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Design and construction of tilting furnace for producing aluminium matrix composites

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Abstract
Aluminium matrix composites (AMCs) are a range of advanced engineering materials that can be used for a wide range of applications within the aerospace, automotive, biotechnology, electronic and sporting goods industries. AMCs consist of a non-metallic reinforcement (SiC) incorporated into Aluminium matrix which provides advantageous properties over base metal (Al) alloys. These include improved thermal conductivity, abrasion resistance, creep resistance, dimensional stability, exceptionally good stiffness-to-weight and strength-to-weight ratios and better high temperature performance. Oil fired 20 kG tilting furnace with integral mixing mechanism was designed and constructed for the production of AMC. This cost effective furnace can be used in cottage industries without electric power.
Key words: Tilting furnace, Aluminium, SiC, Composite

1. Introduction
Metal matrix composites (MMCs) are a range of advanced materials that can be used for a wide range of applications within the aerospace, automotive, nuclear, biotechnology, electronic and sporting goods industries. MMCs consist of a non-metallic reinforcement incorporated into a metallic matrix which can provide advantageous properties over base metal alloys. These include improved thermal conductivity, abrasion resistance, creep resistance, dimensional stability, exceptionally good stiffness-to-weight and strength-to-weight ratios and better high temperature performance. Hard and strong particles in the form of particulates or fibers are added to improve the thermo-mechanical properties and performance of the lightweight but comparatively soft host metal. Common reinforcement particles include ceramics such as silicon carbide and alumina, B_4C, Si_3N_4, AlN, TiC, TiB_2, TiO_2 and hard metals such as titanium and tungsten (Tjong, 2008; Law et al.,2011; Senthilkumar et al.,2011).

There are two basic processing routes for producing Metal Matrix Composites; Liquid state and solid state routes. Liquid fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification.

The methods of liquid state fabrication of Metal Matrix Composites:

- Stir Casting
- Infiltration
- Gas Pressure Infiltration
- Squeeze Casting Infiltration
- Pressure Die Infiltration

Solid state fabrication of Metal Matrix Composites is the process, in which Metal Matrix Composites are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure.

There are two principal groups of solid state fabrication of Metal Matrix Composites:

- Diffusion bonding
- Sintering

This work is an example of liquid state fabrication of Metal Matrix Composites using stir casting method.

