# DESIGN AND ANALYSIS OF DUAL FUEL STIR CASTING FURNACE

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Abstract: This project focus on the design and analysis of dual fuel stir casting machine for aluminium hybrid to explore the materials for automotive and aerospace applications using stir casting technique. The Stir Casting furnace can be operated using fuels like LPG, Diesel, Oil and can be electrical also. This project designed and analyzed for dual fuel furnace which operates on LPG and Diesel, since the solenoid coils will get damaged during combustion by other fuels and the oil may not be effective for quick firing and also it will make a sudden combustion inside the small chamber i.e. sudden explosion. The main objective is to design and analyse a dual fuel stir casting machine to improve uniform stirring reinforcements in the base metal aluminium. The design is carried out in Solid Works the thermal analysis of stir casting furnace is carried out by ANSYS. The crucible and the stirrer are exposed to the heating zone hence they are subjected to various thermal analysis. Steady state thermal analysis and static structural analysis is carried out on the stirrer rod and crucible. The melting temperature of aluminium is 660℃ hence the stirrer rod and the crucible are tested for temperature above the melting point of aluminium. The materials are chosen based on the melting temperature.

*Index Terms* **– Design, Analysis, Uniform Stirring, etc...**

## I. INTRODUCTION

Stir casting of MMC was Started during 1968, when S. Roy introduced by stirring molten aluminium alloys with ceramic powders. The mechanical stirrer is used to distribute the reinforcement phases during stir casting process.

Stirring is the key element in the process. Molten alloys with particles of ceramics can be used for further castings such as die casting permanent mould castings or sand castings. Stir casting in the metal matrix composites is used for the reinforcements at higher volume of fractions. The major concentration of the process is carried out on stirring in order to reduce the settling or segregation of reinforcement particles during melting and casting process. Finally, the distribution of particles depends upon properties of materials and process parameters. Eventual distribution depends on geometry of mechanical stirrer, placing stirrer, melting temperature etc...

Several methods are available to form a metal matrix composite beyond which stir casting is one of the simplest and efficient technique to form a composite particle. Stir casting technique is used for the fabrication of composite materials, which uses mechanical stirring for mixing the dispersed phase with the molten metal matrix. Stir Casting is the simplest and the most effective method on cost for liquid state fabrication. This method is mainly accompanied by most of the industries for the large-scale production purposes.

The existing method ensures with an operating condition of stir casting by using only one fuel operated furnace at a time. When there is a power shutdown in electrical furnace it cannot be operated. And when there is a trouble shouted in the burner setup an alternate burner cannot be used since it should be completely changed. The existing furnaces does not provide any alternate solution to continue the process of production in a large-scale industry. The former method ensures with separating the hot crucible from the furnace and placing it on another setup for the stirring process thus he manual handling of hot crucible is not an easy task. To form a perfect matrix composite there is a requirement of knowing perfect temperature at that time of mixing.

The project focuses on designing and analyzing a dual fuel furnace setup to work on alternate fuels on basis of the requirement. The design focuses on attachment of the furnace and the stirrer setup in a single frame in order to reduce the manual handling of crucible, also by the tilting mechanism handling of crucible is being completely eliminated for the process of solidification. The analyzing concept is based on the design provided is safe in terms of stresses on the elements, thermal conduction of the crucible, heat withstanding capacity of stirrer rod, insulation of heat by the refractory bricks and in terms of the design provided is safe.

Design for the stir casting setup and the analysis for the design is made on the upcoming aspects. The design part withholds a new concept of using a furnace for two fuels by providing the provision over the refractory part within which the furnace is attached on the frame to along with the stirrer rod setup. Hence, the crucible along with refractory setup is been tilted to make sure the pouring of molten metal directly on the die by using the hand wheel. The motion of the stirrer rod setup is been made in the vertical direction along with the motor coupling. A temperature indicator is being provided along with the stirrer closure in order to show the exact temperature of the furnace. An optimized concept involved in the furnace is the stirrer cover overcomes the spilling of molten metal while stirring. Analysis carries the steady state heat flow, analysis of stress on various aspects.

