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DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF MULTIPLE CASTING MACHINE

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Abstract
Design and development of a new casting machine which performs the various casting techniques are presented. It may be noted that during solidification, crystal structures form in every fraction of a second and hence the time taken for solidification, plays an important role in the casting. There should not be any time delay in the transport of molten metal to the mould. Even with a slight delay, solidification may occur before the metal reaches the mould. Due to this, mechanical properties get affected significantly and hence resulting in defects. Therefore, it is necessary to manage time required to transport the molten metal. The complex casting machine has been designed to perform the following techniques: gravity casting, stir casting, squeeze casting, vacuum casting, compocasting and thixoforming. All these casting techniques have been integrated into this complex casting machine as different units which work with the help of automation. Especially this machine designed for Low melting point light metals such as; Al, Cu, and Mg etc. are melted in this furnace by heating up to 1000°C. The particle preheating chamber (1000°C) is also integrated in this machine. This machine is newly designed for multipurpose casting methods and is very helpful to improving all the mechanical properties of materials.

Keywords: Design, Construction, Multiple casting machine, Compo Casting operation.

1. Introduction

The present need for light weight materials with high strength and high stiffness have attracted much interest in the development of metal matrix composites. For this purpose a multipurpose casting machine is designed in this work. The equipment comprises of high temperature electric furnace, stirrer arrangement, stainless steel pot with bottom pouring for melting the materials, squeeze casting and vacuum casting arrangements.In stir casting technique, the non-wettability or floating or settling of particles can be avoided. The squeeze assisted die casting reduces the amount of entrapped air or gas in the die cavity. Vacuum assisted die casting reduces the amount of entrapped air or gas in the die cavity thus the size of the porosity was reduced mainly.

2. Literature Review

According to Nwankwojike [1], a portable soap stamping and tableting machine was designed, fabricated and tested for all categories of small scale soap producers. This machine which cuts and stamps soap tablets simultaneously, reduced drudgery and risks involved in small scale soap production and also its low cost of production. Achi [2] designed a axis control system of an NC milling machine which employs a small stepping motor to digitally actuate hydraulic piston cylinder servo drives existing on the machines is described. The digital control designed in this study was practically tested and found to be a linear servo, thus making it suitable for economic control from a computer.

Squeeze and gravity casting techniques have been used to analyze tensile and wear properties of aluminium composites [3]. It was identified that there is a significant improvement in tensile strength and wear resistance. Logistic performance evaluation of squeeze casting technique has been used to analyze simulation of squeeze casting equipment [4]. It was identified that the utilization rate of feeding robot, take-out robot and spray device decreases with increase of cast’s curing time. The report on vacuum die casting technology to make design and verification of an auxiliary system [5], showed that mechanical vacuum valve that can achieve vacuum venting during the whole process with the response time of only 1.5 milliseconds. Porosity has been found to decrease significantly compared to the conventional die casting.

