British Journal of Applied Science & Technology
12(6): 1-31, 2016, Article no.BJAST.21558
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Design and Fabrication of a Cost Effective Four Cavity Plastic Injection Mould for Bottled Water Handle

H. C. Godwin[1], H. E. Chukwu[1*] and M. C. Nwosu[1]

[1]Department of Industrial/Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author HEC designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors HCG and MCN scrutinized and managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/21558
Editor(s):
(1) Grzegorz Golanski, Institute of Materials Engineering, Czestochowa University of Technology, Poland.
Reviewers:
(1) Brahmananda Pramanik, Montana Tech of the University of Montana, USA.
(2) Chun-Ching Hsiao, National Formosa University, Taiwan.
(3) Kazushi Yamada, Kyoto Institute of Technology, Japan.
(4) Obiekea Kenneth Nnamdi, Ahmadu Bello University, Zaria, Nigeria.
Complete Peer review History: http://sciencedomain.org/review-history/12079

Original Research Article

Received 23rd August 2015
Accepted 1st October 2015
Published 3rd November 2015

ABSTRACT

Design and fabrication of a cost effective four cavity plastic injection mould for production of bottled water handle with locally available materials has been achieved. This research is appropriate considering the impact on sales of a sampled company that used handles for their bottled water before the scarcity of handles as a result of monopoly in importation. The clamping force which is a function of cavity pressure, cavity force and projected area was obtained as 243.2239N. The maximum deflection and the maximum bending stress were calculated to be 2.3282 x 10^{-3} mm and 4.4677 x 10^{5} N/m^{2} respectively. The impact of the handle on the rate of return of the sampled company was tested. It was observed that before the introduction of handle, the Return on Investment (ROI) was approaching 30% and when handle was introduced, the ROI increased to 46.34% and 46.05% for the locally and foreign made handles respectively. However, the ROI declined to 34.41% when the handle was removed in both cases. This clearly shows that the handle has a great impact on the bottled water sales and that the market share for bottled water

**Corresponding author: E-mail: chukwuhillaryejike@gmail.com;*

industries is expected to increase due to public acceptability. Also, the introduction of handle allowed for better convenience in carrying bottled water especially the 1.5 litre sizes.

Keywords: ROI; bottled water handle; regime.

NOMENCLATURES

F_i	–	*Cavity Force*
F	–	*Clamp Force*
W	–	*Uniformly Distributed Load (UDL) as a result of the Clamping Force*
w	-	*Load per Unit length across the face of the mould,* $Uniform\ load\ on\ the\ beam$
l	–	*Length of the beam, Length of the mould face*
E	–	*Modulus of elasticity*
I	–	*Area moment of Inertia*
M	–	*Maximum Bending Moment*
b	–	*Length of horizontal side of the cross-section*
h	–	*Length of vertical side of the cross-section*
Q	–	*Volume flow of the intended resin to be used*
L	–	*Length of Part being considered*
D	–	*Runner diameter*
S_{max}	–	*Maximum wall thickness of the molded part*
R	–	*Hydraulic depth of Runner*
S	–	*Cross-Sectional Area of Runner*
ΔP	–	*Pressure loss at the Gate*
μ	–	*Viscosity of resin*
F_E	=	*Ejection Force*
F_W	=	*Ejection Load*
ROI	–	*Return on Investment*

1. INTRODUCTION

Nowadays, Injection moulding represents a large portion of the entire plastics processing industry and plastic is now one of the most widely used material in the world, according to Pattnaik et al. [1]. Among various plastic production technologies, injection moulding counts for a significant proportion of all plastic products from micro to macro components stated by Garvey [2].

Today, medical experts are encouraging people to drink water always for vitality. Because of this, demand for bottled water has increased as people tend to carry water about.

According to Weissmann [3], the introduction of handle on bottled water started with the introduction of handles on large size extrusion blow moulded containers which made them more user-friendly, especially where the total weight of the package reached several kilos in household product containers, and where larger weights of 5 to 20-litre containers were involved. Therefore, it is no wonder that handles can be found on most large bottles today, including household chemicals, garden chemicals, automotive fluids, beverage containers (non-carbonated), edible oil bottles, and even the 1.75-litre liquor bottles.

In Nigeria today, the standard sizes for bottles of bottled water are 20 liter, 1.5 liter, 0.75 liter and the 0.5 liter Polyethylene Terephthalate (PET). The 20 liter bottles are for water dispensers which cannot be carried about while the 1.5 liters, 0.7 liters and the 0.5 liters are used to package other things, including bottle water, and they can easily be carried about. The bottles are usually blow moulded.

Introduction of injection moulded polyethylene handles to be attached on the neck of the bottled water of smaller sizes of 1.5 liters and the 0.75 liter sizes has become necessary to enhance better convenience in carrying bottled water and increased acceptance by consumers.

This paper presents the design and fabrication of a four cavity Bottled Water Handle Mould. Also the impact of the handle on a sampled company was ascertained to show the level of public acceptability.

2. DESCRIPTION OF THE MOULD

Just like most moulds, the "four cavity bottled water handle mould" is separated into two sides at a parting line, the "A" side, and the "B" side, to permit the part to be extracted. Plastic resin enters the mould through a sprue in the "A" plate, which branches out between the two sides through channels called runners, and enters each part cavity through a gate. Inside each cavity, the resin flows around cores and conforms to the cavity geometry to form the handles. The amount of resin required to fill the sprue, runner and cavities of a mould is a shot. When a core shuts off against an opposing mould cavity or core, a hole results in the part. Air in the cavities when the mould closes escapes through very slight gaps between the plates and pins, into shallow vents created along the ejection pin.

To permit removal of the part, none of its features was allowed to overhang one another in the direction that the mould opens. Sides of the handles that appear parallel with the direction of draw are typically angled slightly with draft to ease release of the handles from the mould. Because areas in the cavities with bucket-like features tend to shrink onto the cores that form them while cooling, and cling to those cores when the cavity is pulled away; the mould is designed so that the moulded handle reliably remains on the ejector "B" side of the mould when it opens by making the bucket-like features remain on the "B" side, and draws the runner and the sprue out of the "A" side along with the handles. The handles then fall freely when ejected from the "B" side. The resin for the handle is thermoplastic, therefore, coolant, usually water with corrosion inhibitors, will circulates through passageways bored through the main plates on both sides of the mould to enable temperature control and rapid part solidification.

To ease maintenance and venting, cavities and cores are divided into pieces, called inserts, and subassemblies, also called inserts, blocks, or chase blocks. Fig. 2.1 depicts moulds and it component parts.

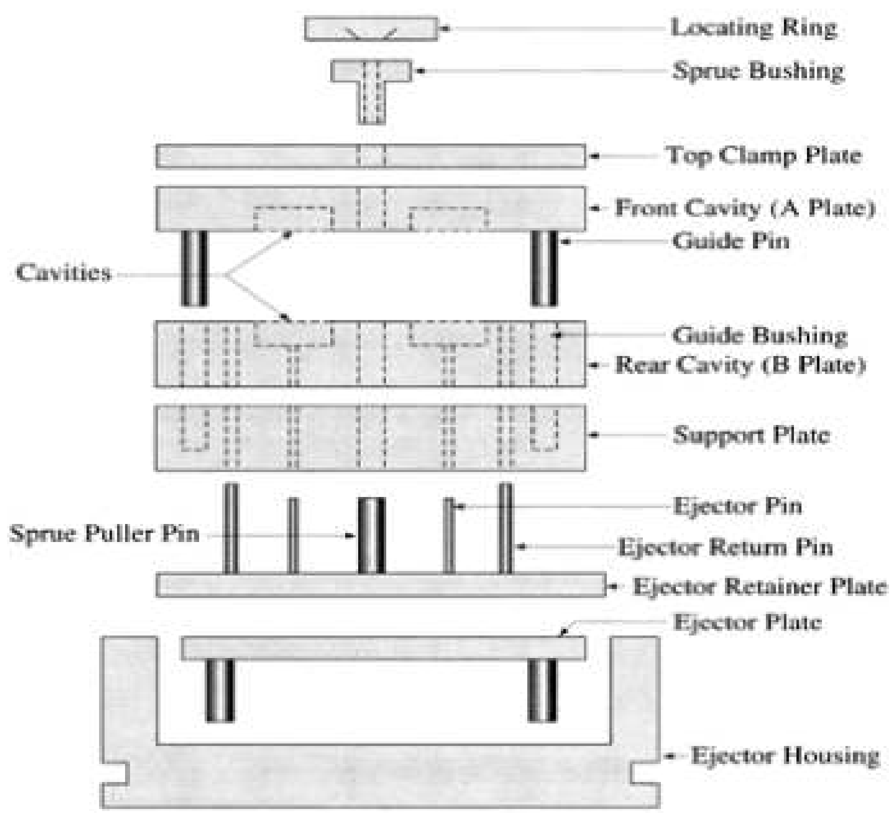

Fig. 2.1. Moulds and its component parts

2.1 Design Considerations

During the mould design, these important considerations and precautions were taken to ensure that the mould meets the required international standard in mould design as in the works of Bayer Corporation [4] and Gupta and Khurmi [5]:

1. Material that will be most suitable for the design.
2. The clamping force for the mould.
3. Availability of material locally.
4. Maintainability.
5. Cost of manufacture.
6. Suitability to local consumers.
7. The cavity features was design to easy separation of the two sides of the mould.

2.2 Design Specifications

The following design specifications were taken into consideration:

a. Mould should be able to withstand loading of 5 tons.
b. Density of material used must be less than that of lead
c. The clamping position of the mould must be inculcated during design to prevent it from slipping.
d. Material used must withstand the melting temperature of resin (about 200℃)
e. The mould is designed to have a proper resting base on the machine platens.
f. Tough and stiff Materials were selected to withstand maximum loading of 5 tons and ensured material does not wear easily.
g. The cavity must have uniform wall thickness.
h. Avoided sharp corners in the design. Sharp inside corners concentrate stresses from mechanical loading, substantially reducing mechanical performance.
i. Provided minimum draft angles or tapers of 0.5° on all product features such as walls, ribs, posts, and bosses that lie parallel to the direction of release from the mould to ease part ejection.
j. The mould is designed so that the cores can separate from the part in the mould-opening direction.

2.3 Design Calculations

The method used for determining the required clamp force was to obtain the product of the projected area of the part to be moulded and a factor of 2 to 8 tons per square inch which is the maximum machine capacity (tonnage) the mould is being designed for. According to Hieber and Isayev, [6], the lower tonnage can be used for high flow materials and the higher tonnage for low flow (stiff) materials. High Density Polyethylene (HDPE) is used and it is a high flow material. Therefore, being on a safe side, an average of 5 tons/in^2 was used.

5 * 6.89 x 10^{-3} MPa or N/mm^2 [conversion factor from lb_f/in^2 (psi) to MPa (N/mm^2)] Cavity Pressure = 3.45 x 10^{-2} MPa.

2.3.1 Projected area determination

Fig. 2.2 shows the diagram of the designed Bottled Water Handle showing labels which indicate the different cross-sections that are present on the handle. These sections are labeled according to the similarity of the figures they represent to aid in the projected area calculation. Each of the labeled areas is demarcated with a yellow line; for instance, label "A" represent a semicircular cross-section while label "B" represents a rectangular cross-section and so on.

The average thickness of the product is estimated to be 2 mm, hence estimated shot volume =6409.06*2 =12818.12 mm^3.

