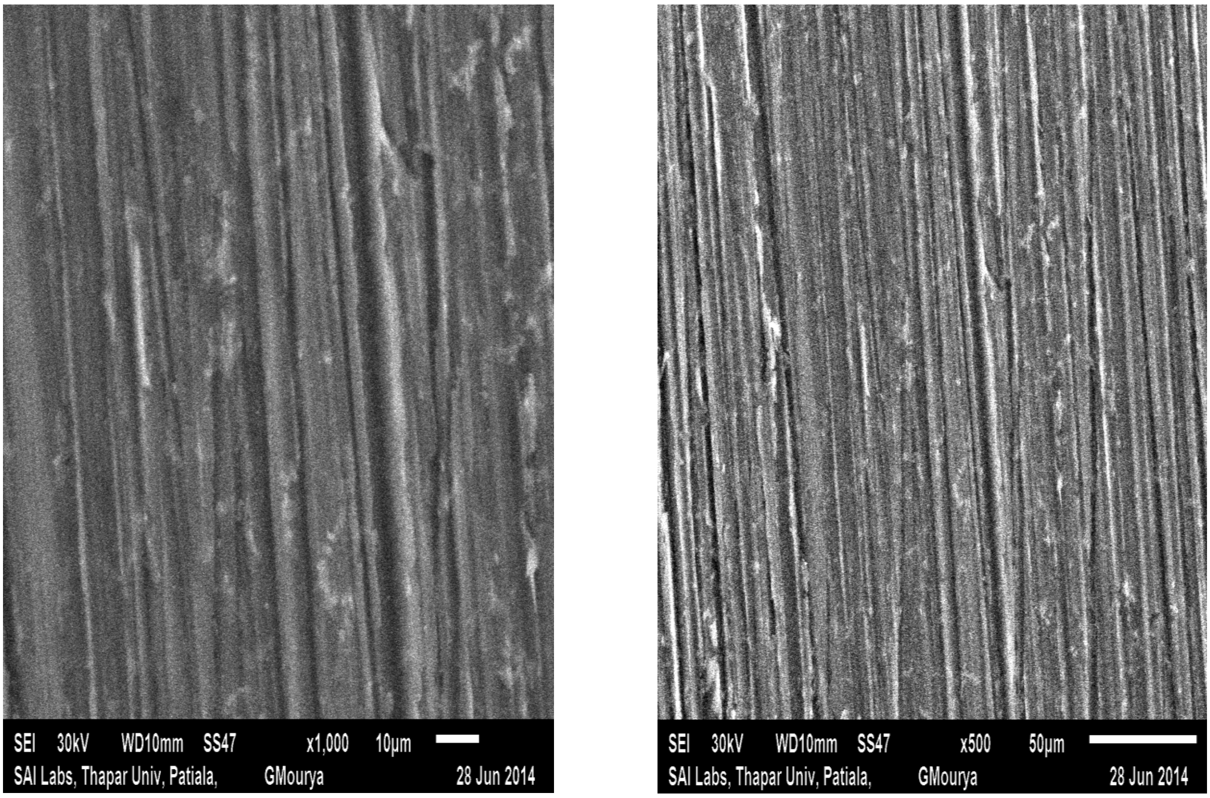

Figure 5.1 Microstructure of LM24, Pouring temp 725^0, Injection pressure 170 Kg/cm^2, Oil+graphite coating, Air cooling