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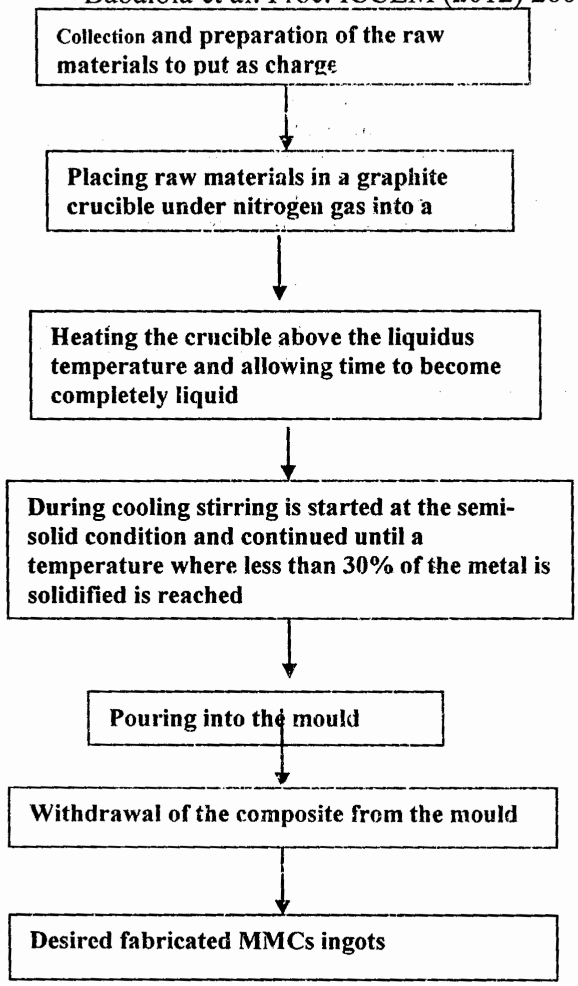
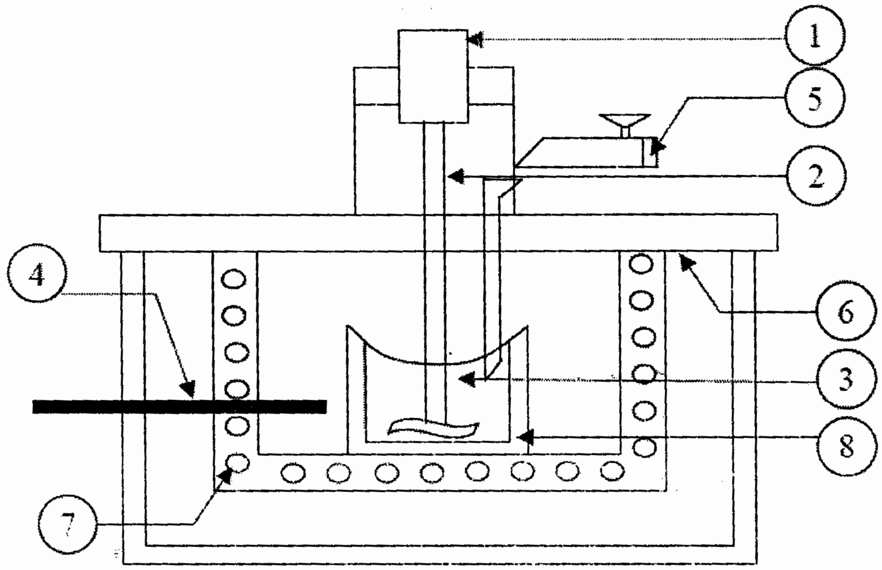


Figure 1. Composites Product Fabrication



1. Motor
2. Shaft
3. Molten aluminium
4. Thermocouple
5. Particle injection chamber
6. Insulation hard board
7. Furnace
8. Graphite crucible

Fig. 2. Schematic view of setup for Fabrication of composite (Singla et al. 2009)

2. Materials and Methodology

2.1 The furnace

2.1.1 Parts functions

The crucible

The crucible is used for holding the molten aluminium which is to be melted.

The shell

The shell is the housing, which holds refractory bricks around the crucible inside of which the heating process takes place.