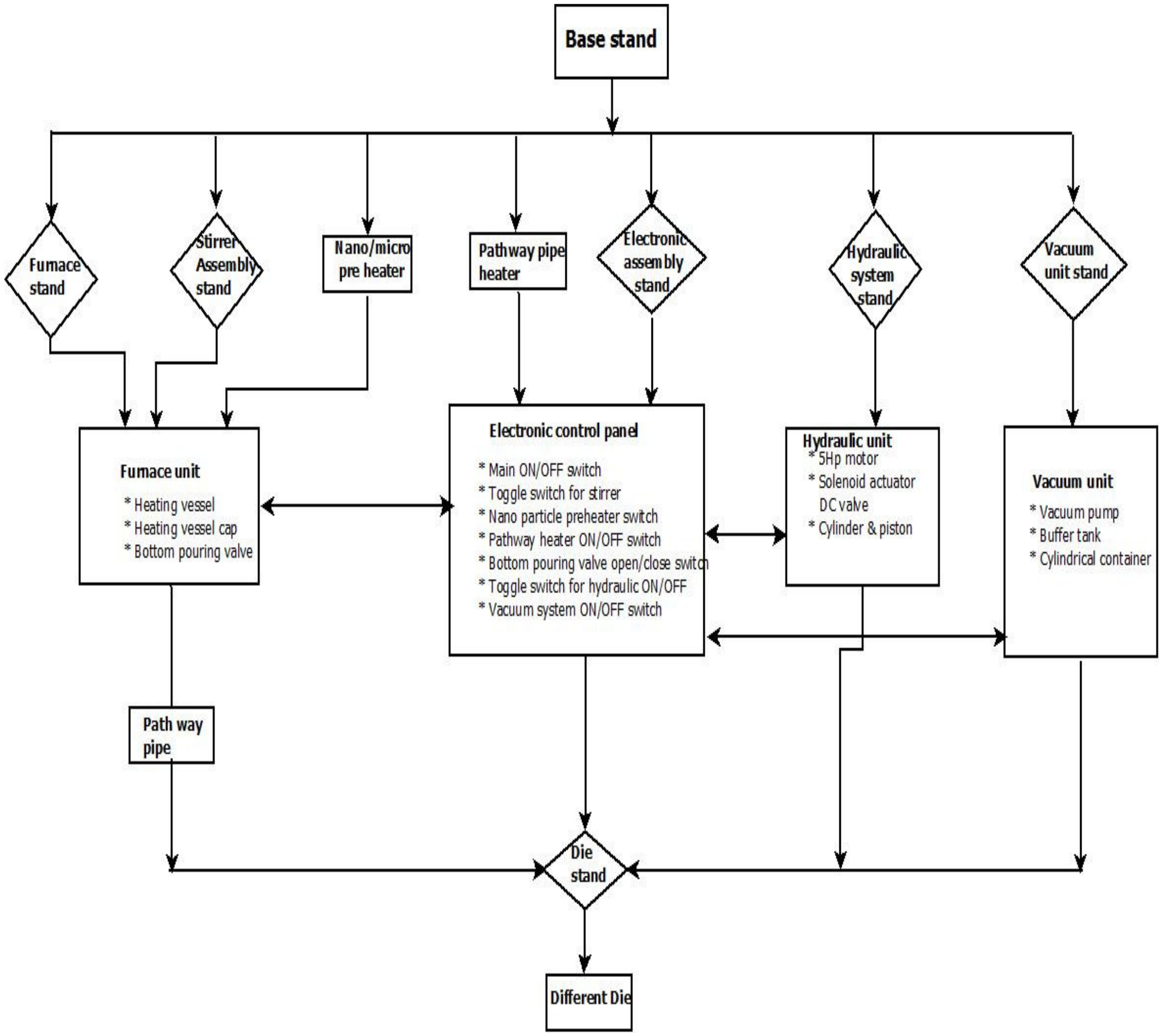


Figure 1: Block diagram of Complex casting machine.

A review of induction furnace [6] showed that by reducing the losses such as; scheduling of operations, molten metal delivery, preheating, no time delay in holding the molten metal helps to increase the efficiency. The following flow chart (figure 1) shows all the different casting techniques used in this machine. It shows the different casting machine components and sequence of operation for different casting processes.

Literature has shown that the design and prototype development of mini-electric arc furnace [7], the heating rate, melting rate, and electrode consumption rate are comparable to existing standard furnaces attaining a temperature of well over 1000°Cwithin an hour and melting time for the first charge is about 95 minutes. From the literature [8], stir cast components are shown with superior mechanical properties, fine microstructure and minimal porosity.

From the published works, it was identified the technology for electromagnetic stirring of aluminium reverberatory furnaces [9], the simplicity of design and the capital costs for installation of the equipment can be lower than a water-cooled stirring technology, with the solid design of the stirrer and specially designed control and drive system, low operating costs through low energy consumption can be achieved.

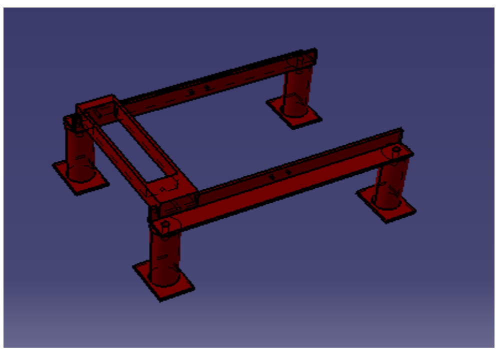
A study of published works showed that investigation of the dimensions design components for the rectangular indirect resistance electrical furnaces [10], the electrical, thermal and economical problems are involved. The literature [11] shown that the design of a coreless induction furnace for melting iron with high production rate, good heating efficiency and clean working environments.

Results on design and construction of an electrical furnace to fire ceramic product [12], the furnace has automation facility with efficiency of 77%. Report on rheocast and conventional gravity die casting techniques to make A356 Al alloy [13] showed that the rheocast alloy showed significant improvement in mechanical properties compared to conventional casting. The important challenges for design of complex casting machine with gravity casting, stir casting, squeeze casting, vacuum casting, compo casting and thixoforming are analysed in this study. In this machine, all the casted parts reduce the porosity and increase the density and mechanical properties. However, the present work elaborates the mechanical property changes in the casting part.

3. Materials and Methods

3.1 Design of different parts of the complex casting machine

The 3D solid model of the base stand component having length 710 mm, height 220 mm, and with 500 mm is shown in figure 2a. Similarly, the solid model of furnace stand length 1000 mm and width 410 mm and thickness 75 mm is shown in figure 2b. These two stands were made with mild steel. This base stand used for supporting the furnace.