Therefore, the projected area is **6409.06 mm^2**; it substitute in equation (1) to obtain;

$$F_i = P * A \qquad (1)$$

F_i – Cavity Force
P – Cavity pressure
A – Projected Area

$$\therefore \text{Cavity Force}, F_i = 221.11 \text{ N}$$

$$\text{Therefore, Clamping Force}, F = 221.11 + 10\% \, F_i$$

$$= 221.11 + 22.11$$

$$\therefore F = 243.22 \text{ N}$$

The force on the face of the mould which is equal to the clamping force is a Uniformly Distributed Load (UDL).

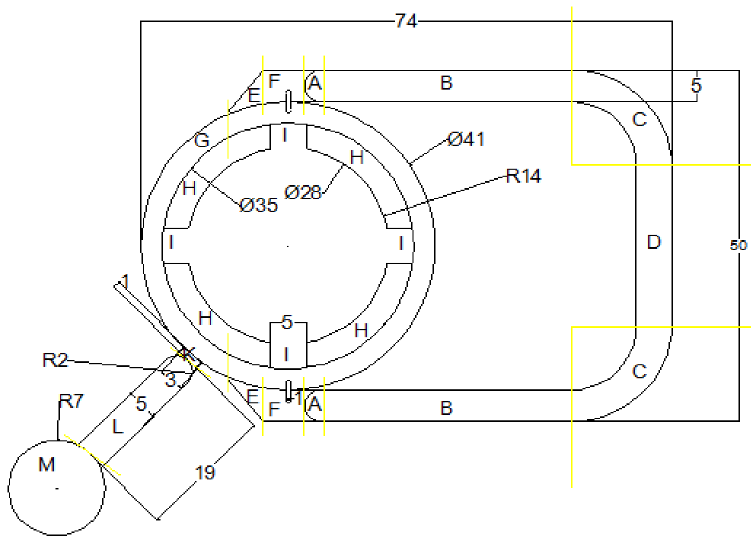

Fig. 2.2. Cross-section of handle showing the dimensions and labels

S/N	Portion label	Number per cavity	Number on mould	Formula used for the section	Unit area (mm^2)	Area on cavity (mm^2)	Total area on mould (mm^2)
1	A	2	8	$\frac{\pi r^2}{2}$-	39.30	78.60	314.40
2	B	2	8	Lb	185.00	370.00	1480.00
3	C	2	8	$\frac{1}{4}[\pi R^2 - \pi r^2]$-	90.32	180.64	722.56
4	D	1	4	Lb	110.00	110.00	440.00
5	E	2	8	$\frac{1}{2}[bh]$-	19.25	38.50	154.00
6	F	2	8	$lb - \frac{\pi r^2}{2}$-	32.87	65.73	262.92
7	G	1	4	$\frac{1}{4}[\pi R^2 - \pi r^2]$-	358.14	358.14	1432.56
8	H	4	16	$\frac{1}{4}[\pi R^2 - \pi r^2]$-lb	69.09	276.36	1105.44
9	K	1	4	Lb	3.00	3.00	12.00
10	L	1	4	Lb	85.50	85.50	342.00
11	M	1	1	πr^2-	143.14	143.14	143.14
				Total projected area			**6409.06**

2.3.2 Determination of the reactions R_A and R_B at supports "A" and "B"

$$R_A+R_B = W \tag{2}$$

Taking moment about 'A', we have

For Equilibrium,

+ve

$$\sum M_A = 0 \tag{3}$$

$\therefore R_A = 121.61$ N and $R_B = 121.61$ N

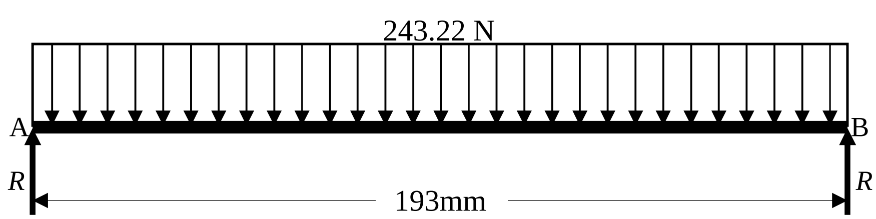

Fig. 2.3. The Free Body Diagram (FBD) of the force acting on the face of the mould at maximum clamping force

2.3.3 Determination of Shear Force (SF) equation at any given point on the face plate

$$V_x = R_A - wx \quad (4)$$

$$V_x = 121.61 - 1.26x$$

2.3.4 Determination of Bending Moments (BM) on the mould

$$M = \frac{wx}{2}(l - x) \quad (5)$$

Note:

$$\frac{dM}{dx} = \frac{wl}{2} - wx = V_x$$

However, @ x $= \frac{l}{2}$, M has its maximum value

$$\therefore \mathrm{M}_{max} = 5.87 \text{ Nm}$$

2.3.5 Determination of maximum deflection on the mould

According to Bayer Corporation [4], Maximum elastic deflection (at the mid-point along l) of a beam under a uniform load is given as follows:

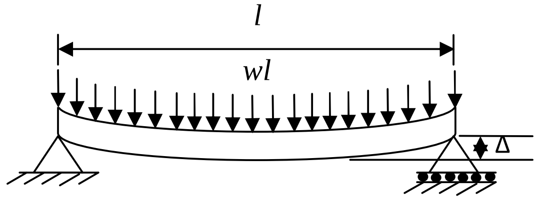

Fig. 2.4. Rectangular face plate showing details of deflection

$$\Delta_{max} = \frac{5wl^4}{384EI} \quad (6)$$

Where,

w − Uniform load on the beam (force per unit length)
l − length of the beam
E − Modulus of elasticity
I − Area moment of Inertia

For tool steel, E is at the range of 190 – 212. For the sake of this work, it adopt 190 GPa = 190 x 10^9 N/m^2 = 190 x 10^3 N/mm^2.

But,

$$I = \frac{bh^3}{12} \quad (7)$$

$$b = 197\ mm, and\ h = 20\ mm$$

$$I = \frac{193 * 20^3}{12}$$

$$I = 128666.67\ mm^4$$

$$\therefore \Delta_{max} = 2.3282\text{x}10^{-3}\ mm$$

2.3.6 Determination of maximum bending stress on the mould

The maximum bending stress for a rectangular cross section could be given as stated below according to Bayer Corporation [4].

$$\text{Maximum Bending Stress, } \sigma_{max} = \frac{\mathrm{Mc}}{\mathrm{I}} = \frac{\mathrm{M}}{\mathrm{Z}} = \frac{6\mathrm{M}}{\mathrm{bh}^2}$$

$$\sigma_{max} = \frac{6\mathrm{M}}{\mathrm{bh}^2} \quad (8)$$

M – Maximum Bending Moment
b – Length of horizontal side of the cross-section
h – Length of vertical side of the cross-section

$$c = \frac{h}{2} \quad (9)$$

Z − Sectional Modulus, $\frac{I}{c}$

$$\sigma_{max} = 4.4677\text{x}10^5\ \mathrm{N/m^2}$$

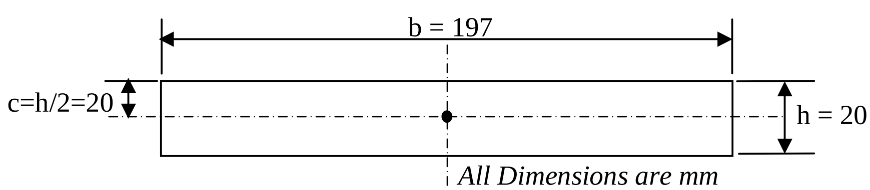

Fig. 2.5. Rectangular cross-section of the face plate

2.4 The Material Selection

The choice of material to build a mould is primarily one of economics. To select the adequate material for the design, the first step was to translate the design requirements, which was done in section 2.1, into a material specification. Making reference to the Ashby's Chart according to Ashby [7], materials that fail constraints in the specification were screened out to obtain the go/no-go criteria. Then the next was ranking (an ordering of the materials that fall within the "go" criteria) by ability to meet objectives in other words called Material Indices. The promising candidates (materials) were sought for. The next step is to seek, from the subset of materials which satisfy the primary constraints, those which maximize the performance of the component. For instance, for the design of stiff components; the modulus E is plotted against density ρ, on log scales of the Ashby chart. The performance index (tension on stiff beam) is given as shown:

$$C = \frac{E}{\rho} \quad (10)$$

Taking logs of equation (1),

$$\log E = \log \rho + \log C \quad (11)$$

This is an equation of the form y = m*x* + b which is a family of straight parallel lines; one line for each value of the constant C. The slope is always 1 and log C is the y intercept. The index for bending on beam is:

$$C = \frac{E^{\frac{1}{2}}}{\rho} \quad (12)$$

Equation (3) will gives another family of lines, this time with a slope of 2.

The index for bending on light-stiff plate is:

$$C = \frac{E^{\frac{1}{3}}}{\rho} \quad (13)$$

Equation (4) will gives another family of lines, this time with a slope of 3.

All materials which lie on ISO-line of $\frac{E^{\frac{1}{2}}}{\rho}$ will perform equally well.

To obtain the optimum material, other Ashby material selection charts that highlight other material qualities were considered. They as stated below:

- Strength – Density chart: $\frac{\sigma_f}{\rho}, \frac{\sigma_f^{\frac{2}{3}}}{\rho}$ and $\frac{\sigma_f^{\frac{1}{2}}}{\rho}$
- Fracture Toughness – Density chart: $\frac{K_{IC}^{\frac{4}{3}}}{\rho}, \frac{K_{IC}}{\rho}, \frac{K_{IC}^{\frac{4}{5}}}{\rho}, \frac{K_{IC}^{\frac{2}{3}}}{\rho}$, and $\frac{K_{IC}^{\frac{1}{2}}}{\rho}$
- Modulus – Relative Cost chart. $C_R = \frac{\text{c/kg of material}}{\text{c/kg of mild steel rod}}$

Finally steel was most favour because it satisfies the criteria:

- Economic machinability
- Smallest change in size upon heat treatment
- Good polishability
- Great compressive strength
- High wear resistance
- Sufficient corrosion-resisting quality

2.5 Manufacturing Processes

Once the design is completed manufacturing begins. Mould making involves many steps which include:

- Marking-Out
- Milling and turning
- Heat-treating
- Grinding and honing
- Electrical discharge machining
- Polishing and texturing

To save cost, common mould components are purchased from suppliers e.g. bolts.

When all of the parts are completed the next step is to fit, assemble and test the mould. The mould must have venting features added to allow the air to escape as earlier stated in the vent design. At last, the mould must be tested to insure the products are correct and that the mould is performing properly.

2.6 The Operation Process Chart

The Fig. 2.6 represents the operational process involved in the manufacture of the mould. The mould is made of two major parts, the cavity and the core. Under the cavity, are the female base plate, female face plate, the sprue bush and the locating ring. While on the core are the male base plate, male face plate, face plate support, locating pin, ejector plate and the ejector pin. Under each are circles and rectangular boxes that indicate the operations and the events taken to produce individual parts before finally assembling them to form the cavity and the core respectively.

