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Development of Laboratory Hot Compression Mounting Press Machine

Oyetunji Akinlabi[1*], Barnabas Abel Adeiza[1] and Obolo Olupitan Emmanuel[1]

[1]Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Ondo State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author OA designed the study, managed the literature searches, performed the design analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BAA and OOE managed the fabrication and performance evaluation of the designed machine. All authors read and approved the final manuscript.

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ABSTRACT

This research focuses on the design, fabrication and performance evaluation of a laboratory hot mounting press machine for metallography using locally sourced materials and indigenous technology. To achieve this research objective, working drawings were produced which were used to produce the parts of the machine. Mild steel plates were used for the housing and the movable platen while stainless steel and mild steel rods were used for the production of the mold and the sturd respectively. From the design, the temperature of 180°C was used to melt resin by heat supplied from band heater and heating time was 10 minutes. The pressure of 28 MPa was applied by the hydraulic jack for the resin. The need to produce a user friendly and low cost laboratory mounting press machine using indigenous technology and locally sourced materials led to this study and hence, this research is recommended for use in metallurgical sectors, tertiary institutions and research institutes such as The National Agency for Science and Engineering Infrastructure (NASENI), Engineering Materials Development Institute (EMDI), Abuja, and National Board for Technological Incubation (NBTI).

**Corresponding author: E-mail: akinlabioyetunji@yahoo.com;*

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1. INTRODUCTION

A mounting press is a device used to encapsulate samples for metallographic preparation [1]. Metallographic examination of samples generally requires encapsulation or mounting of the specimen [2]. The primary purpose of mounting is for convenience in handling specimens during the subsequent steps of preparation and examination [1]. A secondary purpose is to protect and preserve extreme edges of surfaces defects during preparation. The thickness of the mount should be sufficient to enable the operator to hold the mount firmly during grinding and polishing thereby to prevent the metallographist hand and to maintain a flat surface. Mounting produces specimen with uniform size so that it is easier to handle on grinding/polishing machine for further preparation steps (grinding and polishing of metallographic samples). Metals and their alloys have nearly without exception had a direct or indirect impact on all technological developments. Like no other materials, they cover an extensive spectrum of applications with their enormous variety of alloys and their related range of properties. The number of metallic materials extends to several thousand and is continuously growing to meet the latest requirements of technology. The lustre and the good electricity and heat conductivity, as well as the high ductility and strength, combine to provide characteristic and unique properties [3]. Specifically, there are two methods of mounting-cold mounting, and hot mounting [3,4]. For the purpose of this study, the specific mounting press developed is the hot mounting press. Some possible advantages that can be gotten from developed hot-mounting press machine are no mixing or handling of chemical resins; gap-free mounting prevents etchant from leaching out after preparation; high hardness of mounting resins results in good edge retention; mount integrity produces coplanar surfaces; minimal resin flashing and burrs; and easy sample marking with engraver [5].

From researches carried out, studies have shown how expensive it is to acquire a mounting press machine in the metallurgical sector, tertiary institutions in Nigeria (Polytechnics, Universities, Colleges of Education, and Technical schools) and research institutes such as The National Agency for Science and Engineering Infrastructure (NASENI), Engineering Materials Development Institute (EMDI), and National Board for Technological Incubation (NBTI). This machine which is not locally acquired but can only be imported may not be easily acquired since the cost of importing such machine is on the high side and the duration for importation may take months before its arrival. Since the parts needed to produce this machine can be sourced locally and the parts are user friendly, such availability of the materials can aid the production of the mounting press machine which will work exactly as the imported ones since a little amount of money as compared to the huge cost of the imported machine will be needed to produce the machine locally.

The aim of the study is to develop (design, fabricate and testing) a user's- friendly laboratory hot mounting press machine using locally available materials through the use of indigenous technology. The objectives of this study are to; design and acquire the components of the laboratory hot mounting press machine; construct and assemble the designed components); test the constructed machine, and perform and evaluate the cost-effectiveness of the produced machine with the imported one.

2. MATERIALS AND EQUIPMENT

The following materials were used for this study: mild steel plate of thickness 10 mm; 3 tons capacity hydraulic jack; temperature controller (0°C - 400°C); cylindrical stainless steel pipe; stainless steel compression coil spring; pressure gauge; emery paper; and spray paint. disk cutter; lathe machine; drilling machine; grinding machine/angle grinder; marking out tools; hacksaw; shielded metal arc welding machine; bench vice; and spanner were some of the used equipment.