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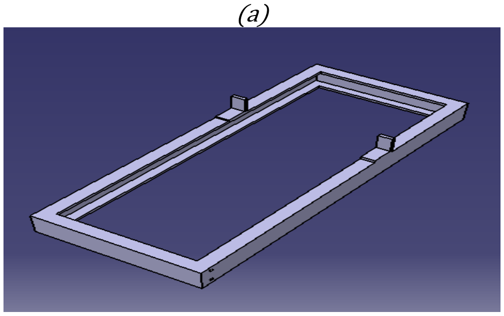

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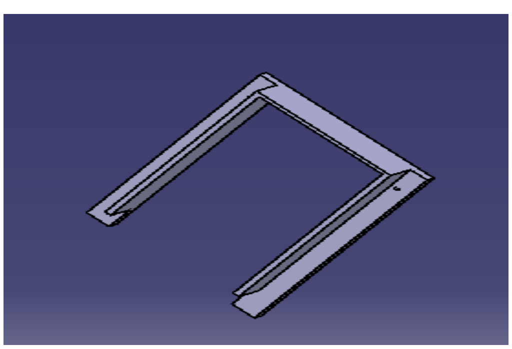
Figure 2: Supporting stands (a) base stand (b) furnace stand



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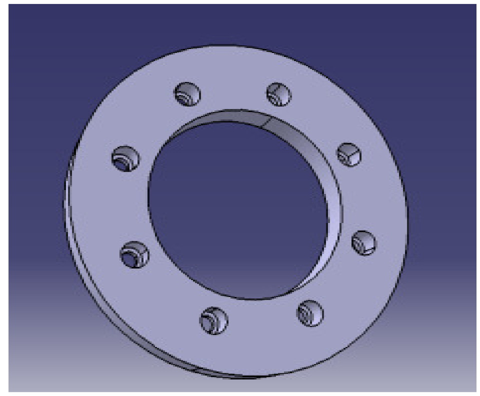

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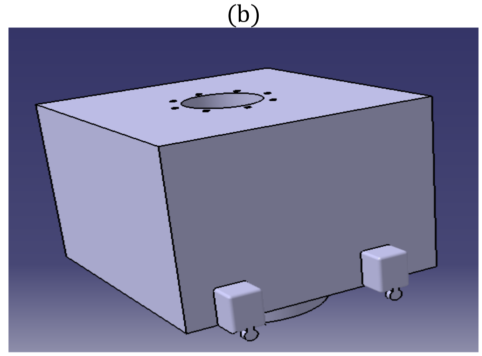

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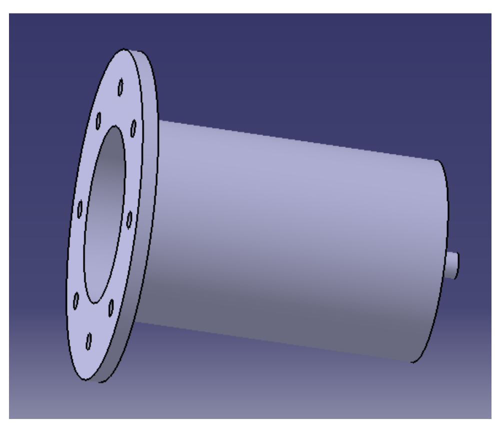
Figure 3: (a) Electronic assembly stand (b) Heating vessel cap (c) Electric furnace

The solid model of electronic assembly stand length 610 mm, width 310 mm and thickness 10 mm is shown in figure 3a. Heating vessel cap outer diameter 220 mm, inner diameter 115 mm, thickness 20 mm and 10 mm diameter holes in 8 numbers on the top of the vessel cap are shown in figure 3b. The electric furnace with length 406 mm, height 330 mm, and inner vessel diameter 115 mm is shown in figure 3c. These three components were made in mild steel. This electronic assembly stand is used for supporting the electronic control panel. The heating vessel cap is used for grip the heating vessel in centre axis of the furnace.



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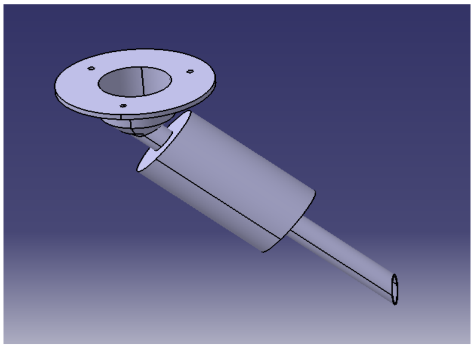
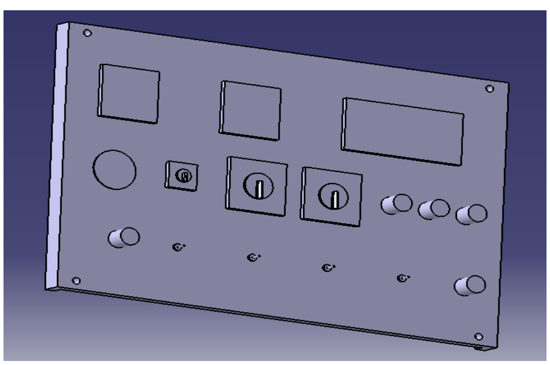


(b)

Figure 4:(a) Heating vessel (b) pathway channel with heater

The solid model of heating vessel having length 206 mm, outer diameter 116 mm and bottom pouring valve diameter 20 mm are shown in Figure 4a. The pathway channel pipe with length of 330 mm and diameter of pipe is 35 mm, with a heater length of 250 mm and diameter 150 mm in the heater. Pathway channel top cover of outer diameter 250 mm, inner diameter 116 mm and 10 mm diameter with three holes are shown in Figure 4b. These two components are made with AISI 310 grade heat resistant and corrosion resistant steel material. The vessel has been heated for producing the molten metal and pathway channel pipe with heater is used for transferring the molten metal into the die with constant temperature of liquid metal.