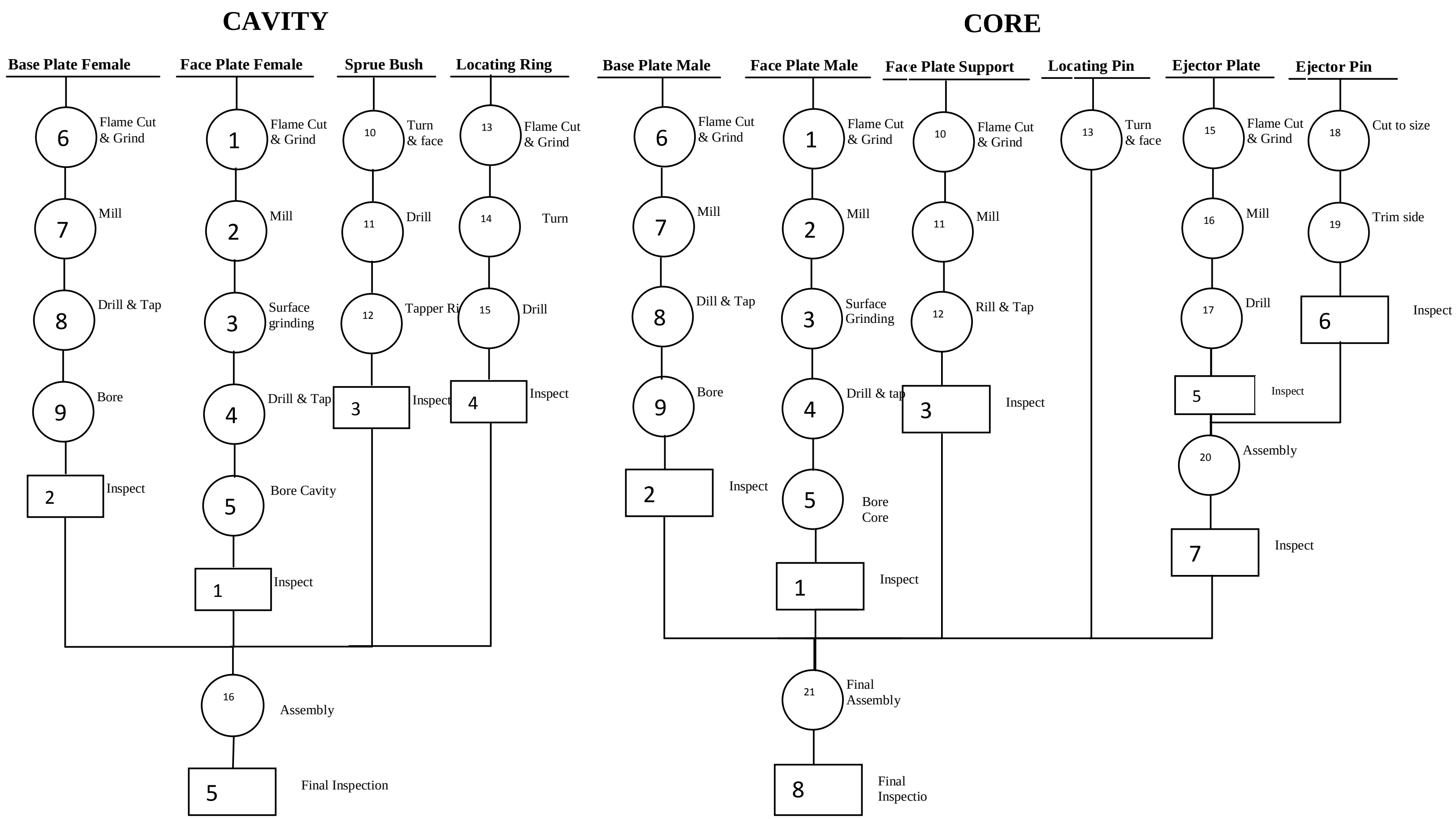

Fig. 2.6. The operation process charts

2.7 Exploded View of Mould

Below is the exploded view of the manufactured mould showing all the parts arranged for assembly.

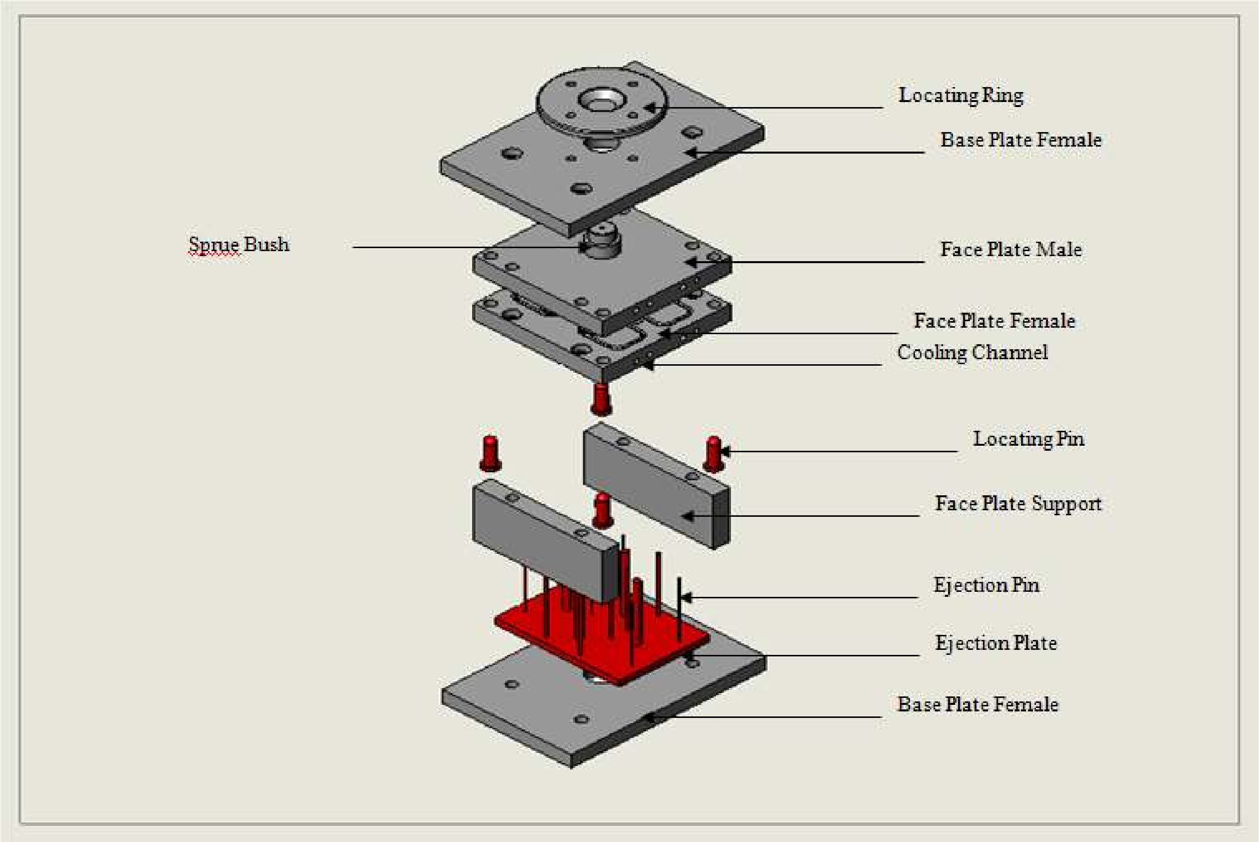

Fig. 2.7. The exploded views of the mould

3. COST ANALYSIS

For a 50 kg material, revenue accrued is given as:

Revenue, R = Cost of Production, C + Profit, P

$$R = C + P \tag{14}$$

Cost, C = Overhead + Transport + Material Cost
Profit, P = Markup, M * Cost, C
From [online] [8] and Jeremiah and Amos [9],
Corporate Tax Rate = 30%
Inflation Rate = 7.9%
Interest Rate, i= 13%

3.1 Weighted Average Cost of Capital (WACC)

$$\text{WACC} = \%\,\text{Debt} * i + \%\,\text{Equity} * r \tag{15}$$

$$\text{WACC} = 0\% * 13\% + 100\% * 18\%$$

$$\therefore \text{WACC} = 18\%$$

3.2 Minimum Acceptable Rate of Return (MARR)

$$\therefore \text{MARR}_{\text{Before Tax}} = \frac{\text{MARR}_{\text{After Tax}}}{(1 - \text{Effective Tax Rate})} \tag{16}$$

From Jeremiah et al. (2013), $\text{MARR}_{\text{After Tax}}$ is at least equal to WACC

$$\therefore \text{MARR}_{\text{Before Tax}} = \frac{0.18}{(1-0.3)} = \frac{0.18}{(0.7)} = 25.71\%$$

Therefore, Markup = 25.71%

For a 50 kg material, the costs are attached as below:

Material cost = ₦ 10000
Transport = ₦ 500
Overhead = ₦ 5021.59
Profit, P = ₦3990.60

$$M_p = 5021.59 + 500 + 10000 + 3990.60$$

$$M_p = ₦19512.20$$

$$R = \frac{R_a * M}{50000\text{g}} \tag{17}$$

R − Revenue from a handle
R_a − Revenue accrued from 50 kg material
M − Mass of a handle (g)

After weighing the handle, it was observed that the weight is 2.314 g; fraction of the runner, sprue and gate weight is 1.72 g.

Therefore, $2.31 + 1.72 = 4.03\text{g}$.

$$\therefore \text{Cost of a Handle} \cong \textbf{₦1.60}$$

3.3 Cost of Introducing Handle in a Company

3.3.1 Work measurement

Table 3.1 shows the “Cycle Study Form” and the time obtained for the element in the work measurement.

To obtain the time taken by a worker to fix one handle on a bottled water, work measurement, which involves motion and time study, was carried out as stated in Table 3.1. Equation (18) shows how the average time was obtained mathematically.

$$T_{av} = \frac{\sum t_o}{N} \tag{18}$$

T_{av} − Average time taken to fix one handle on a bottle

$\sum t_o$ − sum of observed time

N − number of observations

Average time taken to fix one handle on a bottle = 10.50 sec
Average time taken to fix handles on one dozen = 10.50 x 12 = 126 sec
Available working time in a month = 25 days x 8 hrs = 200 hrs/month
= 200 x 3600 = 720,000 sec/month
Average salary of a factory worker for a month = ₦ 18000

$$S = \frac{S_m}{W_T} \tag{19}$$

S − salary of a staff per second
S_m − Salary for one month
W_T − Available working time in a month

Average salary of a staff per second

$$= \frac{18000}{720000} = ₦0.03 \text{ per Sec}$$

$$L = S * T_d \tag{20}$$

L-Labour Cost for hanging handles on a dozen of bottled water
S − salary per second
T_d − time to fix handle on one dozen

Therefore, labour cost of hanging handles on a dozen of bottle water = 0.025 x 126 = ₦ **3.15**

Other cost incurred as a result of introducing the handle for a dozen:

Transportation = ₦ 1.00
Disinfectant = ₦ 3.775
Total = ₦ 4.78

Recall, cost of one handle = ₦ 1.60
Hence, cost of handle for a dozen = ₦ 1.60 x 12 = ₦ 19.20 /Dozen
Therefore, extra cost incurred as a result of introducing Handle for one dozen = Cost of one Dozen of Handle + Labour + Other Cost Incurred
= 19.20 + 3.15 +4.78 = ₦ 27.125 /Dozen

3.4 Tabulated Costs of Material for Conventional Bottled Water

The tables show the materials and their cost for making conventional bottled water without the consideration of the cost of handle.