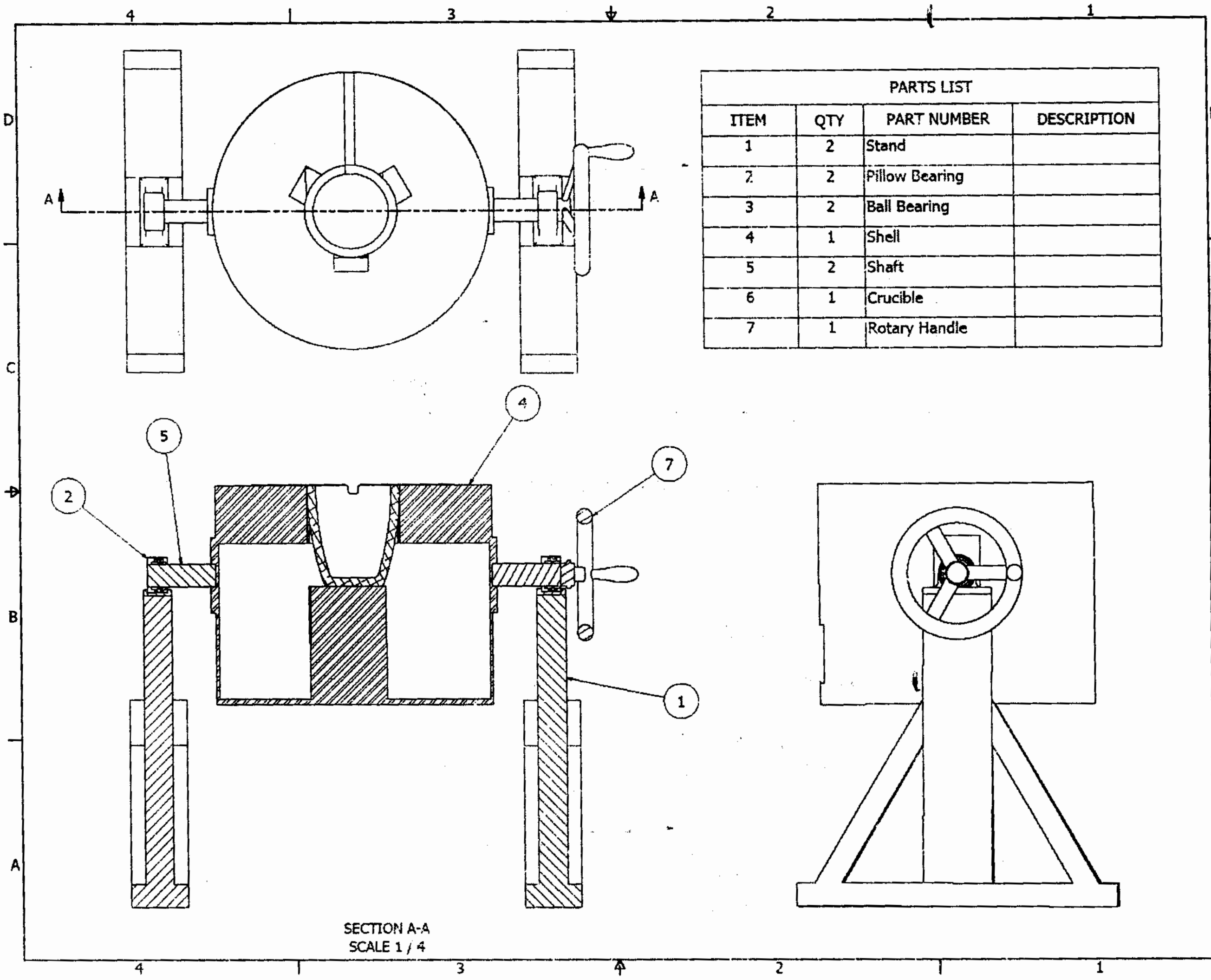
The shaft and rotating handle

The shaft holds the shell in place while the rotating handle, is used in turning the shaft, so as to turn the shell when pouring out the molten aluminium. The rotary assembly comprises of the shafts, the bearings and the rotary handle.

The shafts, which are being held in place by pillow bearings, are connected to opposite sides of the shell from the stands. They are made of stainless steel, and transmit rotary motion from the rotor to the shell, in order to enable tilting of the furnace for easy pouring of the molten aluminium.

The stand

The stand is holds the whole assembly in place and gives support to the assembly



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	Stand	
2	2	Pillow Bearing	
3	2	Ball Bearing	
4	1	Shell	
5	2	Shaft	
6	1	Crucible	
7	1	Rotary Handle	

Figure 3 - Orthographic projection of the furnace assembly, showing the various parts.

2.1.2 Materials selection

The crucible

The crucible is made from graphite. This is because graphite has the following suitable properties

1. It is a good conductor of heat.
2. It has a higher temperature than aluminium.
3. It doesn't react with the molten metal at high temperatures.

This therefore sees to it that the heat is being conducted properly and that crucible is still stable, even at the melting temperature of aluminium (about 660^{0}C).

The shell

The shell serves as the housing for the crucible and the refractory materials. The shell is made of iron steel and assumes a drum shape, with a base. It has an opening, in order to allow for heating up of the furnace, through the firing method. The reason for choosing iron is because:

1. It has a high strength, and so will be able to carry the load (crucible, refractory bricks and binder) required.
2. It is easily worked on and so can be cut and shaped easily.
3. It is still very stable at high temperatures and so can withstand the heat (flames) needed to melt the aluminium

The rotary assembly (the shaft/bearings/rotor)

Stainless steel is chosen as the shaft material. This is because it has high strength and can support heavy load. It can be easily machined and has a very high level of corrosion resistance and also does not wear easily.