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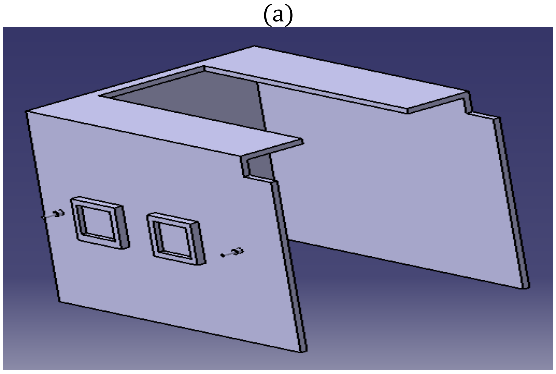


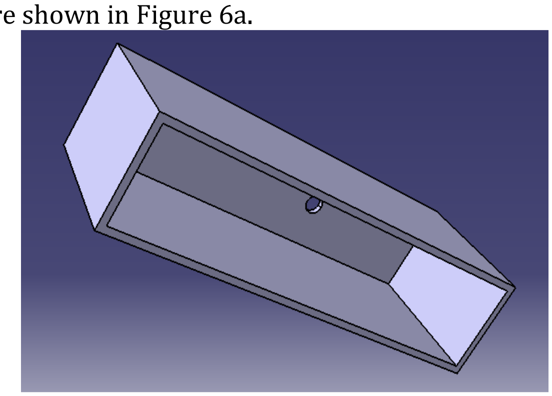
(b)

Figure 5: (a) Electronic assembly cover (b) Heater assembly cover

The solid model of electronic assembly cover with length 470 mm, width 310 mm, and thickness 10 mm is shown in Figure 5a. Numbers of control switches are connected in the electronic assembly cover are also shown in this figure. The heater assembly cover length 445 mm and length 370 mm, width 370 mm and centre hollow cap width 170 mm are shown in Figure 5b. These two components have made in mild steel. This electronic assembly cover is used to keep all the electronic control switches inside the cover. And also, the heater assembly cover is stayed the nano/micro particle preheating control switch and pathway channel pipe heater control switch.

3.2 Design of stir casting machine components

The solid model of stirrer assembly with cover length of 605 mm, width 150 mm, thickness 10 mm, height 230 mm and stirrer rod hole diameter 28 mm are shown in Figure 6a.



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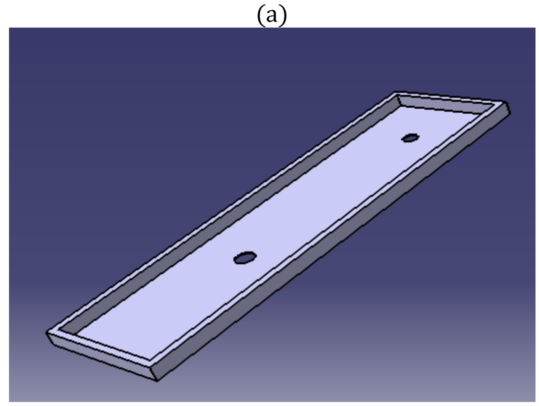

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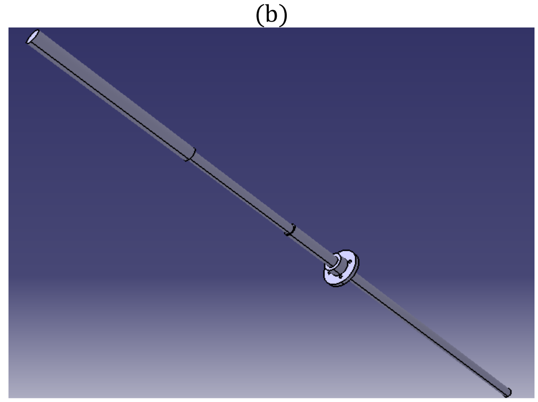

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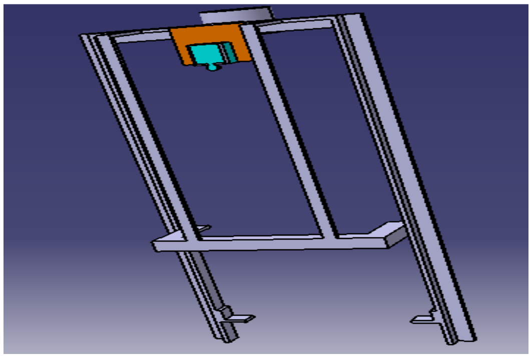
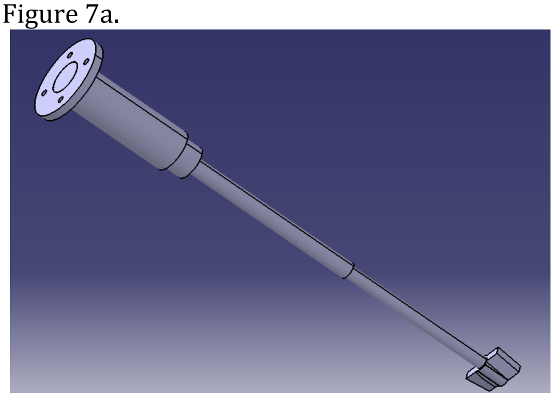