Table 3.1. Cycle study form

S/N	Element	Observed Time, OT (Sec)										Total OT	Ave. OT	R	BT
		1	2	3	4	5	6	7	8	9	10				
1	Hanging of handle on bottle water	10.80	10.60	10.50	10.70	10.60	10.40	10.40	10.30	10.30	10.40	105	10.50		

Note: OT = Observed Time, R = Rating, BT = Basic Time

Table 3.2. Cost of one dozen of 50 cl bottle water

S/N	Description	Quantity	Unit cost (₦)	Cost (₦)
1	Bottle	12	15	180
2	Label	12	3	36
3	Water	12	0.15	1.8
4	Cover	12	2.5	30
5	Shrink wrap	1	5	5
			Total Cost	**252.8**

Table 3.3. Cost of one dozen of 75 cl bottle water

S/N	Description	Quantity	Unit Cost (₦)	Cost (₦)
1	Bottle	12	17	204
2	Label	12	5	60
3	Water	12	0.225	2.7
4	Cover	12	2.5	30
5	Shrink wrap	1	7	7
			Total Cost	**303.7**

Table 3.4. Cost of one dozen of 150 cl bottle water

S/N	Description	Quantity	Unit Cost (₦)	Cost (₦)
1	Bottle	12	21	204
2	Label	12	5.5	66
3	Water	12	0.45	5.4
4	Cover	12	2.5	30
5	Shrink wrap	2	7	14
			Total Cost	**367.4**

3.5 Return on Investment (ROI) Analysis

In order to make decision on which of the investment regime to invest in, return on investment (ROI) analysis is used. This enabled us to choose which of the investment regime has a better return.

$$\mathrm{ROI} = \frac{\mathrm{R_i} - \mathrm{I_c}}{\mathrm{I_c}} \tag{21}$$

ROI- Return on Investment

$\mathrm{I_c}$ – Investment Cost

This analysis was done on the three regimes as stated below:

3.5.1 Considering the response of the locally made handle

3.5.1.1 Before handle regime

$$\mathrm{R_{BHR}} = \sum \mathrm{Av_{BHR}} \tag{22}$$

$\mathrm{R_{BHR}}$ – Average sales of a dozen of the bottled Water sizes before handle regime

$$\mathrm{R_{BHR}} = [\ (\mathrm{A_{50clBHR}}) + (\mathrm{A_{75clBHR}}) + (\mathrm{A_{150clBHR}})] \tag{23}$$

$\mathrm{R_{BHR}}$ – Revenue from Investment

$\mathrm{A_{50clBHR}}$ – Average sales of 50 cl bottled Waterbefore handle regime

$\mathrm{A_{75clBHR}}$ – Average sales of 75 cl bottled Waterbefore handle regime

$\mathrm{A_{150clBHR}}$ – Average sales of 150 cl bottled Waterbefore handle regime

$$\mathrm{I_{cBHR}} = \sum \mathrm{A_{pBHR}} \tag{24}$$

$\mathrm{I_{cBHR}}$ – Average Cost of producing a dozen of the bottled Water sizes before handle regime

$$\mathrm{I_{cBHR}} = [\ (\mathrm{I_{c50clBHR}}) + (\mathrm{I_{c75clBHR}}) + (\mathrm{I_{c150clBHR}})] \tag{25}$$

$\mathrm{I_{cBHR}}$ – Investment Cost

$\mathrm{I_{c50clBHR}}$ – Average Cost of producing a dozen of 50 cl before handle regime

$\mathrm{I_{c75clBHR}}$ – Average Cost of producing a dozen of 75 cl before handle regime

$\mathrm{I_{c150clBHR}}$ – Average Cost of producing a dozen of 150 cl before handle regime

3.5.1.2 During handle regime

$$\mathrm{R_{DHR}} = \sum \mathrm{Av_{DHR}} \tag{26}$$

$\mathrm{R_{DHR}}$ – Average sales of a dozen of the bottled Water sizes During handle regime

$$\mathrm{R_{DHR}} = [\ (\mathrm{A_{50clDHR}}) + (\mathrm{A_{75clDHR}}) + (\mathrm{A_{150clDHR}})] \tag{27}$$

$\mathrm{R_{DHR}}$ – Revenue from Investment

$\mathrm{A_{50clDHR}}$ – Average sales of 50 cl bottled Water During handle regime

$\mathrm{A_{75clDHR}}$ – Average sales of 75 cl bottled Water During handle regime

$\mathrm{A_{150clDHR}}$ – Average sales of 150 cl bottled Water During handle regime

$$\mathrm{I_{cDHR}} = \sum \mathrm{A_{pDHR}} \tag{28}$$

I_{cDHR} – Average Cost of producing a dozen of the bottled Water sizes before handle regime

$$I_{cDHR} = [\ (I_{c50clDHR}) + (I_{c75clDHR}) + (I_{c150clDHR})] \tag{29}$$

I_{cDHR} – Investment Cost

$I_{c50clDHR}$ – Average Cost of producing a dozen of 50 cl During handle regime

$I_{c75clDHR}$ – Average Cost of producing a dozen of 75 cl During handle regime

$I_{c150clDHR}$ – Average Cost of producing a dozen of 150 cl During handle regime

3.5.1.3 After handle regime

$$R_{AHR} = \sum Av_{AHR} \tag{26}$$

R_{AHR} – Average sales of a dozen of the bottled Water sizes After handle regime

$$R_{AHR} = [\ (A_{50clAHR}) + (A_{75clAHR}) + (A_{150clAHR})] \tag{27}$$

R_{AHR} – Revenue from Investment

$A_{50clAHR}$ – Average sales of 50 cl bottled Water After handle regime

$A_{75clAHR}$ – Average sales of 75 cl bottled Water After handle regime

$A_{150clAHR}$ – Average sales of 150 cl bottled Water After handle regime

$$I_{cAHR} = \sum A_{pAHR} \tag{28}$$

I_{cAHR} – Average Cost of producing a dozen of the bottled Water sizes After handle regime

$$I_{cAHR} = [\ (I_{c50clAHR}) + (I_{c75clAHR}) + (I_{c150clAHR})] \tag{29}$$

I_{cAHR} – Investment Cost

$I_{c50clAHR}$ – Average Cost of producing a dozen of 50 cl After handle regime

$I_{c75clAHR}$ – Average Cost of producing a dozen of 75 cl After handle regime

$I_{c150clAHR}$ – Average Cost of producing a dozen of 150 cl After handle regime

4. RESULTS

The design was done with the proper engineering design procedure and the following results were obtained.

The cost of introducing handle was determined; also the difference in the Cost/mass was obtained between the foreign and locally made handle and presented in the table.

4.1 Comparison of Locally Made Handle and Foreign Handle

The locally made handle showed a significant reduction in weight to that of the foreign made handle. This reduction also shows that the material usage is reduced from the cost/mass ratio column. This in turn shows a reduction in cost of production.

4.1.1 Financial implication of using bottle water handle

From section 3.2, the cost of handle was obtained as ₦ 1.60per handle. This value was in turn used to obtain the cost of introducing handle into the bottled water company in section 3.3 to be ₦ 27.13 /Dozen. Furthermore, with reference to the sales data presented in Appendix AI, the rate of return on investment (ROI) as a result of this extra cost.

4.1.2 Considering the response of the locally made handle

The graph above represents the response of the Locally Made Handle. The graph shows that before the introduction of handle, the ROI was approaching 30% and when handle was introduced, the ROI increased to 46.34%. However, the ROI took a nose dive when the handle was removed to the tune of 34.41%.

4.1.3 Considering the response of the foreign made handle

The graph above represents the response of the Foreign Made Handle. The graph shows that before the introduction of handle, the ROI was approaching 30% and when handle was introduced, the ROI increased to 46.05%. However, the ROI took a declined to 34.41% when the handle was removed.

Table 4.1. Results from mechanical design

S/N	Features	Numerical values
1	Cavity Pressure.	0.03 MPa
2	Projected Area Determination	6409.06 mm^2
3	Clamping Force	243.22 N.
4	Reactions at the supports R_A and R_B	121.61 N
5	Determination of Shear Force (SF)	$V_x = 121.61 - 1.26x$
6	Determination of Bending Moments (BM) on the mould	5.87 Nm
7	Maximum Deflection	2.3282×10^{-3} mm
8	Maximum Bending Stress	4.4677×10^5 N/m^2

Table 4.2. Comparison of locally made handle and foreign handle

Handle type	Cost (₦)	Mass (g)	Cost/Mass ratio (₦/g)
Foreign	2.50	2.47	1.01
Local	1.60	2.31	0.69
Difference	0.90	0.16	0.32

Table 4.3. locally made handle responses

	Before handle regime (%)	During handle regime (%)	After handle regime (%)
Response of Locally Made Handle (ROI)	29.69	46. 34	34.41

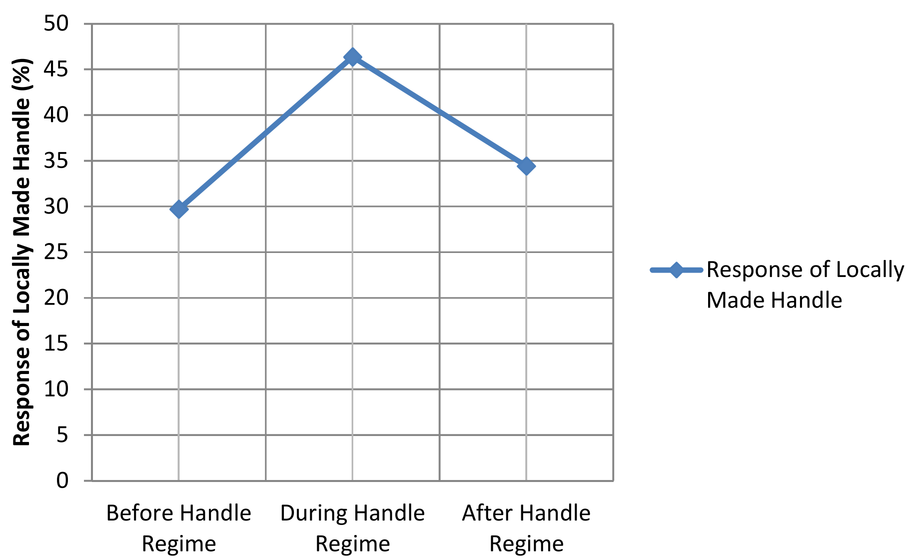

Fig. 4.1. Response of locally made handle

Table 4.4. Foreign made handle responses

	Before handle regime (%)	During handle regime (%)	After handle regime (%)
Response of foreign made handle	29.69	46.05	34.41

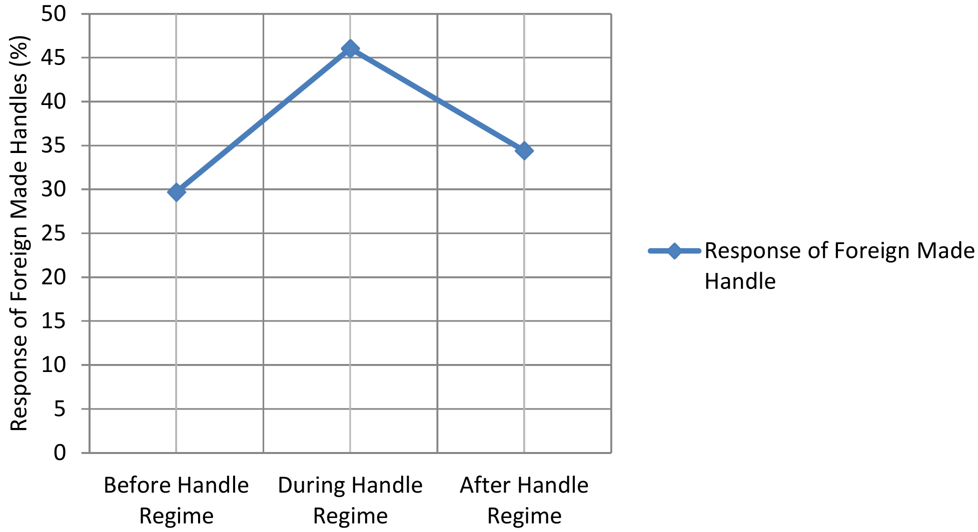

Fig. 4.2. Response of foreign made handle

5. DISCUSSION

The design results as obtained shows that maximum deflection is 2.33 x 10^{-3} mm. Therefore, the deflection obtained is minimal, therefore is negligible. The maximum bending stress is 4.4677 x 10^5 N/m^2 this indicates that the material can withstand the stress as the yield strength, S_y and ultimate tensile strength, S_u of steels are within the values 5.1x10^8 N/m^2 and 7.1x10^8 N/m^2 according to Todd et al. [10].