2.1 Methods

The methods adopted for the study are as follows:

(i) Design Concept

The compression hot mounting press machine consists of a mould which sits on top of the frame and is being heated up by a band heater. A 3-tonne capacity hydraulic jack attached to a pressure gauge is placed in the frame which moves the platen attached to the stud into the mould. The compression spring is attached to the movable platen which stores mechanical energy from the jack and also applies a compressive force to the jack via the platen once the oil valve is released to lower the hydraulic cylinder back to its normal position as shown in Fig. 1.

(ii) Assumptions Made in the Course of the Study

It was assumed that:

(a) A weight of 3 tons acts on the piston of the cylinder; and
(b) The ASTM specifications were used.

(iii) Design Calculations

a) The hydraulic jack

The following specifications were used in the course of this design:

(i) Capacity: 3 tons minimum; (ii) Maximum height: 380 mm; (iii) Lifting height: 125 mm (iv) Adjustable height: 60 mm. (v) Net weight: 3.5 kg; (vi) Gross weight: 4 kg.

(i) The piston rod

The piston rod is circular in shape and has a length of 150 mm. The piston rod was made up of mild steel SA 36 Grade A. The compressive stress of SA 36 mild steel is 407.7 MPa. Since the oil concentrates in the cylinder when pumped by plunger pump. This oil creates pressure in the cylinder and as the piston is free to move in the cylinder, the whole pressure acts on the cross sections of the piston. To design hydraulic cylinder, the load-bearing capacity of the hydraulic cylinder depends on these two factors:

(a) Load bearing capacity of the piston rod, and (b) Load bearing capacity of the barrel [6,7].