(d)

Figure 6: (a)Stirrer assembly cover, (b) Stirrer assembly bottom cover, (c) Screw rod (d) Stirrer assembly stand

The stirrer assembly bottom cover length is 625 mm, width 170 mm, thickness 22 mm. Stirrer rod hole diameter is 25 mm is shown in Figure 6b. Screw rod height 1660 mm, diameter vary from 25 mm to 30 mm are shown in Figure 6c. Figure 6d shows stirrer assembly stand with height 1190 mm, width 490 mm, thickness 40 mm. These four components are made of mild steel. This stirrer assembly cover for the purpose of keeping the stirrer motor and stirrer rod. Screw rod for up and down movement of stirrer rod into molten metal for mixing purpose and also stirrer assembly stand for supporting the stirrer assembly cover.

The solid model of stirrer rod with total length of 835 mm, diameter 15 mm and bottom of stirrer blade thickness 10 mm and blade height 32 mm are shown in Figure 7a.



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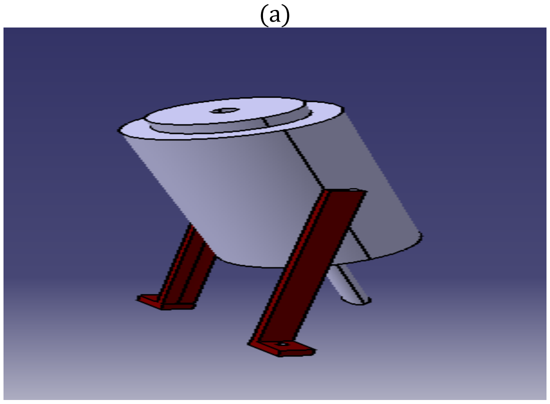

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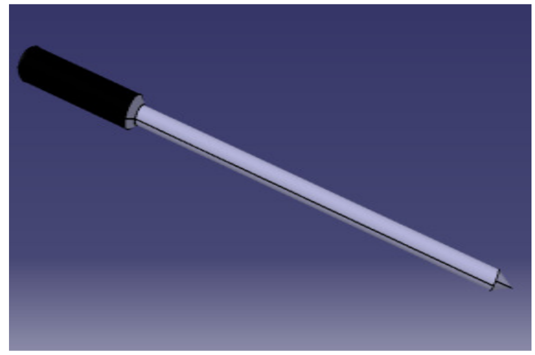


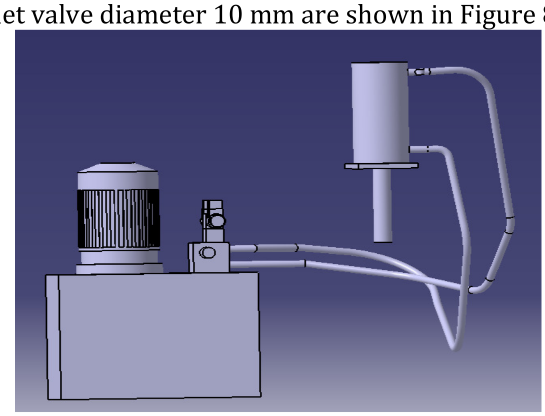
(c)

Figure 7: (a) Stirrer rod , (b) Nano particle pre heater ,(c) Particles push rod

The nano particle pre heater length 230 mm, diameter 440 mm, top cover diameter 100 mm, and centre push rod holes diameter 17 mm, bottom pipe channel diameter 17.5 mm and length 125 mm are shown in Figure 7b. The nano particle push rod wood handle length 110 mm and length of the rod 335 mm at the bottom of sharp angle at 60^{O} are shown in Figure 7c. These three components are made of AISI 310 grade heat resistant and corrosion resistant steel material. This stirrer rod is used for mixing purpose of liquid metal with solid nano particles. Nano particle pre heater is used for heating the nano particle at different temperature and nano particle push rod is used to push the heated nano particle into liquid metal with uniform flow of nano solid particles are shown in Figures 7b and 7c.

3.3 Design of squeeze casting machine components

The solid model of hydraulic system with cylinder of length 300 mm, diameter 140 mm, squeeze piston length 350 mm, and piston diameter 46 mm, and also tank length 501 mm, height 370 mm, width 300 mm are shown in Figure 8a with a hydraulic pressure variation from 0-100 Tone. The split die length of 270 mm, width 110 mm thickness 260 mm and 6 numbers clamping holes diameter 10 mm are shown in Figure 8b. The cooling die length 260 mm, outer diameter 110 mm, inner diameter 46 mm, water inlet valve diameter 10 mm are shown in Figure 8c.