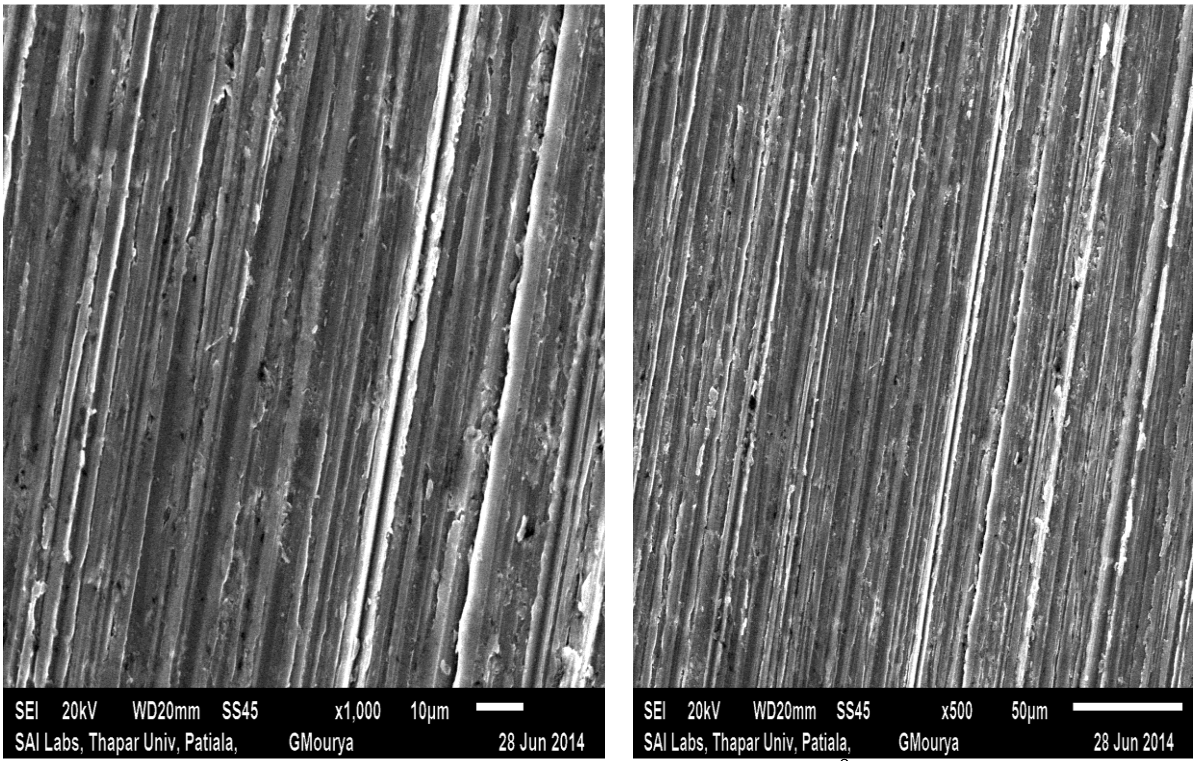

Figure 5.2 Microstructure of LM24, Pouring temp 750^0, injection pressure 180 kg/cm^2, Dycote+ graphite coating, Water cooling

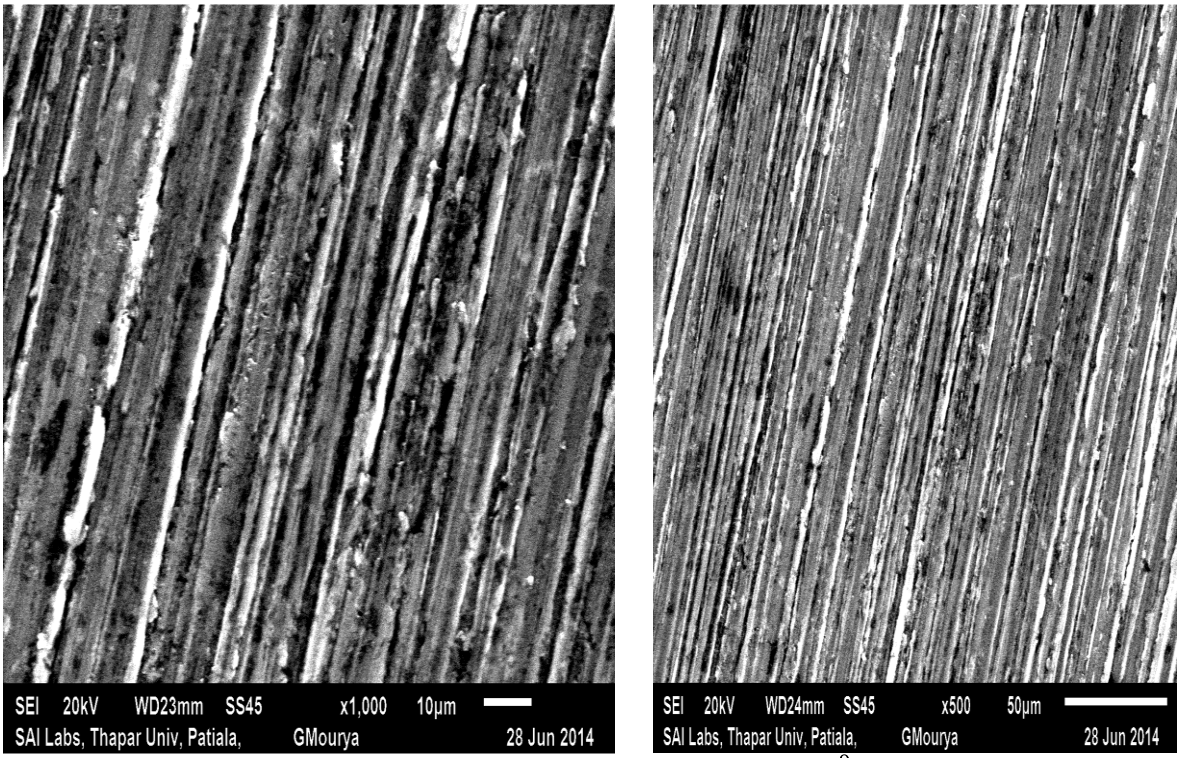

Figure 5.3 Microstructure of LM24, Pouring temp 775^0, injection pressure 190 kg/cm^2, Dycote, Oil cooling