The cost of introducing handle was determined; also the difference in the Cost/mass was obtained between the foreign and locally made handle and presented in the table.

It was presented that the difference in cost/mass ration is 0.3199 N/g. This means that in every 50 kg of handle, the bottled water company saves:

50000 x 0.32 = ₦ 15995.

This amount of money saved is significant enough to encourage the bottled water companies in Nigeria.

5.1 Comparing the Responses of the Locally and the Foreign Made Handle

The graph above represents the superimposition of the responses of the locally and Foreign Made Handle. The graph curves show that before the introduction of handle, the ROI was approaching 30 % and when handle was introduced, the ROI increased to 46.34 % and 46.05 % for the locally and foreign made handles respectively. This 0.29 % difference during the introduction of handle could be attributed to ₦ 0.90 (₦ 2.50 - ₦ 1.60) in foreign and locally made handle price. However, the ROI took a declined to 34.41 % when the handle was removed in both cases though this is still higher than the response at the initial time before the introduction of handle. This is

Table 4.5. Comparison of foreign and locally made handle responses

	Before handle regime (%)	During handle regime (%)	After handle regime (%)
Response of locally made handle	29.69	46.34	34.41
Response of foreign made handle	29.69	46.05	34.41

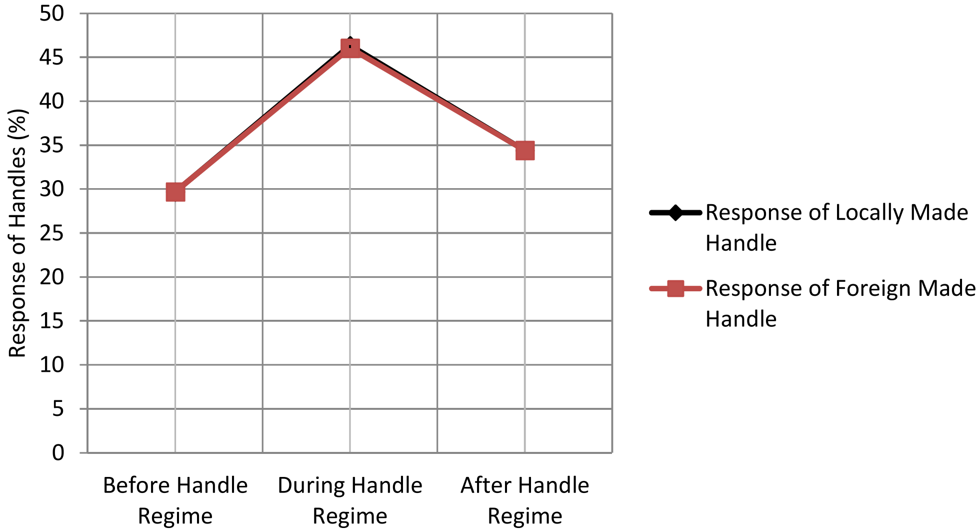

Fig. 5.1. Comparing the responses of the locally and the foreign made handle

attributed to the fact that the company still retains some of the market share gained during the introduction of handle.

6. CONCLUSION

This work has demonstrated the ability to design and manufacture an injection mould for bottled water handle from locally available materials. With the increase in the number of bottled water industries, this project would have a profitable application in bottled water production due to increased demand for bottled water. The simplicity of the design and the availability of materials for the mould design, and the handle from local petrochemical industries make this work practicable. The impact of the handle on the financial returns of the sampled company is enough reason to encourage bottled water companies to venture into the use of handle for their smaller sizes, 1.5 liter and 0.75 liter, of bottled water. Nevertheless, the cost incurred as a result of introduction of handle to the bottled water is small compared to the benefit accrued to the company. Commercializing this will be cheap and economically viable to the mould manufacturing industry, the plastic industry and the bottled water industry.

In the future, it is recommended that more work be done on the optimization of number of cavities for economic use of machines. Also, it is recommended that more research work be done to ascertain the acceptability of the product owning to the effect of the handle noticed on the company as reported in this work.

Therefore, we recommend that local plastic industries should embark on the production of bottled water handle for local consumption. Also, bottled water companies should patronize local manufacturers of bottled water handle at reduced cost.

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance given to us by Scientific Equipment Development Institute (SEDI), Enugu, Nigeria by allowing us use their equipments and facilities in the course of this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pattnaik SR, Karunakar DB, Jha PK. Application of computer simulation for finding optimum gate location in plastic injection moulding process. International Journal of Advanced Engineering Research and Studies, IJAERS/Vol. I/ Issue II/January- March, 2012, E-ISSN2249–8974, 2012, 159-161.

2. Garvey EB. On-line quality control of injection moulding using neural networks. Master's thesis, Applied Science and Information Technology, Department of Computer Science, Royal Melbourne Institute of Technology, Melbourne, Australia; 1997.
3. Weissmann Dan, Plastics in Packaging, Sayers Publishing Group. November 27; 2012.
4. Bayer Corporation, Part and Mould Design Guide, Pittsburgh, PA 15205-9741. 1 800-622-6004; 2000. Available:http://www.bayer.com/polymers-usa,
5. Gupta JK, Khurmi RS, Theory of machines (ed), Eurasia Publishing House, New Delhi; 2008.
6. Hieber CA. In Isayev AI. (ed) Injection and compression molding fundamentals, New York: Marcel Dekker. 1987;703.
7. Ashby MF. Materials selection in mechanical design, Butterworth Heinemann, 1999, Chapters 1-4.
8. Available:www.ieconomics.com/nigeria-corporate-tax-rate-forecast, (accessed: 11th. June, 2015)
9. Jeremiah U Idialu, Amos O. Arowoshegbe. Toward a reliable cost of capital department of accounting, Ambrose Alli University, Ekpoma, Edo State, Nigeria; 2013.
10. Todd Robert H, Allen Dell K, Alting Leo. Manufacturing Processes Reference Guide. Industrial Press, Inc; 1994.

APPENDIXES

Appendix I

Data showing the weekly sales and financial details of bottle water before, during and after the use of bottle water handle by Impact Pharmaceuticals ltd, Opposite Anamco, Emene Indusial Layout, Enugu. November, 2014-January, 2015.

Table App I-1. Data Showing the weekly sales and financial details of bottle water before the use of bottle water handle

	Sales before the use of bottle water handle (₦)					
	50cl		**75cl**		**150cl**	
	Quantity (Dozens)	**Cost (₦) ₦300 Each**	**Quantity (Dozens)**	**Cost (₦) ₦400 Each**	**Quantity (Dozens)**	**Cost (₦) ₦600 Each**
November 2007 week						
1	119	35700	219	87600	14	8400
2	113	33900	221	88400	12	7200
3	117	35100	227	90800	17	10200
4	118	35400	225	90000	16	9600
December 2007 week						
1	113	33900	217	86800	15	9000
2	121	36300	230	92000	19	11400
3	118	35400	227	90800	13	7800
4	116	34800	222	88800	14	8400
January 2008 week						
1	114	34200	221	88400	20	12000
2	116	34800	231	92400	14	8400
3	120	36000	226	90400	12	7200
4	116	34800	217	86800	16	9600
February week						
1	116	34800	213	85200	13	7800
2	113	33900	228	91200	17	10200
3	121	36300	223	89200	14	8400
4	119	35700	233	93200	16	9600
March week						
1	113	33900	212	84800	25	15000
2	118	35400	222	88800	13	7800
3	111	33300	231	92400	11	6600
4	122	36600	225	90000	14	8400

Before handle regime				
		50cl	**75cl**	**150cl**
	Mean Quantity	116.7	223.5	15.25
	Mean Sales	35010	89400	9150

Table App I-2. Data showing the weekly sales and financial details of bottle water during the use of bottle water handle

Sales during the use of bottle water handle (₦)						
	50cl		**75cl**		**150cl**	
	Quantity (Dozens)	**Cost (₦) ₦320 Each**	**Quantity (Dozens)**	**Cost (₦) ₦500 Each**	**Quantity (Dozens)**	**Cost (₦) ₦650 Each**
April week						
1	125	40000	229	114500	19	12350
2	124	39680	245	122500	20	13000
3	131	41920	263	131500	21	13650
4	130	41600	267	133500	27	17550
May week						
1	133	42560	273	136500	25	16250
2	130	41600	292	146000	23	14950
3	125	40000	330	165000	31	20150
4	129	41280	263	131500	32	20800
June week						
1	127	40640	260	130000	22	14300
2	135	43200	306	153000	27	17550
3	136	43520	296	148000	31	20150
4	132	42240	299	149500	33	21450
July week						
1	128	40960	300	150000	23	14950
2	127	40640	288	144000	28	18200
3	131	41920	292	146000	29	18850
4	135	43200	283	141500	34	22100
August week						
1	126	40320	294	147000	26	16900
2	134	42880	309	154500	30	19500
3	133	42560	317	158500	31	20150
4	137	43840	305	152500	35	22750

During handle regime				
		50cl	**75cl**	**150cl**
	Mean Quantity	130.4	285.55	27.35
	Mean Sales	41728	142775	17777.5

Table App I-3. Data showing the weekly sales and financial details of bottle water after the use of bottle water handle

	Sales after the use of bottle water handle (₦)					
	50cl		75cl		150cl	
	Quantity (Dozens)	Cost (₦) ₦300 Each	Quantity (Dozens)	Cost (₦) ₦420 Each	Quantity (Dozens)	Cost (₦) ₦600 Each
September week						
1	118	35400	221	92820	13	7800
2	113	33900	228	95760	19	11400
3	119	35700	233	97860	21	12600
4	120	36000	231	97020	25	15000
October week						
1	122	36600	230	96600	13	7800
2	114	34200	233	97860	20	12000
3	124	37200	235	98700	22	13200
4	121	36300	234	98280	21	12600
November week						
1	111	33300	232	97440	12	7200
2	129	38700	235	98700	23	13800
3	121	36300	229	96180	18	10800
4	111	33300	231	97020	19	11400
December 2008 week						
1	131	39300	227	95340	15	9000
2	119	35700	232	97440	18	10800
3	103	30900	237	99540	19	11400
4	115	34500	233	97860	21	12600
January 2009 week						
1	101	30300	231	97020	13	7800
2	113	33900	233	97860	18	10800
3	135	40500	234	98280	22	13200
4	120	36000	230	96600	17	10200

After handle regime				
		50cl	**75cl**	**150cl**
	Mean Quantity	117.8	231.45	18.45
	Mean Sales	35340	97209	11070