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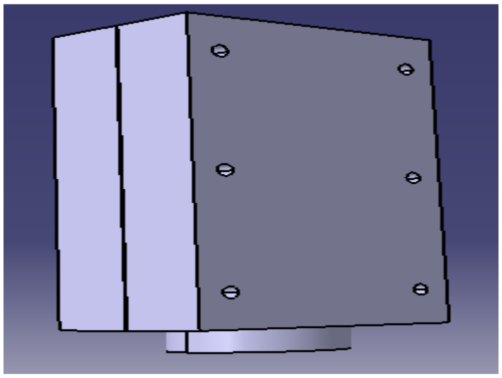

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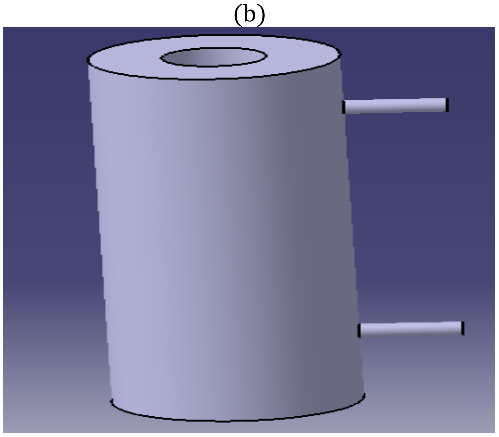

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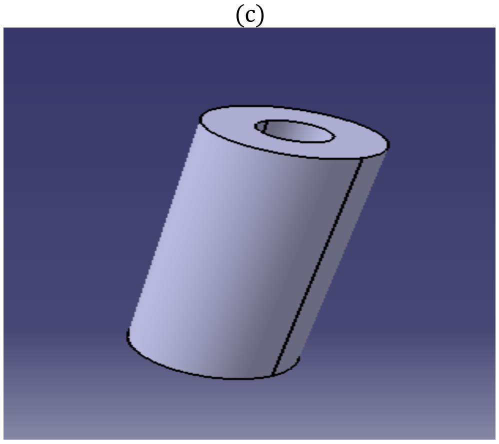

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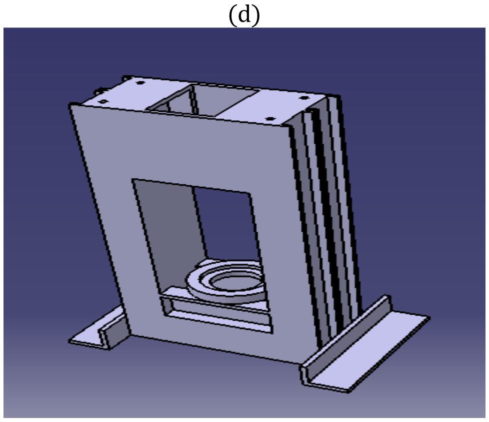


(e)

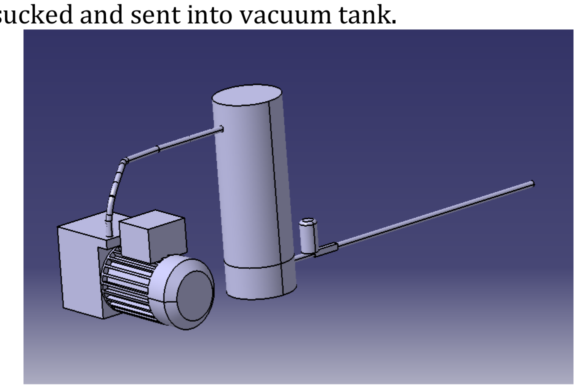
Figure 8: (a) Hydraulic system, (b) split die (c) Cooling die,(d) without cooling die (e) Die and squeeze cylinder stand

Without cooling die of length 260 mm, outer diameter 110 mm, inner diameter 46 mm is shown in Figure 8d. Die and squeeze cylinder stand length 300 mm, height 690 mm, thickness 130 mm, centre hollow slot length 130 mm, width 105 mm are shown in Figure 8e. The split die, cooling die and without cooling dieare made of die steel material, mild steel material and stainless steel material respectively.

The split die is used for casting parts without coating and sticking the from the die cavity. The cooling die after squeezing the solidified molten metal cannot come out easily from the mould die because of thermal expansion of die. That is why cooling water is circulated around the die cavity. This cooling effect improves the mechanical properties. The die and squeeze cylinder stand are made up of mild steel. This stand is to keep and grip the die for different casting technique.

3.4 Design of vacuum casting machine components

The solid model of vacuum unit cylinder of height 310 mm, diameter 120 mm and copper hose length of 430 mm, diameter 10 mm are shown in Figure 9a. Vacuum die height 260 mm, outer diameter of die 110 mm and inner diameter of die 46 mm are shown in Figure 9b. The vacuum tank is made of stainless steel and vacuum split die is made of AISI 310 grade heat resistant and corrosion resistant steel. When vacuum pump is run, the air from the vacuum die is sucked and sent into vacuum tank.



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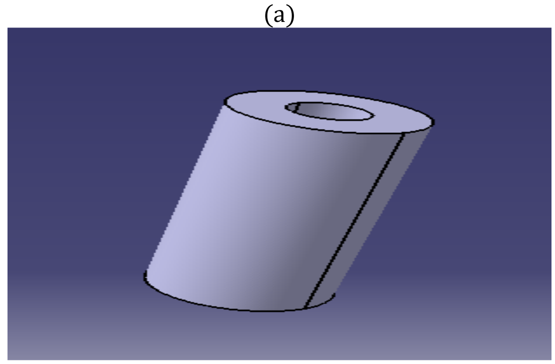

(b)

Figure 9: (a) Vacuum unit (b) Vacuum die

The split die after solidification of molten metal can be easily split and removed from the die.