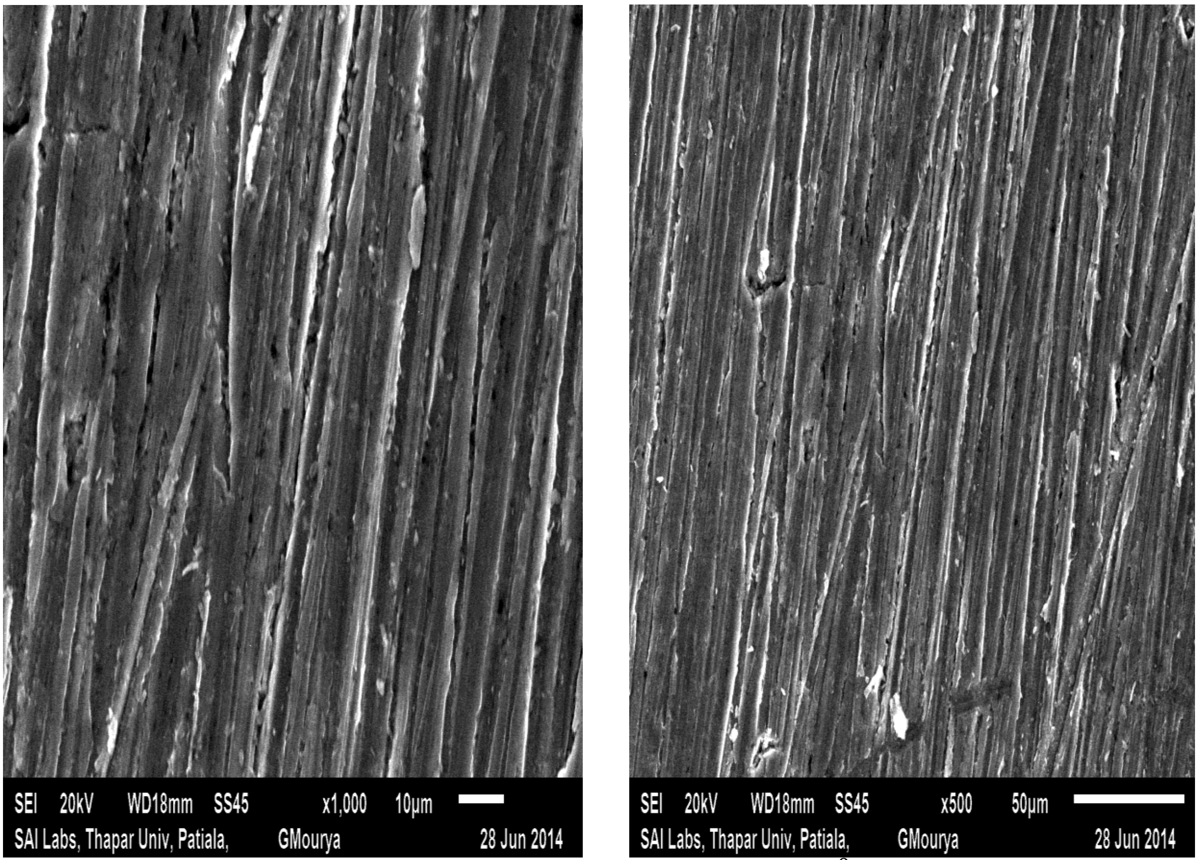

Figure 5.4 Microstructure of LM24, Pouring temp 750^0, injection pressure 170 kg/cm^2, Dycote+ graphite coating, Water cooling