## II. LITERATURE SURVEY

Graphite crucible is used for the purpose of higher melting temperature about 2700℃ which is higher than requirement, since our requirement is to melt lighter materials such as aluminium and Ceramic materials which is less than 1000℃. From the study insulating materials are made of asbestos sheets, insulating paints, and refractory bricks which are remarkably light in weight helps to reduce the overall weight of the furnace. To fill the gaps between refractory parts a paste made of ceramic powder, water and glue acts as the cement for refractory bricks.

Aluminium crucible of 30kg to melt aluminium and other metals whose melting temperature falls below the operation temperature range of 800℃.The furnace drum was made from a 3mm thick mild steel plate rolled into a cylinder of diameter of 800mm and height 800mm with the overall combustion space of diameter 560mm and height 570mm.The efficiency of the furnace was calculated to be 26.5%, which falls within the efficiency range of conventional furnace, shows that most of the heat generated in the furnace was actually used in the melting of the metal.

The flow pattern of the liquid pattern is decided by the blade angle and number of blades. Two third of the molten metal should be immersed by the stirrer. The stirring speed ranges from 250-800 rpm but the optimum stirring speed is 400 rpm. To make an easy movement from one place to another wheels are used. The top portion lid of the furnace is covered by using the same refractory bricks used for insulation in the furnace. The door of the lid is hinged on the frame.

Helical shaped stirrer is designed to improve uniform distribution of composite materials in stir casting process. The experiment conducted by Sahil Kumar Prajapati (2018) is carried out using helical shaped stirrer. The experiment proved that the stirrer speed of 500 rpm is enough for uniform distribution of the Metal Matrix Composites. The project analyzed about the temperature and total heat flux of the crucible and the stirrer rod using ANSYS and described about its properties.

## III. METHODOLOGY

### 3.1 Conceptual Design

The conceptual design of the prototype is designed by using Solid works software is shown in Fig.3.1.

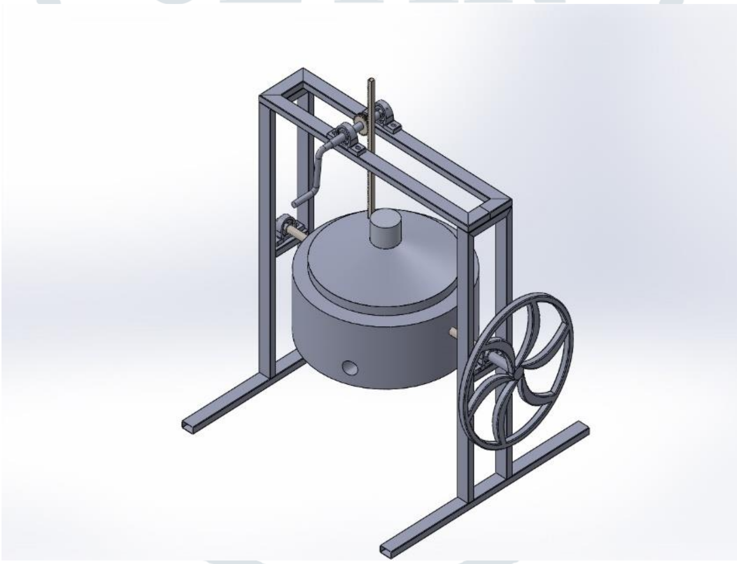

**Fig.3.1 Conceptual design**

### 3.2 List of components

The major components employed in the design are as follows.

i. Frame
ii. Crucible
iii. Rack and Pinion
iv. Stirrer rod
v. Hand wheel
vi. Refractory
vii. Bearing
viii. Handle

### 3.2.1 Design of frame

The frame is made of mild steel material. The whole parts are mounted on this frame structure with the suitable arrangements. This frame consists of four legs are having same size. The arc welding process is used to fabricate the frame.