4.0 Parts list of complete complex casting machine

The following Tables 1 – 3 shows the lists the complete components involved for design of the complex multipurpose casting machine.

Table 1: Assembly of furnace and control panel parts

Sl.No.	Name of the component	Material	Quantity
1	Base stand	Mild steel	1
2	Furnace stand	Mild steel	1
3	Electronic assembly stand	Mild steel	1
4	Vessel top cover	Mild steel	1
5	Electric furnace	Mild steel	1
6	Heating vessel	310 steel	1
7	Pathway channel with heater	310 steel	1
8	Electronic assembly cover	Mild steel	1
9	Heater assembly cover	Mild steel	1

Table 2: Stirrer and pre heater assembly parts

Sl.No.	Name of the component	Material	Qty
10	Stir assembly cover	Mild steel	1
11	Stir assembly bottom cover	Mild steel	1
12	Screw rod	Mild steel	1
13	Stirrer assembly stand	Mild steel	1
14	Stir rod	310 steel	1
15	Nano particle pre heater & injector	310 steel	1
16	Nano particle push rod	310 steel	1

Table 3: Squeeze and vacuum casting assembly parts

Sl.No.	Name of the component	Material	Quantity
17	Hydraulic system	Mild steel and 310 steel piston	1
18	Split die	Die steel	1
19	Cooling die	Mild steel	1
20	Without cooling die	Stainless steel	1
21	Die and squeeze cylinder stand	Mild steel	1
22	Vacuum unit	Mild steel	1
23	Vacuum die	310 steel	1

5.0 Assembly of complex casting machine

The figure 10 shows the assembled view of the multipurpose casting techniques machine and the corresponding parts numbers with its materials used for design the machine are listed in Tables 1 – 3.

6. Main specifications the complex machine

The major specifications of the machine are
Capacity of the melting pot: 3.6 kg (max)
Operating temperature : 1000° C.
Temperature indication: Digital Display by electronic Indicator
Pressure and Stir speed indication: Digital Display by electronic Indicator
Temperature Control: Electronic ON/OFF type temperature controller.
Operating Voltage: 440 V. AC three Phase 50 c/s.
Power consumption: 7.5 KW for furnace and 5 KW for motors

6.1 Design analysis and calculations

1. Stirrer speed

Rotation is sensed by micro controller through proximity switch mounted near the stirrer shaft. Rotation every second is multiplied for minute and indicated in digital display. It's speed varies from 0 - 2000 rpm

2. Die design

Material of the die= Mild steel/ Die steel/ Stainless steel
Die height = 260 mm
Die diameter = 46 mm
Volume of die (v) = $\pi/4 \times D^2 \times h$ = 432.09 cm^3

3. Nano particle pre heater design

Material of the pre heater = AISI 310 grade heat and Corrosion resistant steel material
Preheater length = 170 mm
Preheater diameter =46 mm
Volume of preheater (V) = $\pi/4 \times D^2 \times h$ = 282.5 cm^3

4. Heating vessel design

Material of the vessel= AISI 310 grade heat resistant and corrosion resistant steel
Length of the vessel = 160 mm
Diameter of the vessel = 105 mm
Volume of vessel (V) = $\pi/4 \times D^2 \times h$ = 1385.44 cm^3

5. Pressure

Ram area = 280 cm^2
Load = 100800 Kg
Pressure applied = 100800/280 = 360 kg/cm^2 = 35.31 MPa

6. Vacuum pump

Maximum capacity = 760 mm of Hg=101396 N/m^2 =1.013 bar (vacuum pressure)
Before pouring the molten metal, run the vacuum pump and create vacuum up to 700 mm of mercury. This will continue for 1 or 2 minutes. During this vacuum condition the molten metal is poured into the die, allowed to solidify and take out casting part from the split die.