The stand

The stand was fabricated from hollow rectangular iron beams. The hollow beams were chosen in order to reduce the weight of the assembly. Iron was chosen as the material, because of much attention to details such as corrosion. Iron on the other hand apart from being cheaper, has the ability to support the assembly due to its high strength.

2.1.3 Constructing the furnace

The stand was fabricated from hollow rectangular iron beams cut to size and then joined together in such a way as to support the weight of the shell, refractory bricks, shafts, refractory binder and crucible. The shell was fabricated by first cutting out a section out of a large cylindrical iron pipe. The bottom of the shell was covered. The cut out, where the flame source would pass, was then cut out. The mounts on which the shafts were to be connected were welded onto the body of the shell at opposite sides of the shell. The refractory bricks were put in the shell to support the crucible as a base from the bottom. The crucible was placed on the bricks, and then held in place by the use of a refractory binder, with hot gas exhaust routes from the sides of the crucible, through spaces made between the crucible and the refractory binder in some sections of the circumference around the crucible. The shell was mounted in the pillow block bearings on the stand. The revolving handle is then connected to the shaft end to allow for rotating of the shaft, in order to rotate the shell for ease of pouring. The whole assembled was mounted on the floor through the legs of the stand.

2.1.4 Part analysis

Here are the parts used for the furnace construction and why they were used.

Table 1 - Part description for the furnace

Parts	Material	Characteristic
Crucible	Graphite	It is a good conductor of heat and electricity, is resistant to acids and alkalies, and is readily molded. It is infusible, subliming at 3704°C (6700°F) Brady et al
Shell	Cast Iron	High melting(1525^{0}C)temperature and tensile strength (~400 MPa)
Pillow Block Bearing	Mild Steel	High melting temperature and tensile strength
Shafts	Stainless Steel	High melting temperature and tensile strength
Revolving handle	Cast Iron	High melting(1525^{0}C)temperature and tensile strength (~400 MPa)
Stand	Cast Iron	High melting(1525^{0}C)temperature and tensile strength (~400 MPa)
Refractory Brick	Refractory materials (Ceramic)	Ceramic material with resistance to very high temperature, used for furnace linings and metal-melting pots

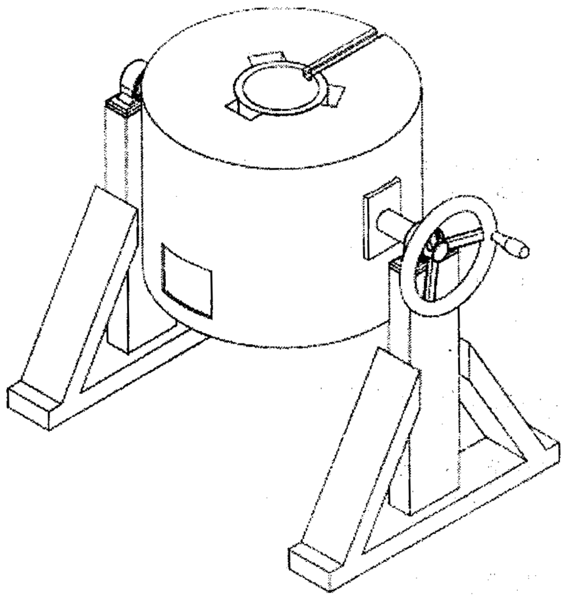


Figure 4 Isometric view of the furnace

2.1.5 Heating the furnace

The furnace is heated up from flames resulting from the combustion of a fuel (diesel or used engine oil) in the presence of air. The burner is a nozzle with 50mmθ air pipe from the blower and 8mmθ pipe conveying the fuel (Fig.7). The air line is directed into the furnace, through the opening located in the shell. The air pump is first of all started in order to pump air into the line. The fuel valve is then adjusted to allow for flow of the fuel down the pipe into the air line in order to create a combustible mixture. This mixture is then ignited to generate the flame needed for heating.