### 3.2.1.1 Design calculation of frame

Length = 1025 mm

Breath = 850 mm

**3.2.2 Design of crucible**

The study focused on ensuring a high efficiency in melting of aluminium, by effectively minimizing heat losses, and maximizing heat generation. To achieve this, a composite refractory material consisting of refractory bricks are used. The material used for the design of crucible is Cast Iron.

**3.2.2.1 Design calculation of combustion chamber**

The furnace drum was made from a 3mm thick mild steel plate rolled into a cylinder of diameter of 600mm and height 225mm with the overall combustion space of diameter 370 mm and height 225mm.

The detailed dimensions of the furnace drum are as follows

| | | | |
|---|---|---|---|
| i. | Height of the furnace drum before laying bricks(h) | = | 225 mm |
| ii. | Height of combustible space of the furnace drum after laying of bricks(h1) | = | 225 mm |
| iii. | Internal diameter of the furnace drum before laying of the bricks(d) | = | 590mm |
| iv. | Internal diameter of the furnace drum after laying of the bricks(d) | = | 370mm |
| v. | Inlet diameter of the burner nozzle | = | 550mm |
| vi. | Outlet diameter of the burner nozzle | = | 85mm |
| vii. | Height of the cover | = | 98mm |
| viii. | Total height of the drum = height of the drum + height of the cover | = | 225+98=323mm |
| ix. | Diameter of the chimney hole (on cover) | = | 60mm |
| x. | Thickness of the metal plate | = | 3mm |

Volume of the combustible chamber of the furnace(V) = $\pi \times d1^2 \times h1/4$

V = $3.142 \times 560 \times 560 \times 570/4$

V = 0.0242 cubic. Meter

**3.2.3. Design of Stirrer rod**

The stirrer rod is made of stainless-steel material. The stirrer is rotated through an external medium that can be attached to the furnace at any point through the top. The stirrer rod is driven by a ½ HP AC motor and rotates at about 400 rpm.

**3.2.4 Selection of bearing**

In this project UC205-16 set screw lock ball bearing is selected. The bearing is selected based on the application. The Set screw locking is the reliable method for using on low torque and low speed (less than 20 rpm) mechanisms. In this project the rpm of the shaft is less than 20 rpm and it is not constantly rotated. Hence UC205-16 bearing is selected. The properties of the bearing are shown in the table 3.2.

| | | |
|---|---|---|
| Dynamic Load | = | 14 KN |
| Static Load | = | 7.85 KN |
| Inner Diameter | = | 25mm |
| Outer Diameter | = | 52mm |
| Bolt Size (inch) | = | M10 (3/8) |
| Weight | = | 0.8 Kg |

**3.2.5 Bending moment calculation for the shaft**

The bending moment can be calculated by the equation

$$\frac{M}{I} = \frac{\sigma}{y}$$

Where,

M = Bending moment

I = Moment of Inertia

σ = Bending stress

y = Distance from neutral axis

Formulas for the substitute

$I = (\pi/64) \times d^4$

$y = d/2$

$\sigma = 525$ kg-f/cm$^2$ from PSG design data book pg.no: 7.24

(Refer Fig.3.2)

$= 5148.49$ N / cm$^2$

$= 5148.49 \times 10^{-2}$ N / mm$^2$.

The internal diameter

of the shaft (d) $= 25$ mm

Inertia $= (\pi/64) \times (25)^4$

$= 19.174 \times 10^3$.

Distance from neutral axis

$Y = 25/2$

$= 12.5$ mm.

Bending moment (M) $= (\sigma \times I) / y$

$= (5148.49 \times 10^{-2} \times 19.174 \times 10^3) / 12.5$

Bending Moment $= 0.0789$ N-mm.