Appendix II

MATLAB Programme for Plots

Programme for 50cl Response

```
a1=[119 113 117 118 113 121 118 116 114 116 120 116 116 113 121 119 113 118 111 122];%Quantity of 50cl sold before the use of handle
mean(a1)%Mean Quantity of 50cl sold before the use of handle
b1=[125 124 131 130 133 130 125 129 127 135 136 132 128 127 131 135 126 134 133 137];%Quantity of 50cl sold during the use of handle (but without handle)
mean(b1)%Mean Quantity of 50cl sold during the use of handle
c1=[118 113 119 120 122 114 124 121 111 129 121 111 131 119 103 115 101 113 131 120];%Quantity of 50cl sold after the use of handle
mean(c1)%Mean Quantity of 50 cl sold after the use of handle
x1=a1.*300;%Price of corresponding quantity sold before the use of handle
mean(x1)%Mean Sales of 50cl sold before the use of handle
y1=b1.*300;%Price of corresponding quantity sold during the use of handle
mean(y1)%Mean Sales of 50cl sold during the use of handle
z1=c1.*300;%Price of corresponding quantity sold after the use of handle
mean(z1)%Mean Sales of 50cl sold after the use of handle
plot(a1,x1,'k-*',b1,y1,'k-o',c1,z1,'k-s')
grid on
xlabel('Quantity Sold Per Week(Dozens)')
ylabel('Sales(Naira)')
title('Response of 50cl During the three Regime')
legend('S1=300Q1','S2=300Q2','S3=300Q3',0); %Creates Legend and position it @ best fit
```

Programme for 75cl Response

```
a2=[219 221 227 225 217 230 227 222 221 231 226 217 213 228 223 233 212 222 231 225];%Quantity of 75cl sold Before the use of Handle
mean(a2)%Mean Quantity of 75cl sold before the use of handle
b2=[229 245 263 267 273 292 330 263 260 306 296 299 300 288 292 283 294 309 317 305];%Quantity of 75 cl sold During the use of Handle
mean(b2)%Mean Quantity of 75cl sold during the use of handle
c2=[221 228 233 231 230 233 235 234 232 235 229 231 227 232 237 233 231 233 234 230];%Quantity of 75 cl sold After the use of Handle
mean(c2)%Mean Quantity of 75cl sold after the use of handle
x2=a2.*400;%Price of corresponding quantity sold before the use of handle
mean(x2)%Mean Sales of 75cl sold before the use of handle
y2=b2.*(475-20.4);%Price of corresponding quantity sold during the use of handle
mean(y2)%Mean Sales of 75cl sold during the use of handle
z2=c2.*420;%Price of corresponding quantity sold after the use of handle
mean(z2)%Mean Sales of 75 cl sold after the use of handle
plot(a2,x2,'k-*',b2,y2,'k-o',c2,z2,'k-s')
grid on
xlabel('Quantity Sold Per Week(Dozens)')
ylabel('Sales(Naira)')
title('Response of 75cl During the three Regime')
legend('S1=400Q1','S2=(475-20.4)Q2','S3=420Q3',0); %Creates Legend and position it @ best fit
```

Programme for 150cl Response

```
a3=[14 12 17 16 15 19 13 14 20 14 12 16 13 17 14 16 25 13 11 14];%Quantity of 150cl sold Before the use of Handle
mean(a3)%Mean Quantity of 150cl sold before the use of handle
b3=[19 20 21 27 25 23 31 32 22 27 31 33 23 28 29 34 26 30 31 35];%Quantity of 150 cl sold During the use of Handle
```

```
mean(b3)%Mean Quantity of 150cl sold during the use of handle
c3=[13 19 21 25 13 20 22 21 12 23 18 19 15 18 19 21 13 18 22 17];%Quantity of 150 cl sold After the use of Handle
mean(c3)%Mean Quantity of 150cl sold after the use of handle
x3=a3.*600;%Price of corresponding quantity sold before the use of handle
mean(x3)%Mean Sales of 150cl sold before the use of handle
y3=b3.*(700-20.4);%Price of corresponding quantity sold during the use of handle
mean(y3)%Mean Sales of 150cl sold during the use of handle
z3=c3.*600;%Price of corresponding quantity sold after the use of handle
mean(z3)%Mean Sales of 150cl sold after the use of handle
plot(a3,x3,'k-*',b3,y3,'k-o',c3,z3,'k-s')
grid on
xlabel('Quantity Sold Per Week(Dozens)')
ylabel('Sales(Naira)')
title('Response of 150 cl During the three Regime')
legend('S1=600Q1','S2=(700-20.4)Q2','S3=600Q3',0); %Creates Legend and position it @ best fit
```

From Matlab programme, the mean values, as stated below, were obtained as:

Mean Quantity and Sales for 50cl bottle water handle

Results

Mean Quantity of 50cl sold before the use of handle = 116.7000 Dozens
Mean Quantity of 50cl sold during the use of handle = 130.4000 Dozens
Mean Quantity of 50cl sold after the use of handle = 117.8000 Dozens

Mean Sales of 50cl sold before the use of handle = ₦35010
Mean Sales of 50cl sold during the use of handle = ₦39120
Mean Sales of 50cl sold after the use of handle = ₦35340

Mean Quantity and Sales for 75cl bottle water handle

Mean Quantity

Mean Quantity of 75cl sold before the use of handle = 223.5000 Dozens
Mean Quantity of 75cl sold during the use of handle = 285.5500 Dozens
Mean Quantity of 75cl sold after the use of handle = 231.4500 Dozens

Mean Sales

Mean Sales of 75cl sold before the use of handle = ₦89400
Mean Sales of 75cl sold during the use of handle = ₦129810
Mean Sales of 75cl sold after the use of handle = ₦97209

Mean Quantity and Sales for 150cl bottle water handle

Mean Quantity

Mean Quantity of 150cl sold before the use of handle = 15.2500 Dozens
Mean Quantity of 150cl sold during the use of handle = 27.3500 Dozens
Mean Quantity of 150cl sold after the use of handle = 18.4500 Dozens

Mean Sales

Mean Sales of 150cl sold before the use of handle = ₦9150
Mean Sales of 150cl sold during the use of handle = ₦19145
Mean Sales of 150cl sold after the use of handle = ₦11070
Average quantity sold during the use of handle = 285.55 + 27.35 = 312.9
Average Cost of using handle = 312.9 x 20.4 = ₦6383.16