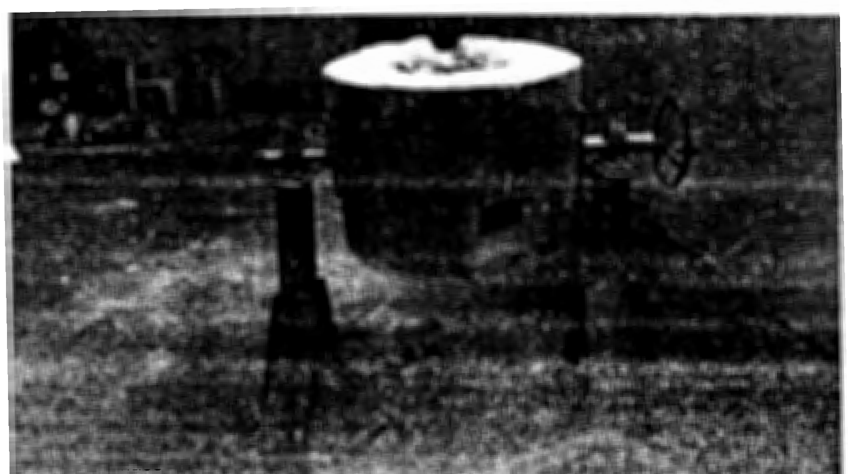


Figure 5. The furnace

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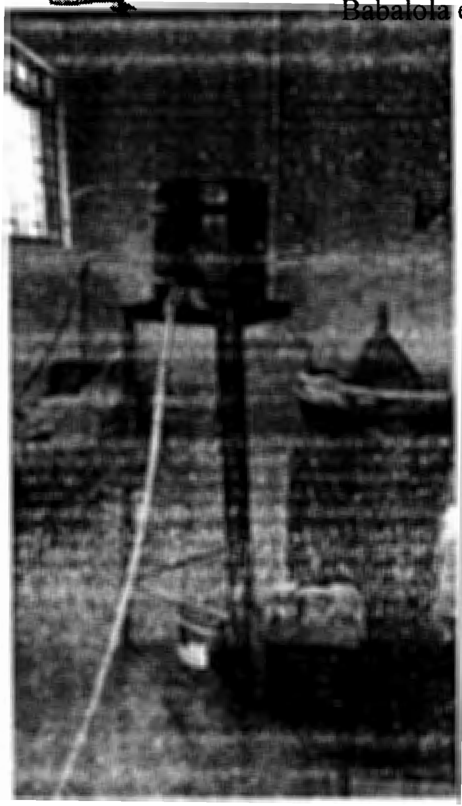


Figure 6. The fuel reservoir

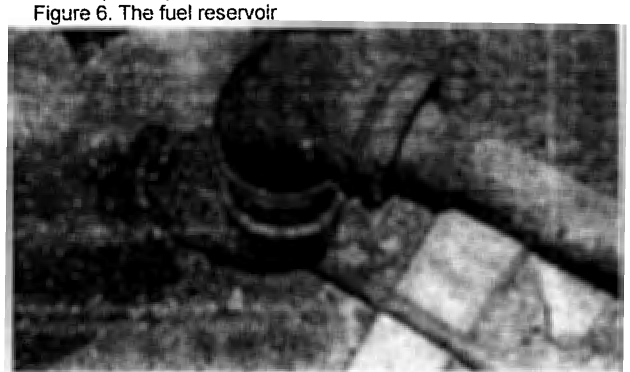


Figure 7. The air-fuel supply connection, showing how air and fuel pipes are connected

2.2 The mixer

The purpose of the mixer is to mix (using stirring action) the reinforcement and the molten metal together. This is achieved by transferring the molten aluminium from the furnace to the mixing container where the aluminium is stirred while adding the reinforcement materials.