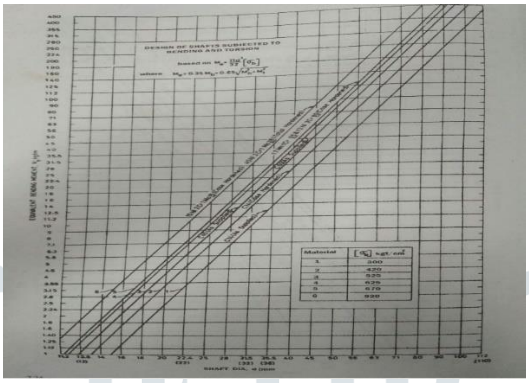

**Fig.3.2 Bending stress graph**

### 3.3 Working

The melting is carried on in a dual fuel stir casting furnace in a range of 660°C. In the present study, a dual-fired tilting furnace has been used. A new stir caster was developed to fabricate metal matrix composite. It has been used to obtain an output of 600 rpm. The stir caster was mounted on the furnace with the help of four legs. Mild steel was chosen as stirrer and impeller material. During experimental work, a six bladed 45degree angled stirrer was chosen. The stirrer is introduced such that position should be like 65 percent of the material should be above the stirrer. First the stirring system has been developed by coupling motor with gearbox and a mild steel stirrer. All the melting was carried out in a graphite crucible in a dual fired furnace. Scraps of aluminium were melted at 660 C before mixing the ceramic materials. To keep the slurry in a semi solid state the furnace temperature is raised above the liquidus to melt the alloy scraps completely and it is then cooled down. Since it is difficult to mix using automatic device when the alloy was in a semi-solid-state manual mixing is preferred. Then the composite ceramic materials were added and automatic mechanical mixing was carried out at a normal stirring rate of 600 rpm.

### 3.4 Specification of Prototype

**Table 3.1 parts of the furnace**

| S.No. | Component | Quantity | Material |
|---|---|---|---|
| 1 | Frame | 1 | Mild Steel |
| 2 | Bearing | 4 | Stainless Steel |
| 3 | Handle | 1 | Mild Steel |
| 4 | Crucible | 1 | Cast Iron |
| 5 | Closing cap | 1 | Mild Steel |
| 6 | Motor | 1 | AC Motor |
| 7 | Stirrer rod | 1 | Mild Steel |
| 8 | Hand wheel | 1 | Mild Steel |
| 9 | Rack and pinion | 1 | Mild Steel |

## IV RESULT AND DISCUSSION

### 4.1 ANALYSIS

The parts of the furnace which are exposed to the heating zone are analyzed for various thermal parameters. Steady state thermal analysis and static structural analysis are carried on the stirrer. The entire weight of the furnace is supported by the frame. Hence it is subjected to mechanical stress and strain. The stress strain analysis for the frame is also carried out.

### 4.1.1 Analysis of crucible

Fig.4.1shows the steady state thermal analysis of crucible and the figure 4.2 shows the static structural analysis of the crucible.