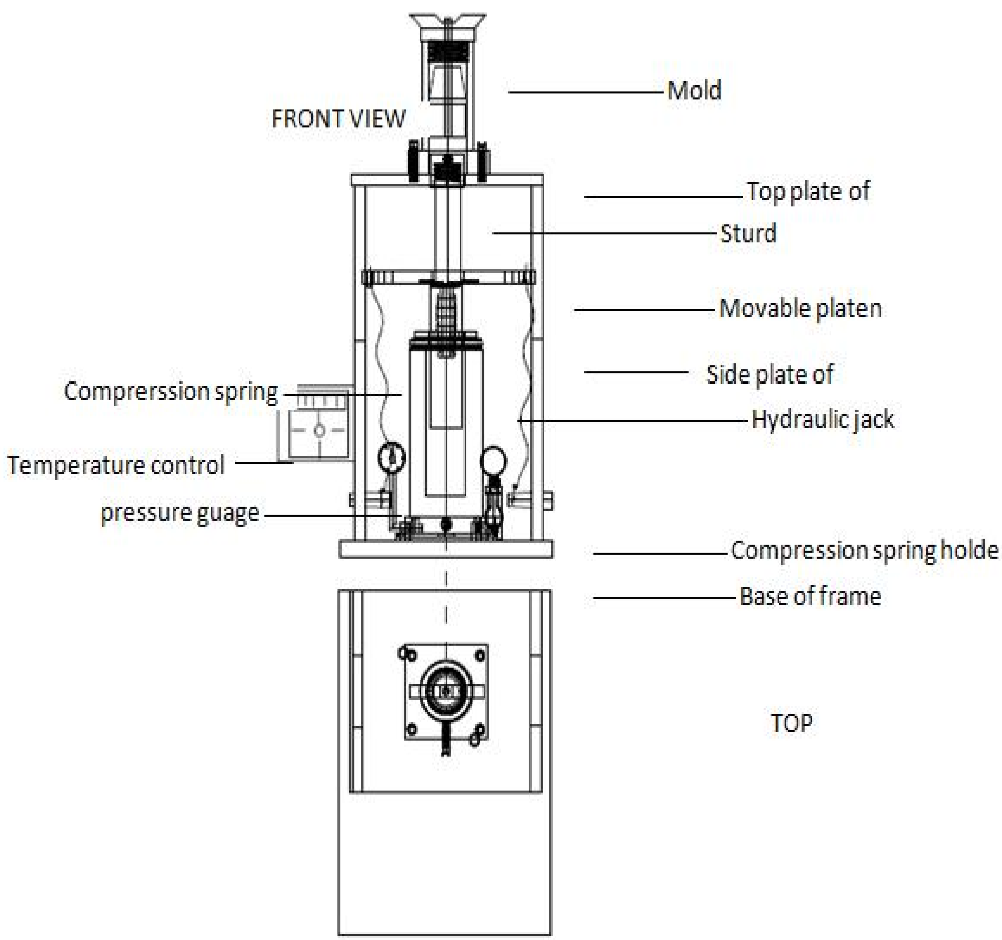


Fig. 1. Conceptual Design of Compression Hot Mounting Press Machine

(ii) Load bearing capacity of the piston rod

In this study, the pressure is applied at one face of the piston while the other cross-section of the piston faces the fixed wall. This means that the failure or breakage of piston rod will occur only due to excessive compressive stress developed in the piston rod.

As earlier established that the maximum limit of compressive stress that a mild steel specimen can bear is 407.7 MPa when the diameter of the piston is 25 mm then the maximum load the piston can carry is calculated using equation (1) [8,9].

$$\sigma = \frac{F}{A} \quad (1)$$

Where;

F = Force (N) and A = area of the piston rod (mm^2)

But $$A = \frac{\pi D^2}{4} \quad (2)$$

For D = 25 mm

$$A = \frac{3.142 \times (25)^2}{4}$$

A = 490.93 mm^2
Force = Stress x Area
Force = 407.7 x 490. 93
Force = 200155. 21 N
Since 1 kg force = 9.81 N

Then,

$$\text{Force} = \frac{200155.21}{9.81}$$

Force = 20, 403.18 kg
Also, 1 tonne = 1000 kg
Force = 20.4 tonnes

This means that 20.4 tonnes are the limit of the load the designed jack can carry. Therefore, the 3 tons capacity hydraulic capacity jack is suitable for the hot compression mounting press machine.

2.2 Calculating the Maximum Pressure Inside the Barrel

It is assumed that a weight of 3 tons acts on the piston of the jack. Therefore, the pressure created by the piston in the cylinder can be calculated using equation (3) [8].

$$\text{Pressure} = \frac{\text{force (N)}}{\text{area (mm}^2\text{)}} \quad (3)$$

where;

Area is cross-section of the piston rod and A = 490.93 mm

Force = 3 tons

But 1 tonne = 1000 kg
3 tonnes = 3000 kg

Also, since 1 kg force = 9.81 N

$$\text{Pressure} = \frac{3000 \times 9.81}{490.93}$$

Pressure = 59.9 4 N/mm^2

This implies that 59. 94 N/mm^2 pressure is generated inside the barrel when the hydraulic cylinder is loaded with 3 tons force.

2.3 The Hydraulic Jack Base Design

The base was designed with such specifications that can easily withstand the maximum pressure exerted by the horizontal hydraulic cylinder. The force exerted by the horizontal cylinder should be less than the tones of the hydraulic jack base.

Then, Let the force in tones applied across the channel be;

F = 3 tonnes = 3000 kg x 9.81 m/sec^2
= 29,430 N

Area of channel in which the force will act (A)
= $a^2 - b^2$ (4)

Where;

a is the side of the outer square, and b is the side of the inner square

Let a= 80 mm and b = 70 mm
A = $80^2 - 70^2$ = 1500 mm^2

Therefore, wall thickness of the channel

$$(t) = \frac{a-b}{2} \quad (5)$$

$$t = \frac{(80-70)mm}{2}$$

t = 5 mm

Stress (σ) applied when force of 3 tons is applied = $\frac{\text{force}}{\text{area}}$ (6) [8]

$$\sigma = \frac{29{,}430}{80^2 - 70^2}$$

$$= \frac{29{,}430}{1500}$$

$= 19.62\ N/mm^2$

$= 19.62$ Mpa

Since the above-calculated stress is very much less than the ultimate tensile stress of mild steel SA36 i.e. 407.7 MPa so our design is within the safe unit.

b) The band heater

These are the following specifications used in the design of the band heater:

(i) Dimensions: 60 mm by 60 mm
(ii) Voltage rating: 230 volts
(iii) Maximum heat temperature: 480°C