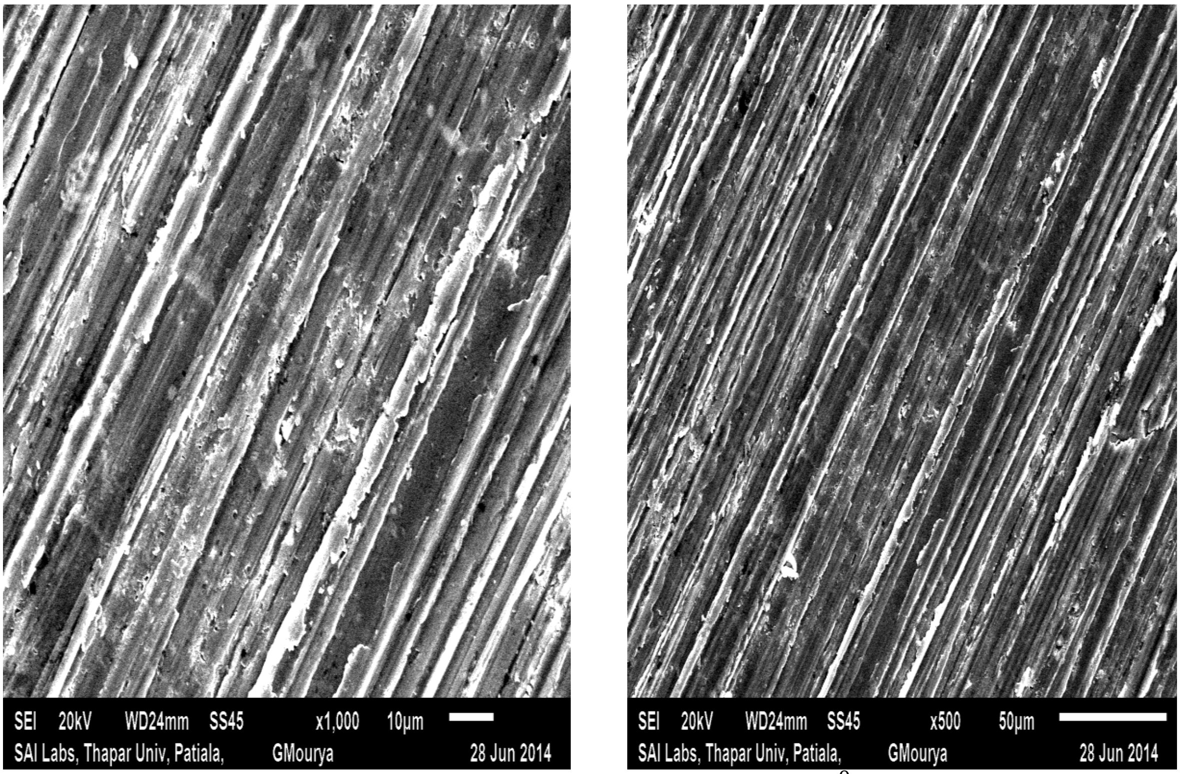

Figure 5.5 Microstructure of LM24, Pouring temp 775^0, injection pressure 180 kg/cm^2, Dycote, Oil cooling

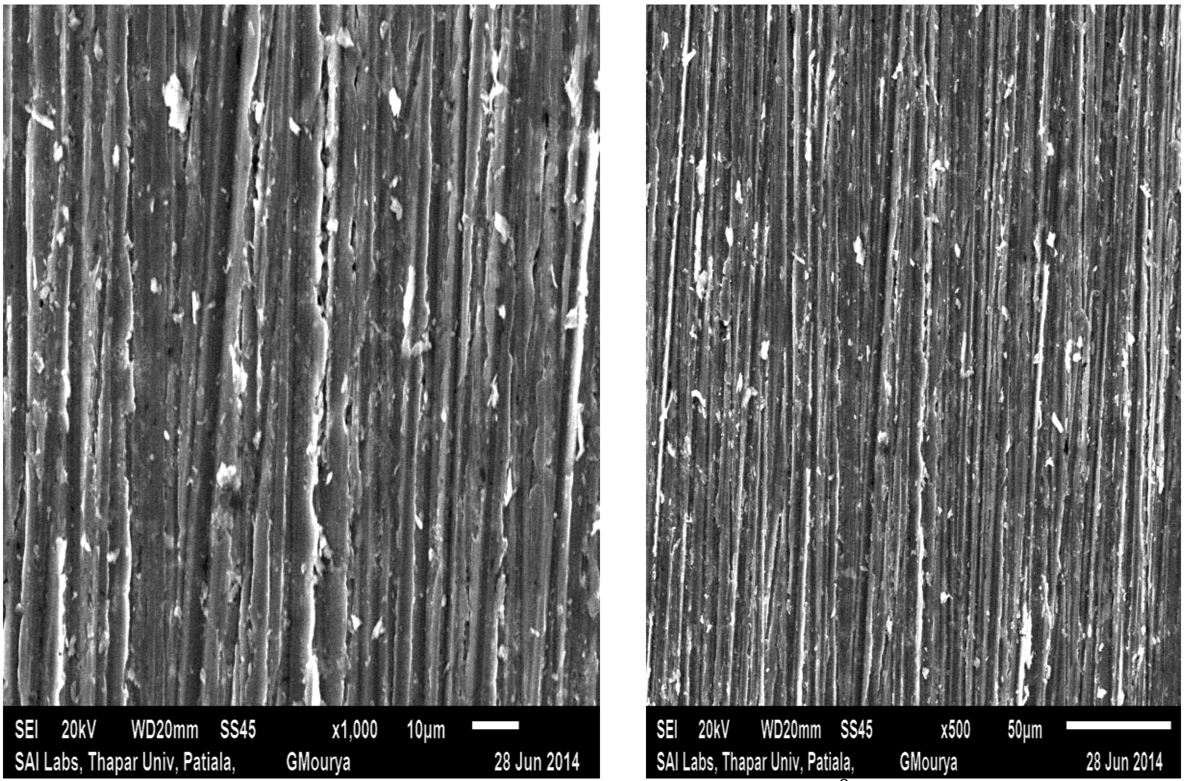

Figure 5.6 Microstructure of LM24, Pouring temp 725^0, injection pressure 190 kg/cm^2, Oil+ graphite coating, Air cooling