2.2.1 Parts

The mixing assembly comprises of

1. The platform
2. Stands
3. Base
4. Motor
5. Shaft and agitator

The platform

The platform acts as the support for the motor. It is mounted on the stands and then the motor is fixed on it with the shaft and agitator extending downwards from it.

The stands

The stands act as supports for the platform. They are made from iron and have a square hollow shape.

Motor

The motor is used to drive the shaft and agitator, which stir the molten aluminium and the reinforcements together. The motor has a speed of 800 rpm however we introduced external variable rheostat to vary the rotation as desired and measure the speed with handheld tachometer. The shaft and the agitator are made from mild steel and iron respectively.

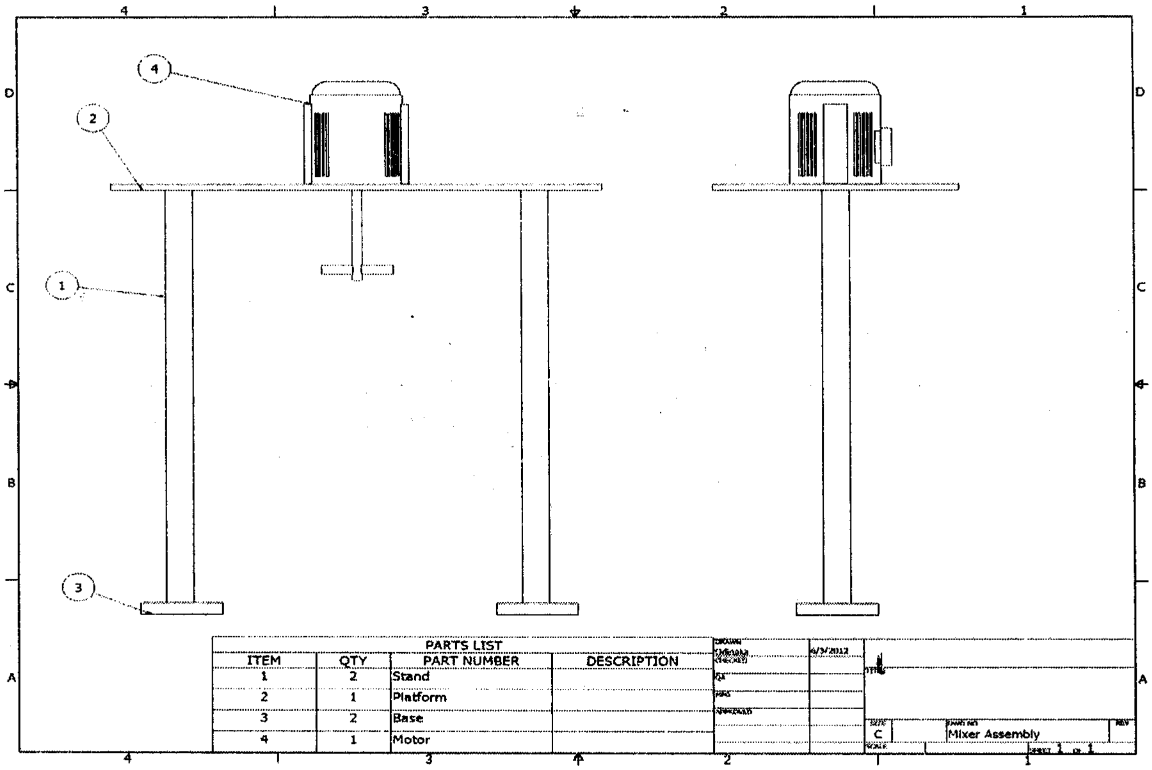


Figure 8. - Front and side views of the mixer

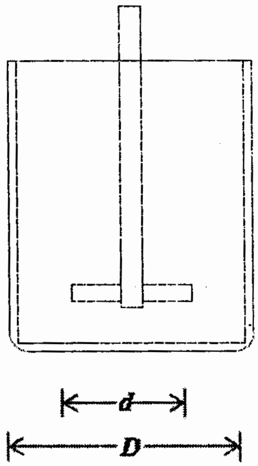
2.2.2 *Fabricating the mixer*

The mixer was constructed by cutting out the stands from 3x3 inches hollow iron bars and welding them onto bases as shown in fig. 3. Welded on the stands is a platform made from flat rolled iron. This platform holds the motor in place. The motor which is fixed on the platform has a shaft extending downwards through a hole in the platform. This shaft also holds the agitator needed to carry out the mixing.