2.4 Expected Heat Supply Rate by the Band Heater to the Mold

From Fourier's law, we have:

$$q = \frac{2\pi kL(t_1 - t_0)}{In(\frac{r_0}{r_1})} \quad (7)\ [10]$$

Where:

q = rate of heat transfer, k = thermal conductivity of the band heater (aluminized steel) = 89W/m˚C, t_1 = maximum temperature of the band heater = 480˚C, l = length of heater = 0.06 m, t_o= ambient temperature = 25˚C, r_o = outer radius of band heater = 0.03 m, r_1 = inner radius of band heater = 0.026 m and ln = natural logarithm.

$$q = \frac{2 \times 3.142 \times 0.06 \times 89 \times (480-25)}{\ln\frac{0.03}{0.026}}$$

$$q = \frac{15268.32}{0.143}$$

q = 106.77KW

If the mass of the mold is M_1, specific heat capacity of the mold is C_1, and the thermosetting resin material has a mass M_2 with specific heat capacity C_2. The total heating time required to reach thermosetting temperature Ts from the ambient temperature T_r will be:

$$qt = (M_1C_1 + M_2C_2)(T_s - T_r) \quad (8)\ [11]$$

The expected time for the thermosetting resin to reach curing temperature will be:

$$\text{Time (t)} = \frac{(M_1C_1 + M_2C_2)(T_s - T_r)}{q} \quad (9)\ [11]$$

Heat loss from the cylindrical stainless steel mold is given as

$$q = \frac{2\pi kL(t_1 - t_0)}{In(\frac{r_0}{r_1})} \quad (10)$$

q = rate of heat loss (W), k = thermal conductivity of the stainless steel pipe = 17 W/m/k, l = length of pipe = 0.11 m, t_1 = maximum temperature of the heater band = 480˚C, t_2 = ambient temperature = 25˚C, r_1 = external diameter of the mold = 0.056 m and r_o = internal diameter of the mold = 0.042 m

$$q = \frac{2\ X\ 3.142\ X\ 17\ X\ 0.11\ (480-25)}{ln\frac{0.056}{0.042}}$$

$$q = \frac{5346.74}{0.287}$$

q =18629.76 W

2.5 Heat Loss Due to Air Flow

The flow rate of mass (Ma) was determined by the speed of air (Va = 0.15 m/s). The air gap height was taken to be 0.11 m (height of the mold used) while the diameter of the mold is 0.056 m.

The volume flow rate of air (Va) = 0.056 m x 0.11 m x 0.15 m s^{-1}

Va = $9.24 \times 10^{-4}\ m^3 s^{-1}$

The mass flow rate of air will be

$$Ma = V_a \rho_a \quad (11)$$

Where:

ρ_a= density of air at s.t.p = 1.29 kg/m^3 [12]

Therefore,

$M_a = 9.24 \times 10^{-4} \times 1.29$

$= 11.92 \times 10^{-4}$ kg/s

The rate of heat gained by air = $FM_aC_p\ (T_1 - T_2)$ (12) [13]

Where:

C_p = specific heat capacity of air = 1, 005 $Jkg^{-1}K^{-1}$, T_1 = maximum temperature of the band heater = 480˚C and T_2 = ambient temperature = 25̊C

F = 0.1

Therefore, rate of heat gained by air
= 0.1 × 11.92×10^{-4} ×1005 × (480 - 25)
= 54.50 W

The total heat loss = heat loss from the mold + heat loss due to airflow

The total heat loss = 18629.76 W + 54.50 W

Total heat loss = 18684.26 W

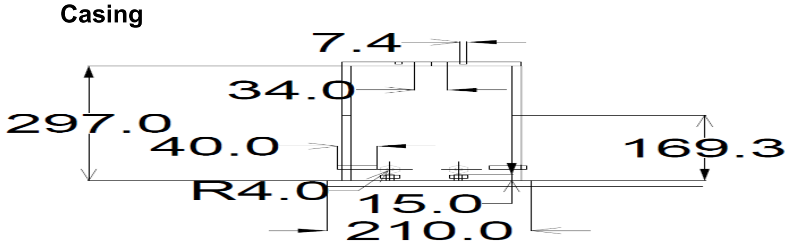
Useful Heat Generated = Maximum Heat Expected to be supplied by the Heating compartment – the total Heat Loss

= 88085.74 W

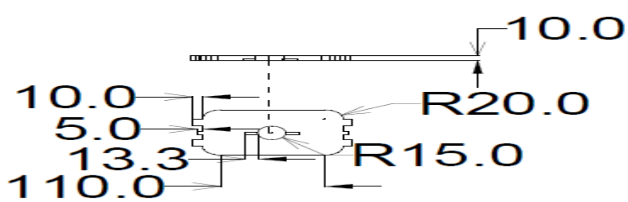
2.6 Design Assembling

The dimensions of some of the machine components as from the designs calculations were as shown:

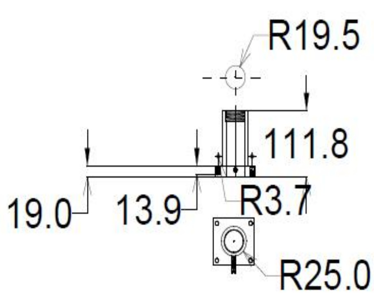
1. Casing



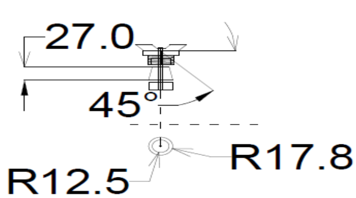
2. Movable platen



3. Mold



4. Mold Cover



(5) Hydraulic Jack with Pressure Gauge

The drawing of the Hydraulic Jack with Pressure Gauge as it was assembled is as shown in Fig. 2.

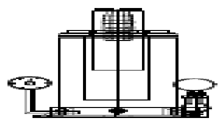


Fig. 2. Pressure Gauge connected to Hydraulic Jack

(6) The components were assembled and the final 3D design of the laboratory Hot Compression Mounting Press Machine is as shown in Fig. 3.

The quantities of machine parts used for the construction of the machine are shown in Table 1.

3. FABRICATION / CONSTRUCTION

The fabrications of the compression hot mounting press machine are as follows:

1. The top plate for casing

The casing was fabricated using a mild steel of 10 mm thickness. After marking out, the steel plate was cut using the cutting disk to the size of 200 mm by 175 mm breadth while the sharp edges of the plate were removed with the aid of the angle grinder as shown in Fig. 4(a).

Table 1. Quantities of Machine Parts listed in Fig. 3

Serial No	Machine Parts	Quantities
1.	Hydraulic jack	1
2.	Bolts	6
3.	Top plate	1
4.	Side plates	2
5.	Bottom plate	1
6.	Movable platen	1
7.	Pressure gauge	1
8.	Contactor	1
9.	Band heater	1
10.	Heat sensor cable	1
11.	Mold	1
12.	Temperature controller	1
13.	Hydraulic press Handle	2