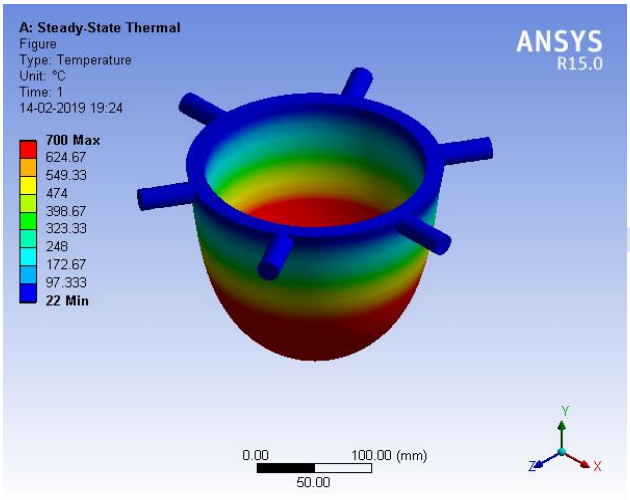


**Fig.4.1 Steady state thermal analysis of crucible**

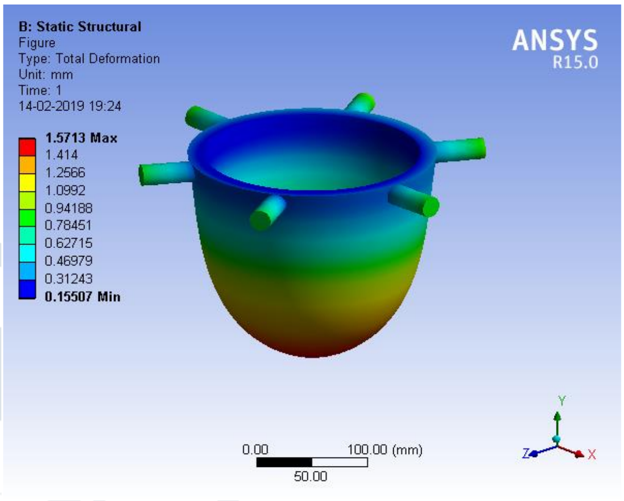


**Fig.4.2 static Structural Analysis**

The maximum temperature distribution occurs on the bottom portion of the crucible which is 700°C and the minimum distribution occurs on the top layer which is 22°C.

**Table 4.1 Steady state parameters**

| S.no | Parameter | Maximum value | Minimum value |
|---|---|---|---|
| 1 | Temperature distribution (°C) | 700 °C | 22 |
| 2 | Total heat flux ($w/mm^2$) | 0.19808 | 9.0139 $e^{-7}$ |
| 3 | Total deformation (mm) | 1.5713 | 0.15507 |

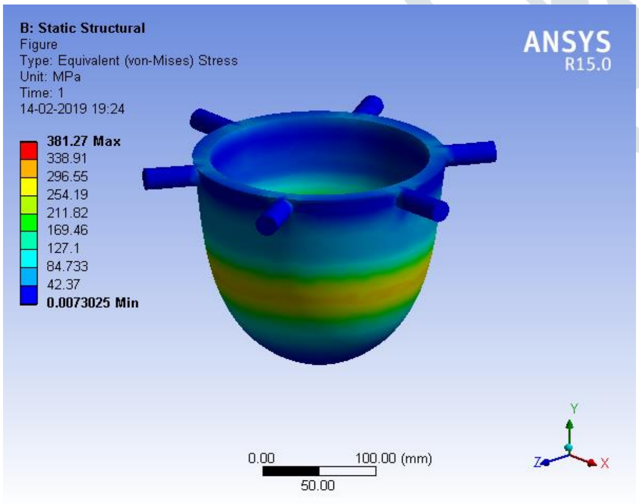


**Fig.4.3 Stress analysis on crucible**

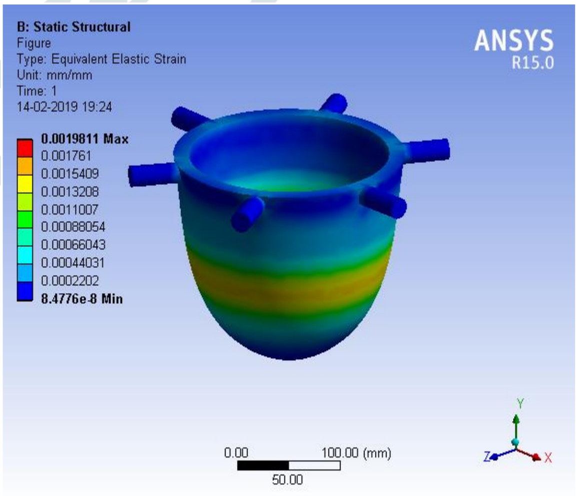


**Fig.4.4 Strain analysis on crucible**

### 4.1.2 Analysis of Stirrer rod

The analysis of the stirrer rod is done using Ansys.Fig.4.5 to Fig.4.8 shows the analysis of stirrer rod.