2.2.3 *Designing the shaft*

The shaft is made from mild steel and was chosen, because of its characteristics which suit the desired operation and also because it is cheaper than stainless steel. The shaft was designed to be able to transfer a speed of 500 rpm directly from the motor to the agitator for mixing the molten aluminium and the reinforcements. The design was based on the following considerations

1. The speed of the shaft is to be 500 rpm.
2. The diameter of the agitator (d) is one-half the mixing ladle (D).
3. The agitator blade is a vertical one.



n = Speed (rpm)

R_e = Reynolds number

d = Impeller diameter (0.5D)

D = Viscosity of molten aluminium (pa.s)

P = Power (W)

T = Torque (Nm)

N_p = Power Number

The Reynolds number for the flow is gotten from the equation

$$R_e = \frac{\rho n d^2}{\mu}$$

The power number is obtained from a power number vs Reynold's number chart.

$$P = N_p \rho n^3 d^5$$

$$P = Tn$$

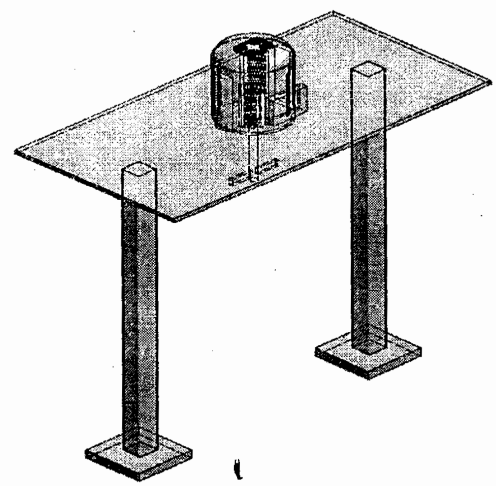


Figure 9. Isometric view of the mixer

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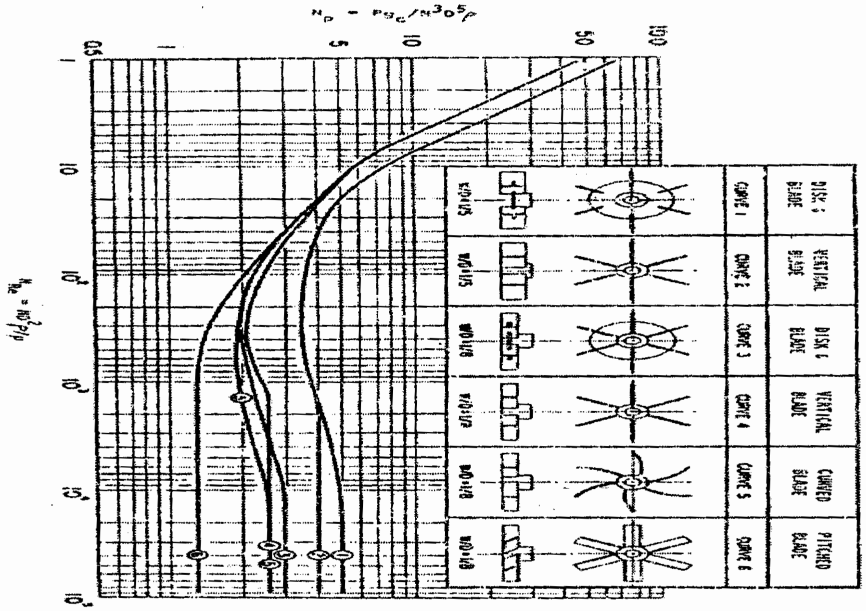