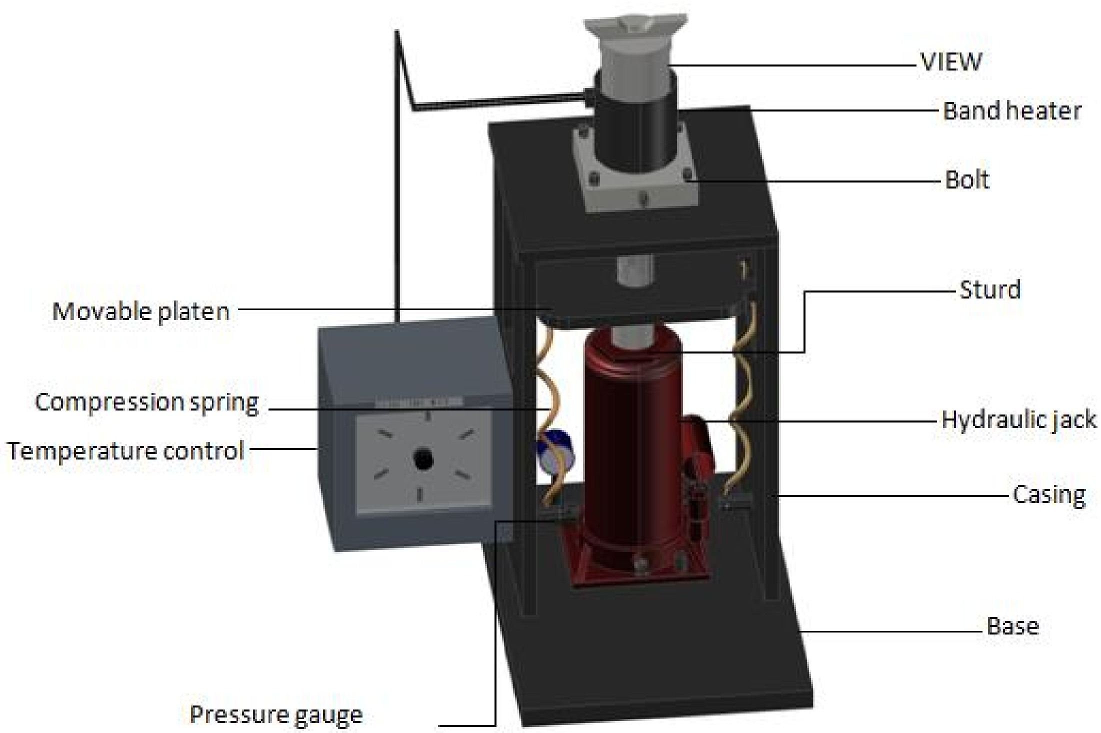


Fig. 3. Final 3D Design of Compression Hot Mounting Press Machine

Fig. 4(a). Cutting the Top Plate for the Casing

Fig. 4(b). Drilling the Top Plate

(a) Drilling: Holes of Ø10 mm were made at the sides of the top plate using the pillar drilling machine to enable the mold to be attached to it by means of bolts as shown in Fig. 4(b).

2. The Side Frames for the Casing

The operations for producing the side plates are as follows:

(a) Cutting and Grinding: After marking out, the 10 mm plate was cut to dimensions of 350 mm length by 200 mm breadth using the cutting disk. Thereafter, the cut sides were grinded with the angle grinder for smooth surface finish and to remove sharp edges as shown in Fig. 4C.

Fig. 4C. Cutting Side Frames for Casing

(b) Drilling: holes of size Ø 10 mm were drilled at the near base end of the side frames.
(c) Welding: small rods of diameter were inserted and welded using the welding machine into the drilled holes for the side plate of the frame.

3. The base for the casing

The following operations were carried out for the base plate:

(a) Cutting and Grinding: The 10 mm steel plate was cut to size 300 mm length by 220 mm breadth after marking out. The subsequent grinding operation was carried out to remove sharp edges of the plate.

4. The mold

The following operations were carried out on the mold using the lathe machine:

(a) Drilling: (b) Tapering; and (c) Threading. These operations were shown in Fig. 4(d)

Fig. 4(d). Operations carried out on Mold using the Lathe Machine

5. Connecting the Pressure Gauge to the Hydraulic Jack

The following steps were carried out to successfully connect the pressure gauge to the hydraulic jack:

(i) The hydraulic fluid was drawn off from the hydraulic jack through the press nipple by means of a siphon;
(j) The cylinder head of the hydraulic jack and its piston were removed using a wrench;
(k) Drilling of the cylinder (the outer cylinder and the barrel) was done with a drilling machine;
(l) A pipe of 5mm diameter was passed into the inner cylinder through the drilled hole in the outer cylinder and the pressure line properly located. The pipe is then welded properly to avoid leakage;
(m) A sealant was then applied to the welded joint to avoid leakage of the hydraulic fluid;
(n) The pressure gauge was then connected to the 5mm diameter pipe which extends

outwards and a screw was used to make its connection tight;

(o) The piston was then replaced into the cylinder barrel and the cylinder head was screwed. The hydraulic press was then filled with the hydraulic fluid and the press nipple was covered.

The operations led to the assembly as shown in Fig. 4e.

Fig. 4(e). Pressure Gauge connected to Hydraulic Jack

6. Assembly of the Parts

The various parts were joined in the following order:

(i) The side plates for the casing were placed standing on the base plate and welded to the base plate using the electric arc welding machine.
(ii) The mold was attached to the top plate and joined by means of bolts to allow firm grip between the mold and the top plate.
(iii) The sturd was inserted into the movable platen and the springs attached to the holder on the platen and also attached to the rods below the near end of the side plates.
(iv) The hydraulic jack was seated at the centre of the base plate directly under the platen. The hydraulic jack handle pipe was inserted into the pumping section for easy operation of the machine.

The entire assembly of the parts that produced the hot mounting press machine is as shown in Figs. 4(f) to 4(g).

7. Finishing operation

The finishing operation carried out includes the following:

(a) Grinding of sharp edges to remove sharp parts which may be injurious to the end users
(b) Use of emery paper to remove oxide film from the surface of the mild steel
(c) Spraying of the mild steel plates with paint to avoid corrosion and make the machine attractive.