**Table 4.3 Analysis results of stirrer rod**

| Analysis | Maximum Value | Minimum Value |
|---|---|---|
| Steady state thermal analysis (W/mm$^2$) | 3.4503e$^{-12}$ | 1.8352e$^{-15}$ |
| Static structural analysis (mm) | 1.4011 | 0.3548 |

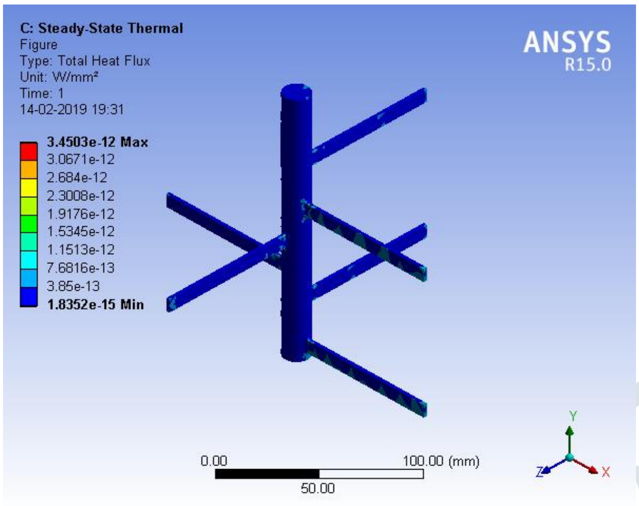


Fig.4.5 Steady state thermal analysis

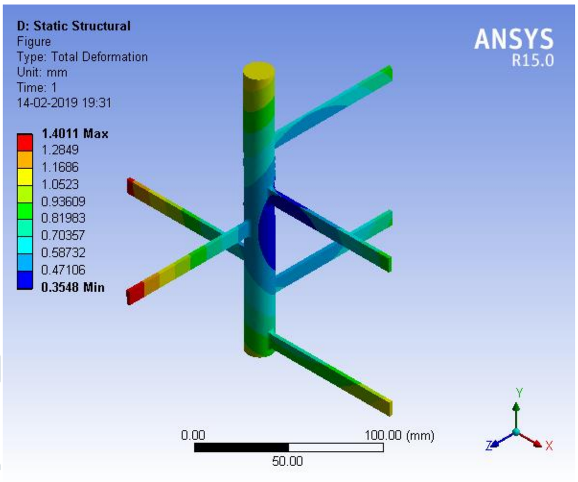


Fig.4.6 Static Structural analysis

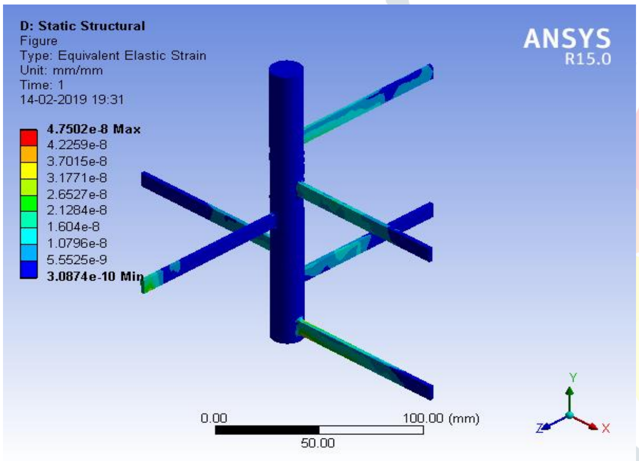


Fig.4.7 Elastic strain on the stirrer

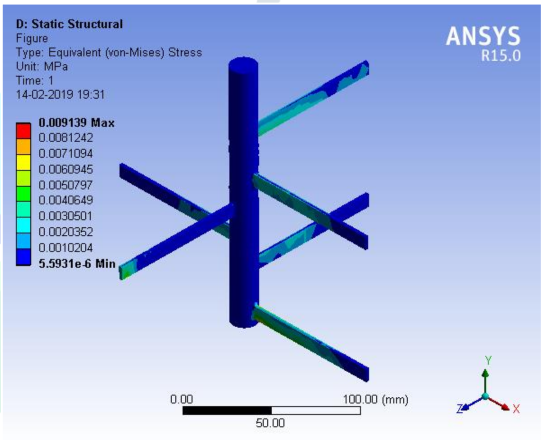


Fig.4.8 Stress analysis on the stirrer

**4.1.3 Analysis of frame**

The total deformation is shown in Fig.4.9. It is observed that the maximum deformation occurs on the top surface and is minimum at the bottom.