Figure 10 - Graph showing the relationship between the power number and reynold's number for various agitator blade arrangement

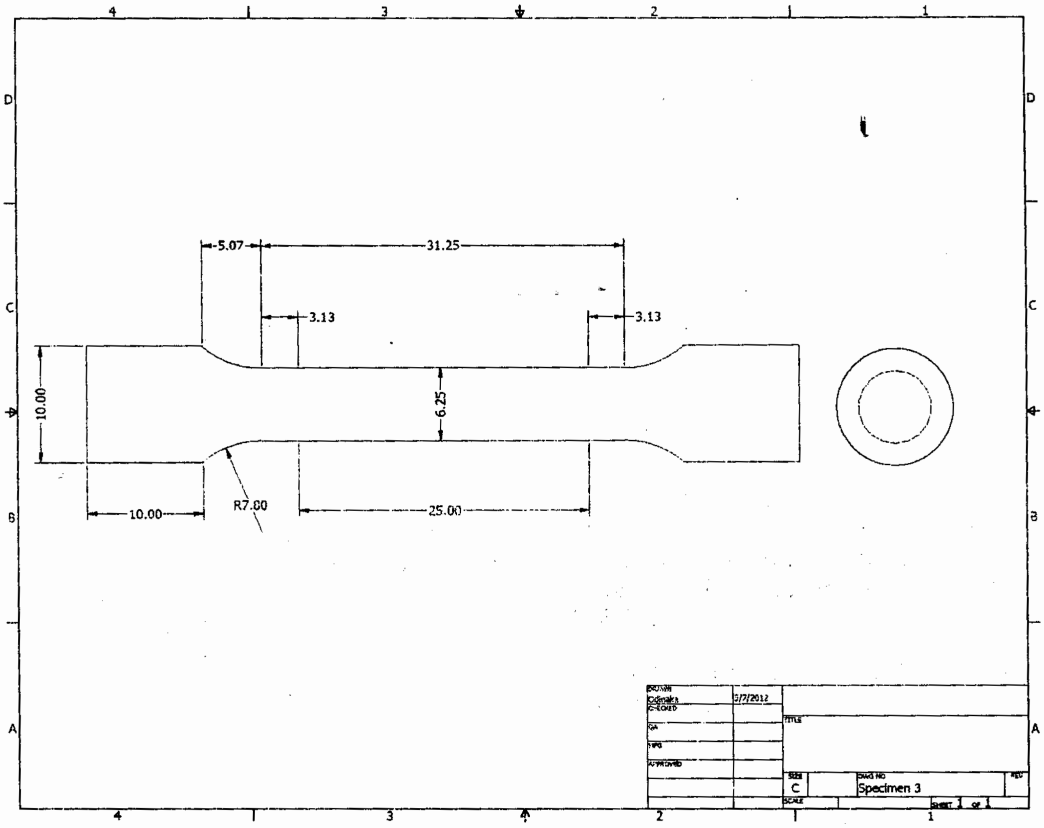

Figure 10 - Tensile specimen (based on asme standards)

3. Testing the furnace

The furnace was tested for functionality and was found to melt 10kG of Aluminium within 20minutes. The furnace diesel fuel consumption rate was found to be 0.15 L/min. The mixer was also used to mix the aluminium and the reinforcements. It was found to be suitable and was able to carry out the mixing properly.

4. Conclusion

The aluminium furnace melts the aluminium to a liquid state, from which it is then transferred to the mixer for reinforcing and then casting to obtain specimens for testing.

The aluminium furnace heats to a temperature higher than the liquidus temperature of aluminium and so melts aluminium. The graphite crucible has the ability to conduct heat and so transfers heat without much loss to the aluminium. Molten metal is easily poured out from the furnace due to its design which permits it to swivel. Mixing the molten aluminium and the reinforcements are mixed in the mixer.

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