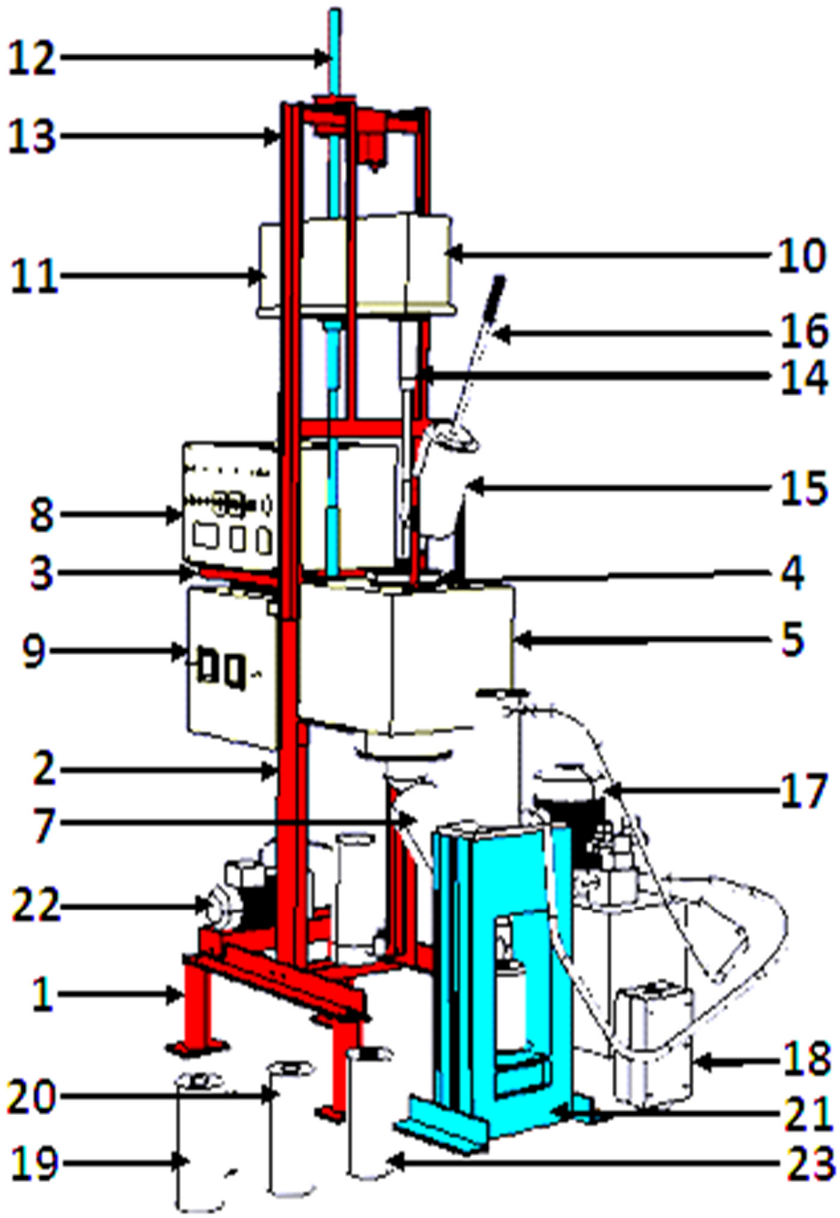

Figure 10: Assembled view of the complex machine.

6.2 Salient features of the casting machine

- Stir cast the aluminium, magnesium and copper at various speeds (0-2000 rpm).
- Cast the aluminium, magnesium and copper at various pressures (0-100 Ton).
- Cast the aluminium, magnesium and copper in vacuum condition.
- Cast the aluminium, magnesium and copper by gravity casting, compo casting, thixoforming etc.
- Cast the aluminium, magnesium and copper with all the above combinations by varying the stirring speed under different pressure, under different vacuum conditions and changing the different die.

7. Conclusions

1. In this study, the design and fabrication of complex casting machine (gravity casting, stir casting, squeeze casting, vacuum casting, compo casting, and thixoforming) were successfully designed for the light materials like aluminium, magnesium and copper to melt and obtain higher mechanical properties for the cast part.
2. The conventional gravity casting often contains internal structural defects such as oxide and gas entrapment, shrinkage and porosity that lead to poor mechanical properties. In this design, the molten metal has been poured into the die with constant temperature before the crystal growth starts. Because, the furnace and the die are

connected through the pathway channel pipe heater.

3. Using this gravity casting technique, the volume of gas porosity was significantly reduced and the size of the porosity was considerably smaller.
4. In squeeze casting process the molten metal is cooled and solidified at a very high level of pressure. The time required for solidification is substantially reduced due to enhanced heat transfer at the mould surfaces under high pressure that leads to higher mechanical properties compared to other casting techniques.
5. After pouring the molten metal in to the mould, it has been immediately squeezed with constant pressure. This machine pressure capacity can be changed and set to any value from 0 to 100 Tons. The same piston is used to remove the cast part from the die.
6. The result of cast components demonstrates that, the squeeze assisted die casting reduces the amount of entrapped air or gas in the die cavity. The volume of gas porosity was significantly reduced and the size of the porosity was reduced mainly.
7. In stir casting machine, the nano particle pre-heater attached in the top of the furnace, because of red hot condition with constant temperature of nano particle injected by push rod into the molten metal. The stirrer rod designed by varying speed for mixing of ceramic particles.Any constant rpm or any varying rpm can be set at any time. The non wettability or floating or settling of particles has to be avoided.
8. The result of cast components demonstrates that the vacuum assisted die casting reduces the amount of entrapped air or gas in the die cavity.
9. Before pouring the molten metal, the mechanical vacuum valve that can achieved venting during the whole process with response time of vacuum only at 0.75 milliseconds. This vacuum continues up to the end point of pouring of molten metal.
10. Squeeze pressure applied to compo casting, after pouring the molten metal in the form of semisolid condition of molten metal. After some time, squeeze pressure was released from the mould die and eject the casting part from the die.
11. Due to the thermal expansion in thixoforming process, the cast part dimensions can be reduced. Casted component has been heated up to red hot condition, put into the die and then the squeeze pressure has been applied which leads to improved mechanical properties.

Acknowledgment

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