Appendix III

Engineering Drawing

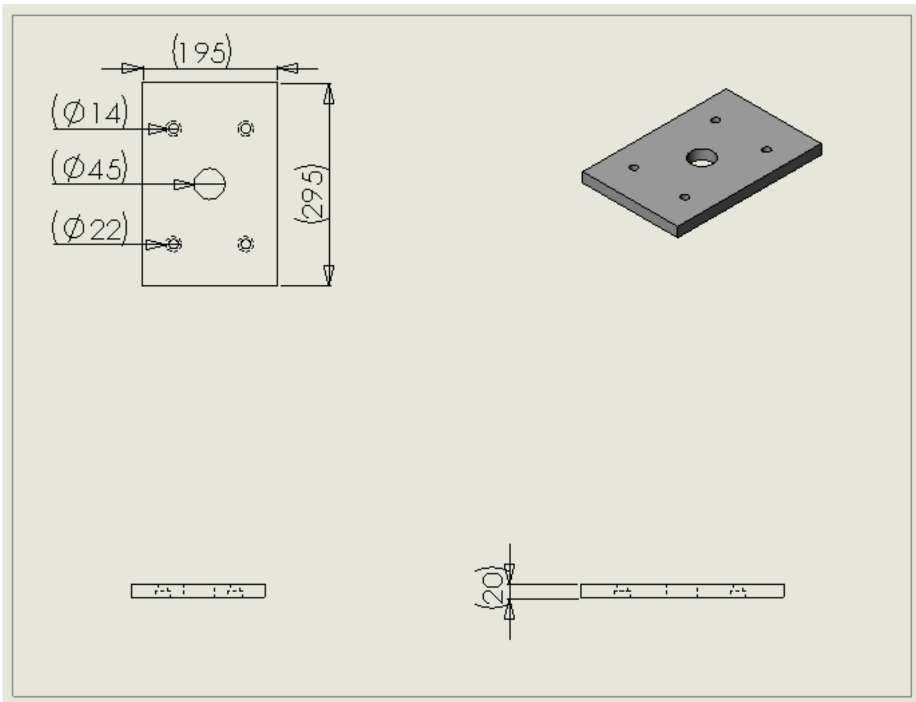

Fig. AIII-1. Back plate for male

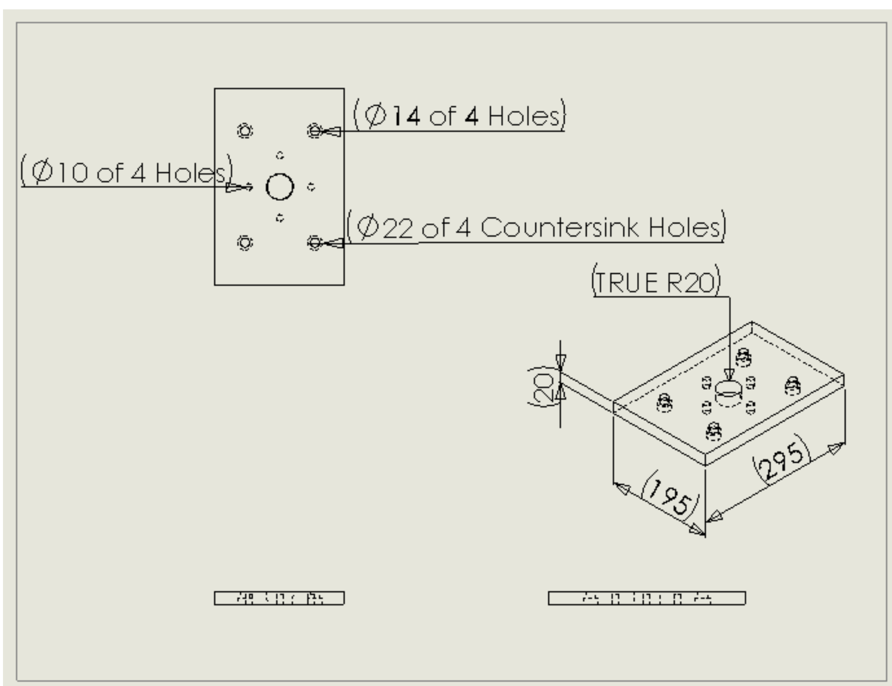

Fig. AIII-2. Back plate for female

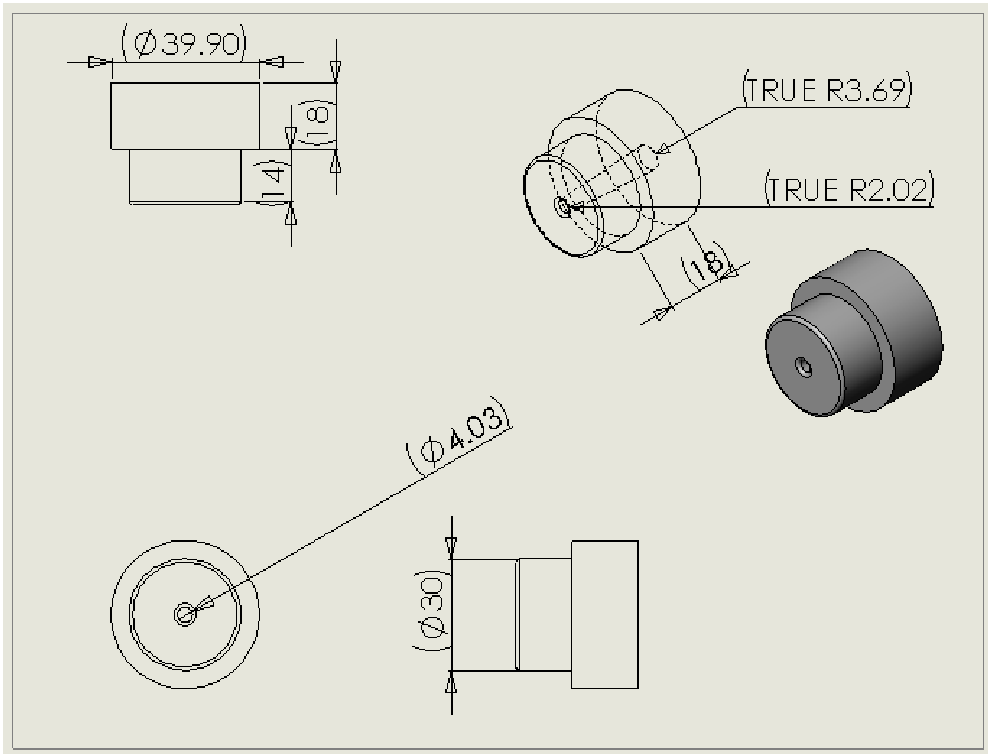

Fig. AIII-3. Sprue bush

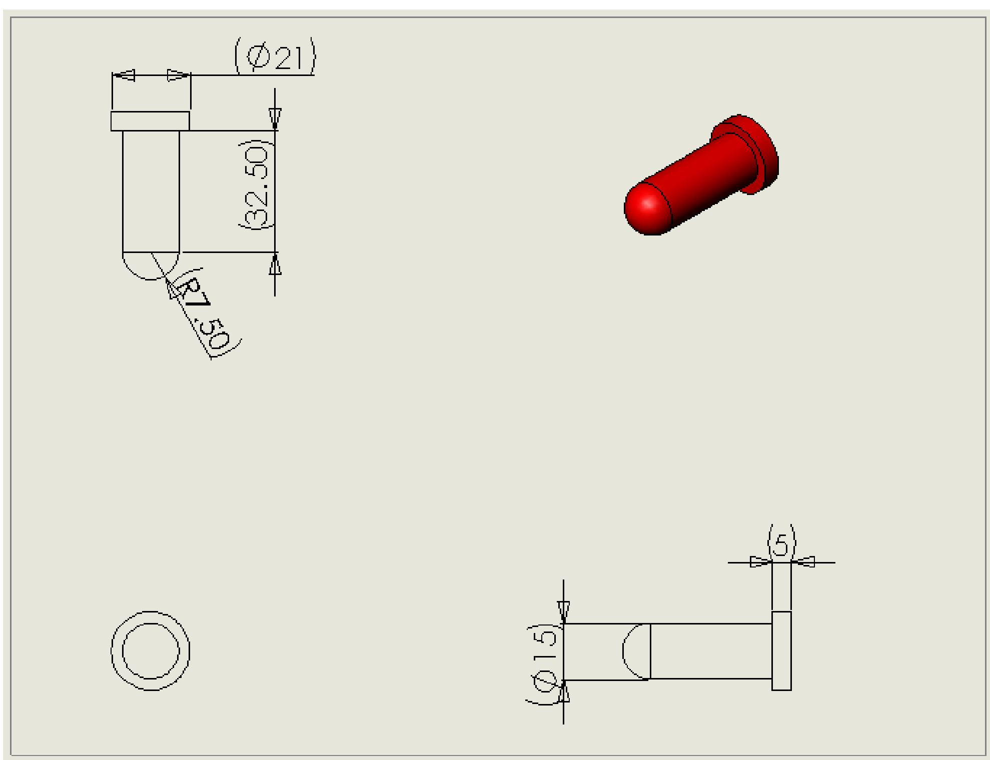

Fig. AIII-4. Locating pin

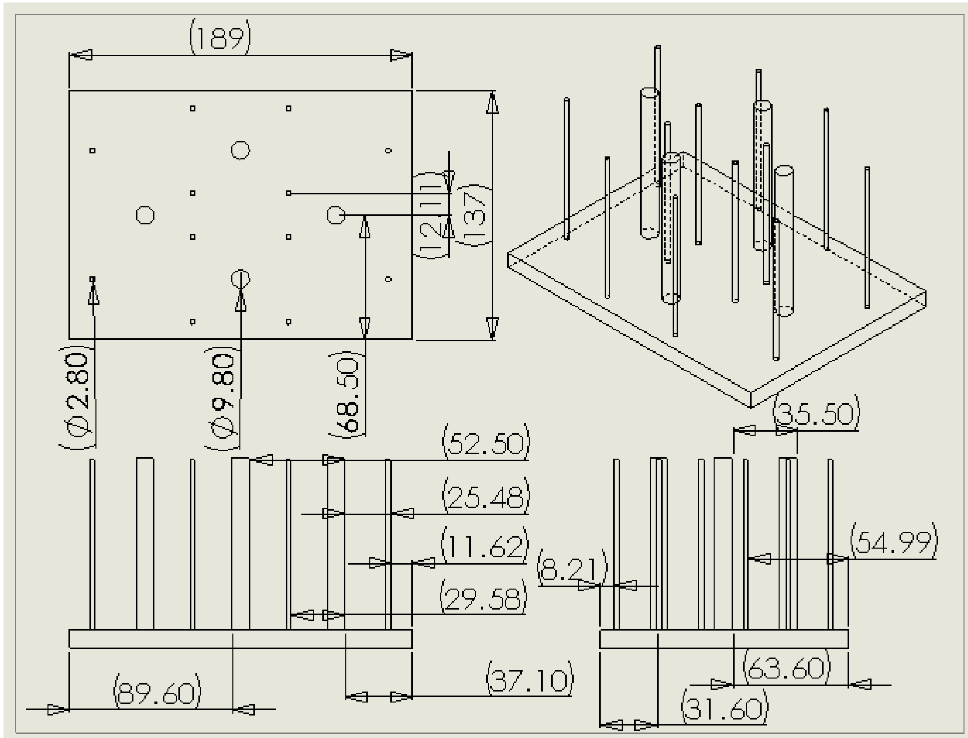

Fig. AIII-5. Ejection plate with ejection pins and guide pins

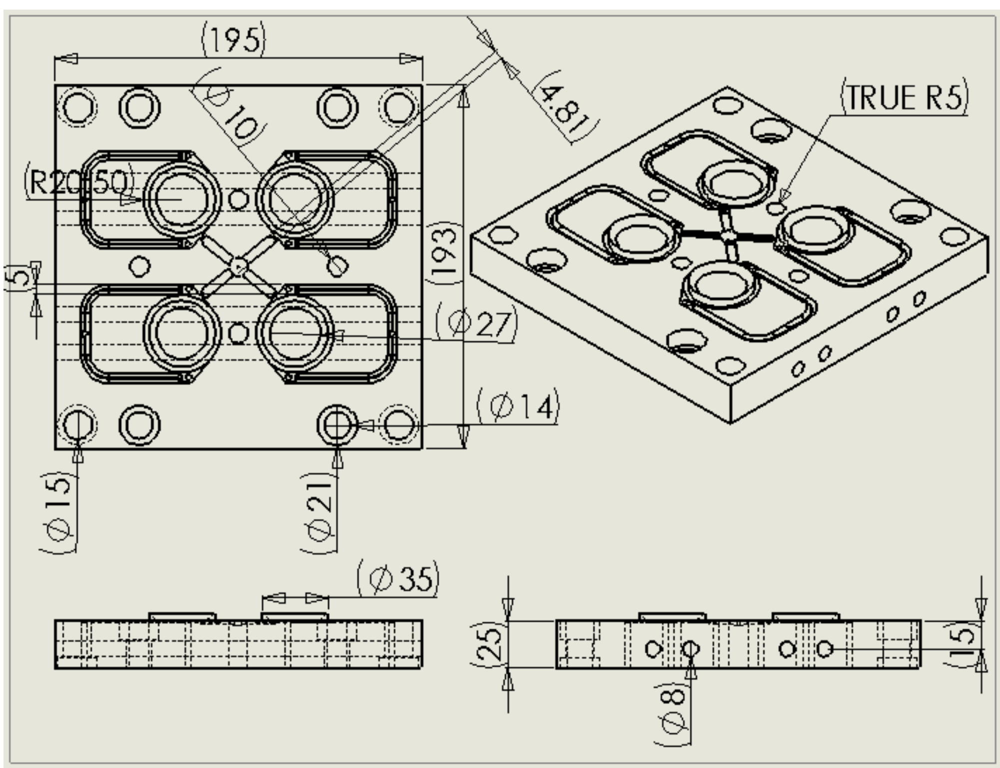

Fig. AIII-6. Face plate projections (male)

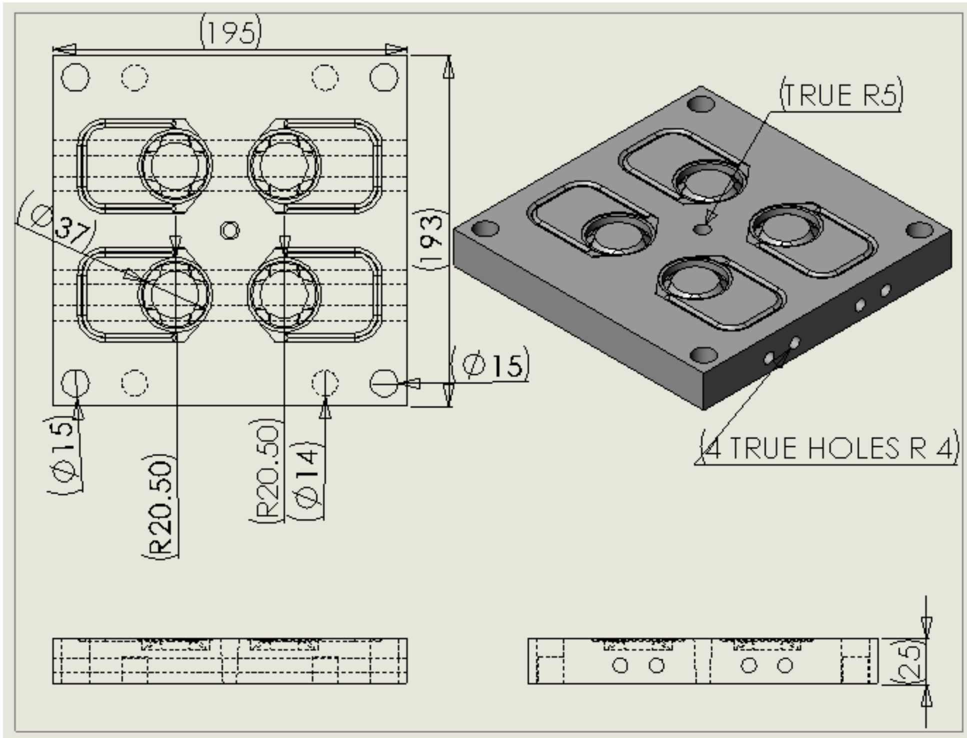

Fig.AIII-7. Face plate projections (female)