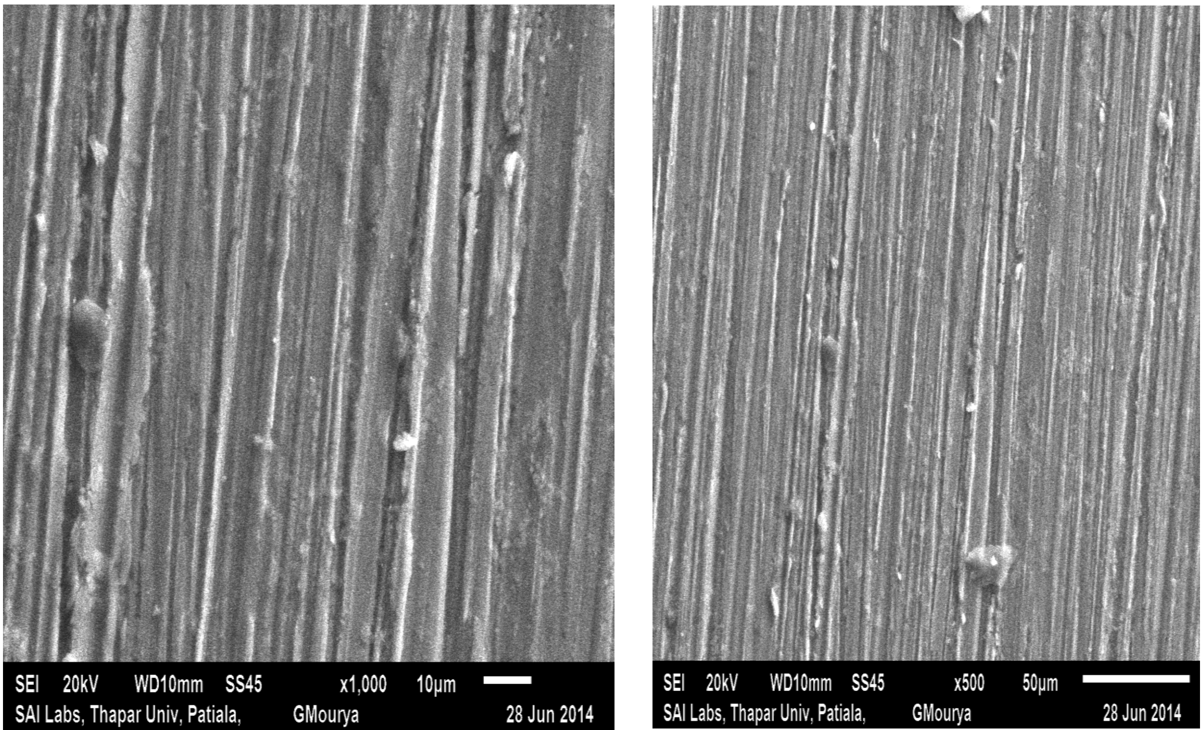

Figure 5.7 Microstructure of LM24, Pouring temp 775^0, injection pressure 170 kg/cm^2, Dycote, Oil cooling