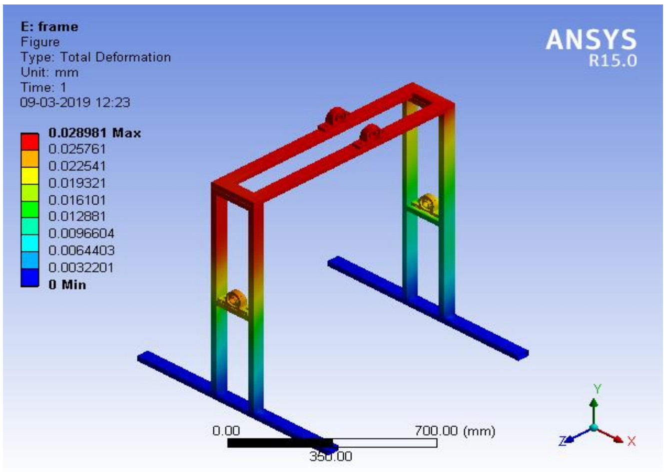


Fig.4.9 Total deformation on frame

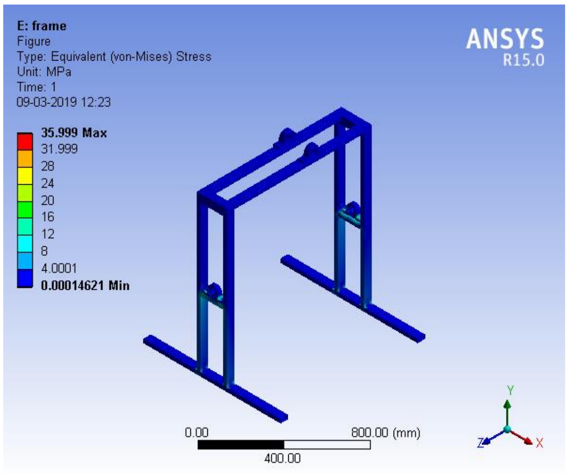


Fig.4.10 Stress developed in frame

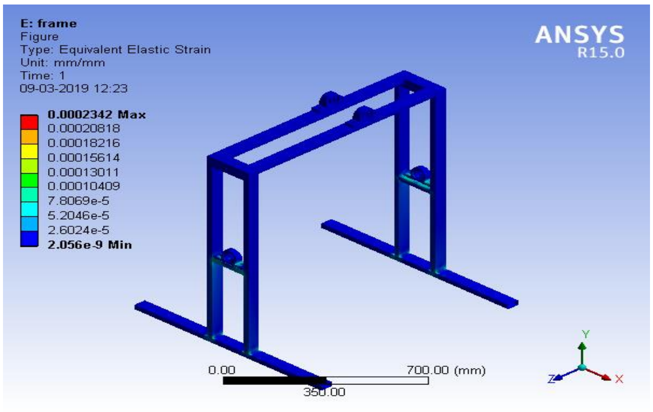


Fig.4.11 Equivalent elastic strain in the frame

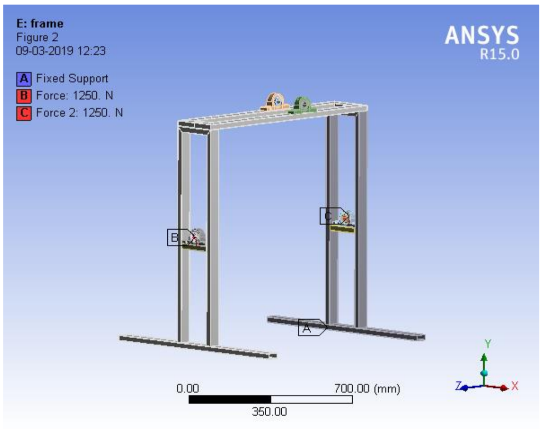


Fig.4.12 Load acting on bearing

**Table 4.4 Analysis results of frame**

| S.no | Parameter | Maximum Value | Minimum Value |
|---|---|---|---|
| 1 | Total deformation (mm) | 0.028981 | 0 |
| 2 | Equivalent Stress (MPa) | 35.999 | 0.00014621 |
| 3 | Equivalent Strain | 0.0002342 | $2.056e^{-9}$ |

## V RESULT AND CONCLUSION

The industry was in need of increasing its productivity and decreasing its labour for handling apparatus, especially in the casting section of its industry for low investment. A stir casting furnace design & analysis as discussed in the previous chapters would serve this need. The summary & conclusion of the whole project with the benefits are discussed in this chapter.

The main objective of the project is to decrease the melting time and increase production rate by designing and analyzing in terms of required parameters by using the dual fuel stir casting furnace. The melting time in comparison with that of previous timing has been reduced and the chances of achieving the target production rates are now possible by means of various operating conditions. The furnace setup required for stir casting furnace is less than the individual stir casting furnace, whereas setup has to be done for each and every furnace in conventional stir casting process. Stir casting furnace can do the same process within a single setup time along with reduction in manual handling of hot crucible as well as on dual fuel provision. Hence the same function is done, with only a quarter of time being utilized. On increasing the setup facilities, more time is saved for production. Hence increasing the total number of workpieces that can be produced, as well as increasing the safety parameters of handling the working process. The dual fuel also provides the alternative way of using the furnace when one source of fuel is shut down. Hence continuous operating conditions can be achieved without any delay in production process.