Fig. 4(f). Assembly of the Parts

Fig. 4(g). Final Assembly of the Part

4. TESTING

In testing the compression hot mounting press machine, the following materials were used:

(i) A small piece of metal and
(ii) Bakelite resin for mounting.

The following steps were followed in testing the compression hot mounting press machine: All safety rules and practices were observed; the small metallic specimen was inserted into the mold; bakelite was poured into the mold to cover the specimen in the mold; the mold was covered tightly; the band heater was fixed on the mold and the power connected to an external source; the temperature control was also connected to an external power source and was set to a temperature of 150˚C; the band heater and the temperature control were switched on; the Bakelite was left to heat and melt in the mold; pressure was applied via the jack to the stud to compress the resin in the mold; after compression, the heater and the temperature control were switched off and the resin was left to cure in the mold; the mold cover was opened and the sturd was lifted up by lifting the jack cylinder to raise up the specimen out from the mold; the pressure valve on the jack was released to compress the hydraulic cylinder via the movable platen and the compression spring; and the mold cover was cleaned and the mold was covered [14,15].

5. RESULTS

The result of the operation from the developed compression (hot) mounting press machine showed a metallic specimen which was well encapsulated by the mounting resin (Bakelite) as shown in Fig. 5(a) to 5(b).

Fig. 5(a). Specimen before Mounting

Fig. 5(b). Specimen after Mounting

6. COST ESTIMATE AND COMPARISON

The cost estimate for the complete execution of this project is summarized as in Table 2.

6.1 Cost of Imported Compression (Hot) Mounting Press Machine (By Hst Manufacturer)

From literature searched, it was seen that a compression (hot) Mounting Press Machine costs $1200 (₦432,000) (conversion rate of $1 to N360) depending on the type and model of the machine which is higher than the above-mentioned price. This cost includes the cost of shipping but without the cost of import duties and VATS; including the cost of import duties and VATS puts the overall cost of the machine on a high side.

From the cost estimated above, it was observed that the total cost for the laboratory mounting press machine produced using locally sourced material in Nigeria and through the indigenous technology is ₦92,500. Comparing the cost of this locally made machine to the imported one, it is much lesser than the cost of purchasing an imported mounting press machine since the cost of importation, payment of tax and time for shipment is taken into consideration which puts the purchase of the imported machine on a high side.

Table 2. Cost Estimate for the Developed Machine

S/N	Materials, equipment and processes	Cost (₦)	Location
1	Band Heater	3,000	Akure
2	Temperature controller (0°C to 400°C)	3,000	Akure
3	3 tons Hydraulic Jack	2,500	Akure
4	Purchase of 10 mm Steel Plate	10,000	Akure
5	Fabrication of Steel Frame	15,000	Akure
6	Purchase and Fabrication of stainless steel mold	20,000	Akure
7	Bolts	500	Akure
8	Pressure Gauge	1,500	Akure
9	Literature Search	5,000	
10	Testing	5,000	
11	Drawing (AutoCAD)	14,000	
12	Finishing	8,000	
13	Miscellaneous	5,000	
	TOTAL	92,500	

7. CONCLUSIONS

The study showed how an environmentally and user- friendly laboratory hot mounting press machine was made using locally sourced materials in Nigeria. It solved the problem faced on the acquisition of a laboratory mounting press machine by Nigerian Universities, research institutes and steel industries.

The following conclusions were drawn from the research:

- **(i) From the design:** The laboratory compression (hot) mounting press machine was produced using a simple design which was easy to operate and users-friendly. The design was based on the use of a hydraulic jack which lifts and applies pressure to the specimen in the mold and a heater which converts electrical energy to heat energy for melting the mounting resin.
- **(ii) From the Construction / Fabrication:** Laboratory compression (hot) mounting press machine can be produced from locally available materials to meet the specification of the imported compression (hot) mounting press machine. The mounting material is reasonably strong, hard and has easy handling. Thus, the mounting material is suitable for use for grinding and polishing purposes.
- **(iii) Testing:** The hot compression mounting press machine was successfully tested using the necessary materials needed such as Bakelite and metal specimen. It was found that the developed machine performed very well the imported machine.
- **(iv) Cost Analysis:** From research, it was seen that a hot compression mounting press machine costs $1200 which is ₦432,000 and with locally sourced materials a locally made users-friendly compression hot mounting press machine was produced at ₦92,000 saving an extra amount of ₦340,000.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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