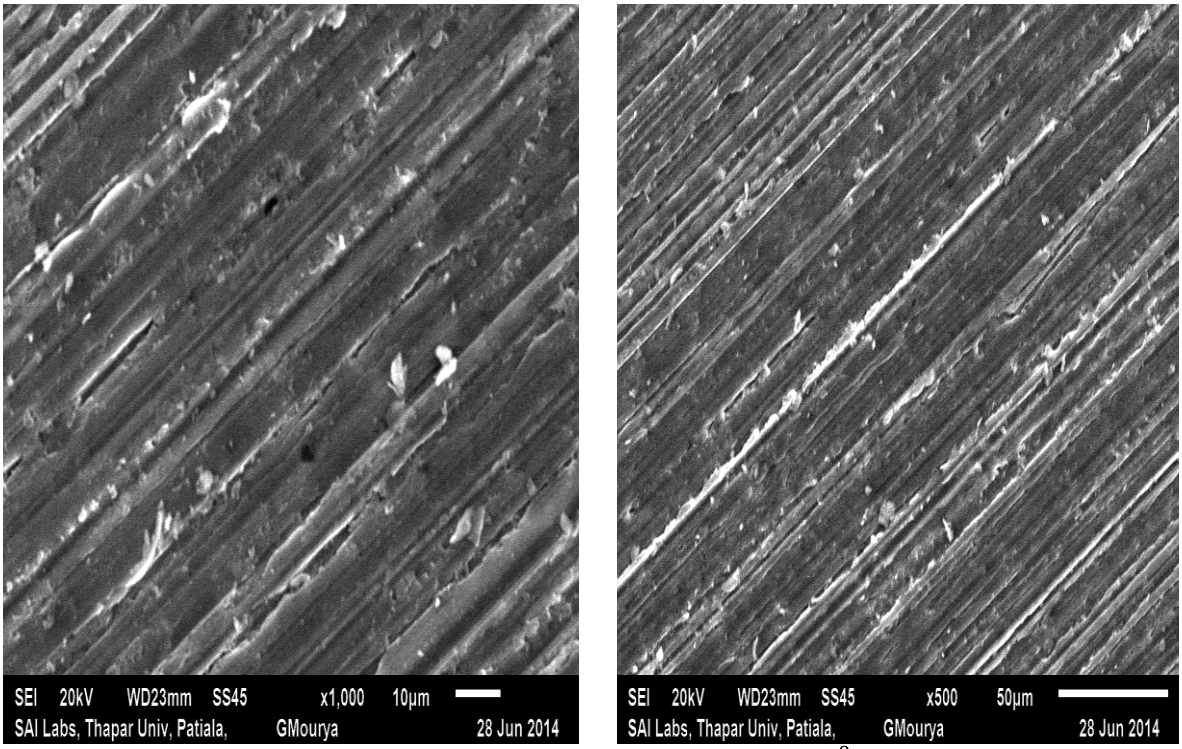

Figure 5.8 Microstructure of LM24, Pouring temp 725^0, injection pressure 180 kg/cm^2, Oil+ graphite coating, Air cooling

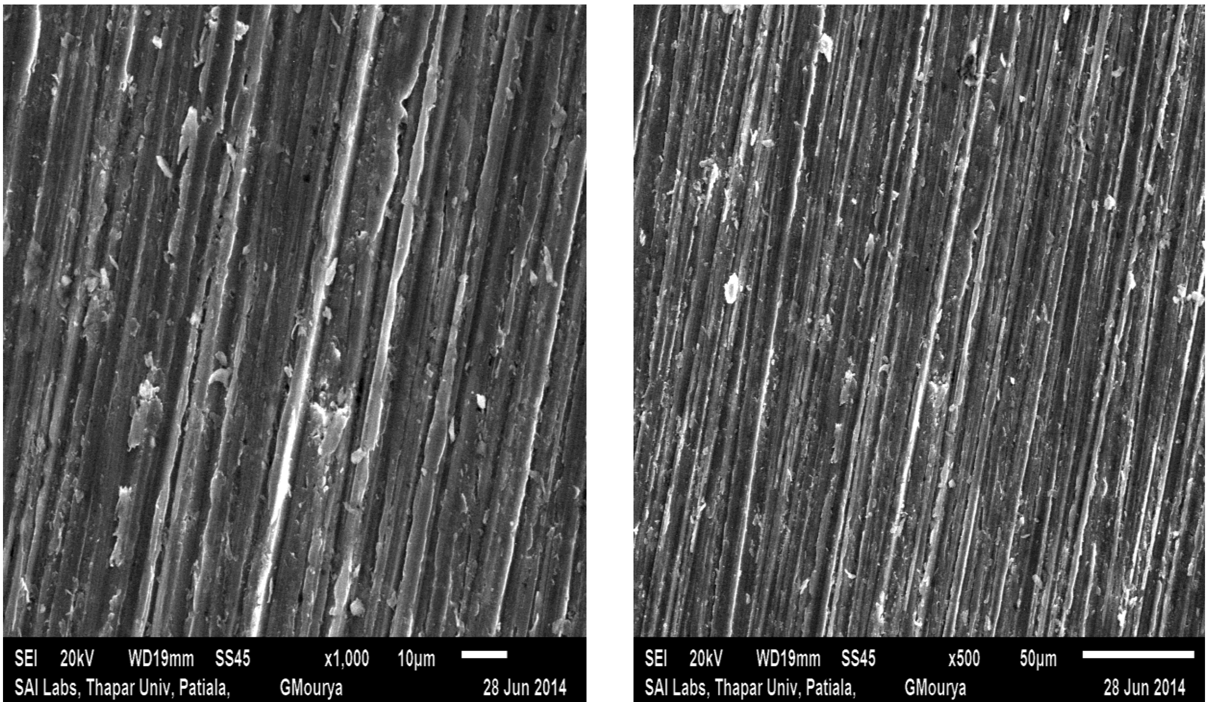

Figure 5.9 Microstructure of LM24, Pouring temp 750^0, injection pressure 190 kg/cm^2, Dycote+ graphite coating, Water cooling