Stir casting furnace, that is designed and analyzed enables students to realize the real-time experience on working on the project with proper design and calculations. By choosing the materials by considering the property and its behavior could be understood by conducting experiments and observations during test of the project.

the dual fuel stir casting furnace has been designed and analyzed on various observations such as on tilting mechanism, temperature provision, ability of the furnace to withstand the highest temperature reach, analysis on steady state heat flow on the objects on the process and stress analysis on the complete setup on various parts were successfully carried out. This project is made with pre-planning, that it provides flexibility in operation. Smoother and easily handling operation are made by the medium of "dual fuel stir casting furnace". This project is designed with the hope that it is very much economical and helpful to many industries and workshops. As per the test conducted on the various aspects the developed dual fuel stir casting reduces 50% of the time consumed by the manual handling of equipment's as well in shutdown of furnace due to lose on resource. The production rate can be optimized effectively by implementing dual fuel stir casting furnace during casting process. The project helped to know that the reduction in periodic steps of processes accompanied in the casting process work. Thus, the project is being completed successfully

i. It is justified that our design is more efficient than manual handling of equipment's, it reduces the overall production time by 50%.

ii. The further development of the design involves attachment of furnace and stirrer setup on a single frame instead of separate setups which makes the handling of the equipment is easier as well in terms of production.

iii. The implementation of provision on temperature indicator adds advantage of knowing the exact temperature of the molten metal.

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