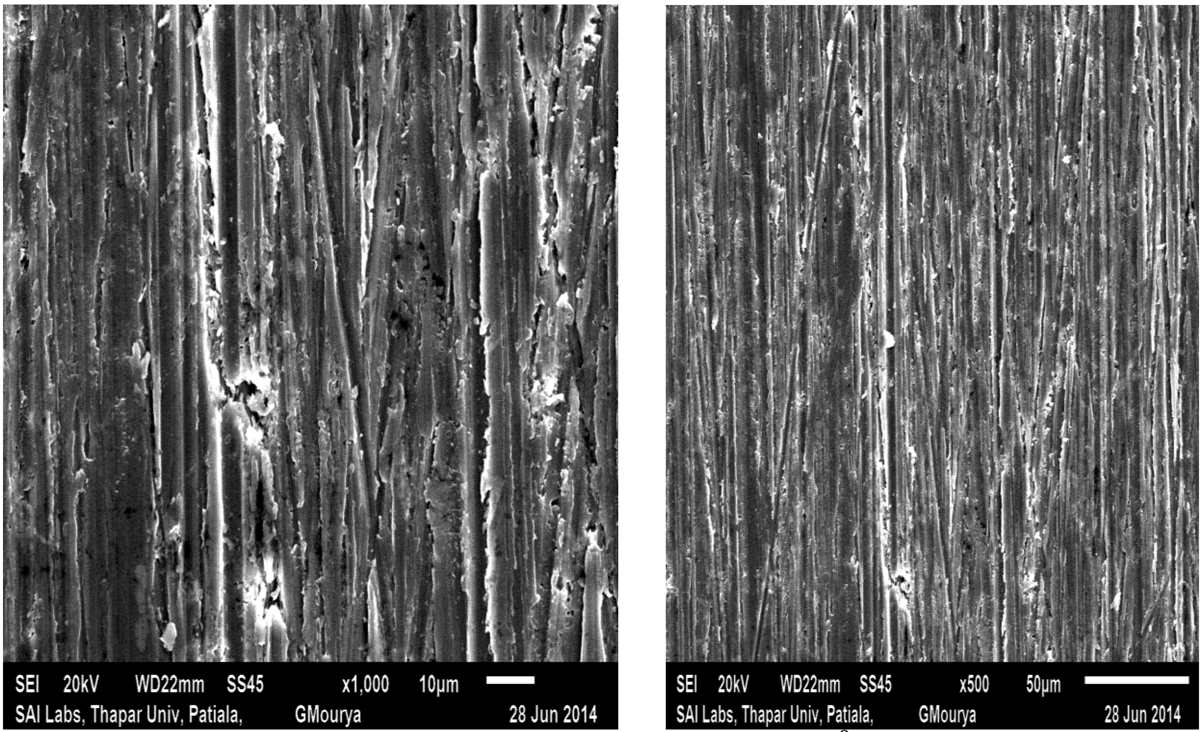

Figure 5.10 Microstructure of LM6, Pouring temp 750^0, injection pressure 150 kg/cm^2, Dycote coating, Air cooling

5.2 MICROSTRUCTURE ANALYSIS

Microstructure of die cast components made aluminium LM24 aluminium alloy has been investigated by means of JSM-6510LV Scanning Electron Microscope available at Sophisticated Analytical Instrumentation labs, Thapar University, Patiala, and Punjab. The effects of parameters i.e. thermal characteristics (temperature of the molten metal), the injection pressure of the molten metal, type of coating (oil coating, oil + graphite coating, and dycote coating) on the microstructure of the cast product were observed on each of 9 experiments. The metallographic specimens were polished in usual manner with final polishing being carried out by hand and they were etched in aqueous solution containing 2.5%HNO_3, 1.5 % HCL and 1% HF acid (etched with Keller's reagent) for about 20 seconds. It is clear from fig 5.1 to 5.9 that the particle size of the alumina is very fine. From the fig it is easily detected that the distribution of the particles is almost uniform by comparing the above micrograph. It was analysed that the microstructure of LM24 is finer than the microstructure of LM6. The effect of pressure is clearly shown in the above all microstructures. When we see the microstructure of LM6 then one thing is totally clear that the injection pressure is increasing then the porosity will also increasing. At the injection pressure of 170 kg/cm^2 then the porosity is more and 180 kg/cm^2 porosity is less as compared to previous. The LM24 alloy used for the experimental analysis was having 2% sodium. The structural modification of the alloy was done because of the presence of sodium. It has been investigated from the previous studies that the addition of sodium or strontium to the melt results in modification due to change of eutectic silicon from plate like fibrous form.

CHAPTER 6 RESULTS AND CONCLUSIONS

6.1 RESULTS

The effect of various input parameters i.e. thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (dycote+graphite coating, oil + graphite coating, dycote coating), and the type of cooling (air cooling, water cooling and oil cooling) were evaluated using ANOVA and factorial design analysis. The purpose of the ANOVA was to identify the important parameters in prediction of surface roughness, density and hardness. Some results consolidated from ANOVA and plots are given below:

6.1.1 Impact Strength

ANOVA analysis showed that Cooling (F value 6.54547) was the only factor that significantly affects the impact strength. All other factors, namely, pouring temperature, Injection pressure and coating were found to be insignificant.

For S/N ratio of impact strength at 95% confidence interval Other than pouring temperature, all other factors, namely coating, cooling and injection pressures were found to be significant in affecting impact strength. According to F-test, Cooling was observed to be the most significant factor affecting the impact strength.

It is concluded that Highest impact strength was observed when cooling type Oil is used and pressure was kept at 180 kg/cm^2 .In S/N ratio highest impact strength was observed when coating type dycote was used and pressure was kept at 190 kg/cm^2. The best value impact strength was observed with the 95% confidence level was 3.676 ±1.6342 micron.

6.1.2 Surface roughness

ANOVA analysis showed that injection pressure (F value 9.55395) was the only factor that significantly affects the surface roughness. All other factors, namely, pouring temperature, coating and cooling were found to be insignificant.

ANOVA results for S/N ratio of surface roughness at 95% confidence interval. Other than cooling, all other factors, namely coating, pouring temperature and injection pressures were found to be significant in affecting surface roughness (R_a).

It is concluded that lowest roughness was observed when injection pressure was kept at 190 kg/cm^2 .In S/N ratio lowest roughness was observed when injection pressure was kept at 190 kg/cm^2, and cooling type air cooling was used as they reduce the variation and improve the surface finish. The best value of surface roughness was observed with the 95% confidence level is 0.3366±1.066 micron.

6.1.3 Density

ANOVA table shows that injection pressure (F value (35.541) is the only factor that significantly affects the density. All other factors, namely, Pouring temperature, Coating and cooling type were found to be insignificant.

ANOVA results for S/N ratio of density at 95% confidence interval. Except injection pressure all other factor namely Coating, Cooling and Pouring temperature are found to be insignificant. According to F-test injection pressure was observed to be the most significant factor affecting the density, followed at small level by temperature 775^{0}C.

It is concluded that highest density was observed when injection pressure was kept at 190 kg/cm^2 and Pouring temperature 775^{0}C is used. The best value for the density was observed with 95% confidence level is 2.697±0.0509 g/mm^3.

6.1.4 Hardness

ANOVA table shows that coating (F value 16.926) and cooling (F value 6.9568) are the factor that significantly affects the hardness, whereas pouring temperature and Injection pressure factor was found to be insignificant.

ANOVA results for S/N ratio of hardness at 95% confidence interval. Except pouring temperature and injection pressure, all other factors are significant. According to F-test coating was observed to be the most significant factor affecting the hardness, followed by cooling according to F-test. It is concluded that Higher hardness was observed when Coating Type Dycote was used and pouring temperature was kept at 775^{0}C and for cooling oil cooling was used during casting because these decrease variation. The best value of hardness was observed with 95% confidence level is 105.66±1.7299HRN.

6.2 Conclusions

LM 24 aluminium alloy was experimental studied by cold chamber die casting machine which is available at D-217 Focal point, Patiala, Punjab. The real life product of P.S.P.C.L, Punjab. Which is made from LM6 and compare with LM24 aluminium alloy. Entire data is taken from [23] and compare that data with my experimental study.

1. Dycote coating was increased the hardness as compared to dycote + graphite coating and oil + graphite coating.

2. Oil cooling was also increased the hardness.

3. As we increase the injection pressure density will increase and the density value of LM 24 is greater than LM6.

4. LM24 aluminium alloy is cheaper than LM6 aluminium alloy.

5. Surface finish, Hardness, Impact strength of LM24 is extremely good as compared to LM6.

6. It was concluded that the high injection pressures was most prominent in casting of aluminium alloys and Water cooling is least preferred from oil cooling and air cooling.

7. It was concluded from the microstructure analysis, the crack propagation was observed in some samples which have low injection pressure i.e. pressure also affects the microstructure of LM24. Porosity of LM24 was less as compared to LM6 at the same pressure conditions because pressure mainly affects the porosity of the aluminium alloy

8. As per the above data of LM24 and LM6, I recommend to use the LM24 instead of LM6 to D-217 focal point, Patiala, because I got better results in favor of LM24.

6.3 SCOPE OF WORK

Aluminium alloy has wide number of applications in marine, aerospace, automobile and so many manufacturing industries, but still not so much work is done on its properties with different process parameters. A vast study should be done to analyze the properties of aluminium alloy by varying the process parameters like injection pressure, pouring temperature, cooling type and coating type and so much work can be done to enhance the properties of aluminium alloys from addition of different metals like copper, iron, bismuth, strontium etc. Die design may also contribute significant effect on process parameter by providing multiple channels for pouring and pressurizing the metal into the die, this may effect evenly distribution of molten metal into the die and can result in better material characteristic.

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