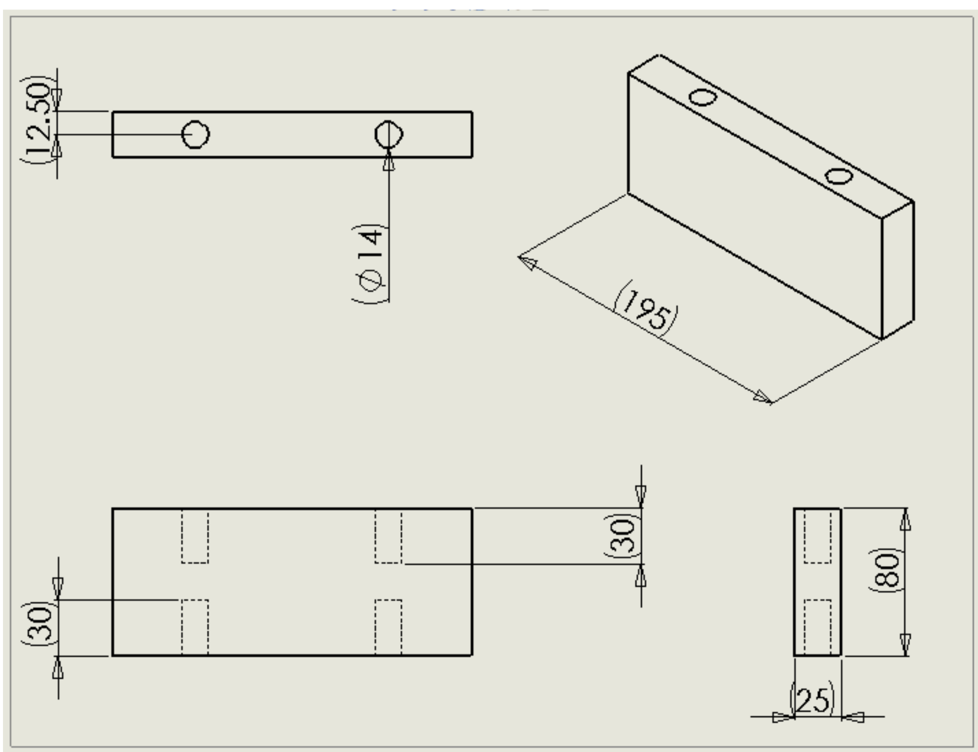

Fig. AIII-8. Face plate support (wire frame)

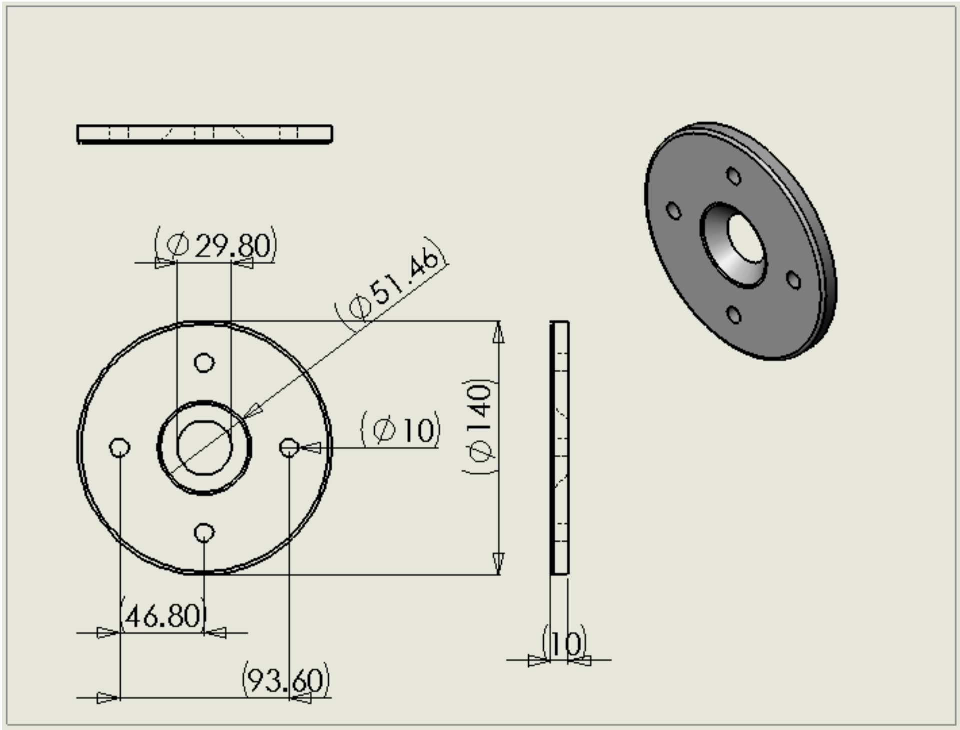

Fig. AIII-9. Locating ring

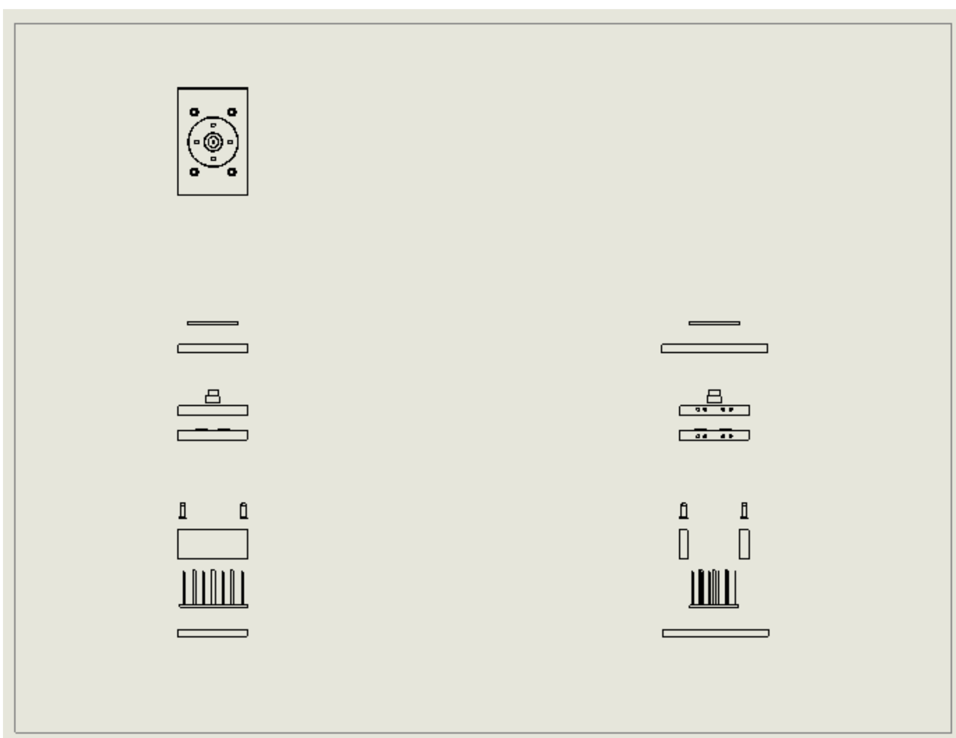

Fig. AIII-10. Explosion projections of mould assembly

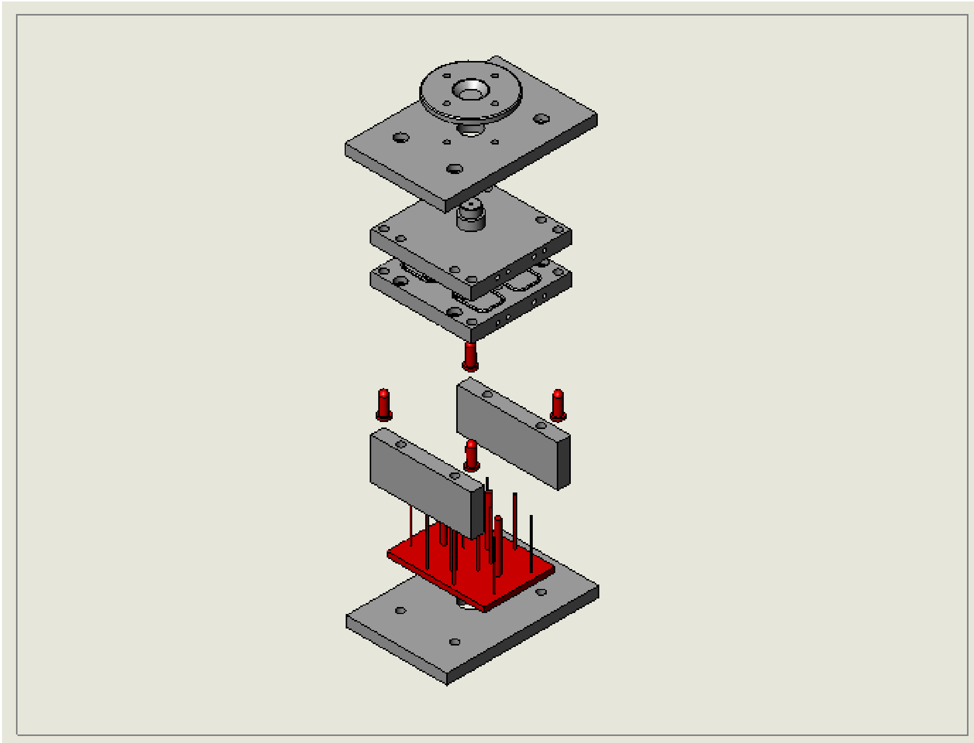

Fig. AIII-11. Pictorial projection of mould assembly with explosion

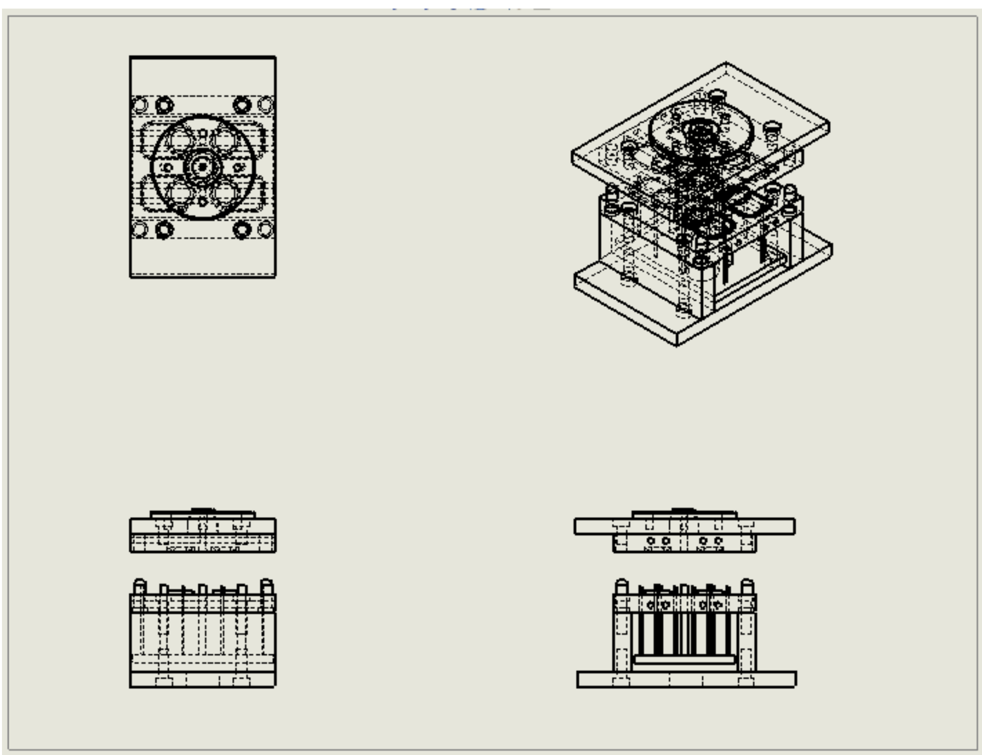

Fig. AIII-12. Projections of assembled mould (wire frame)

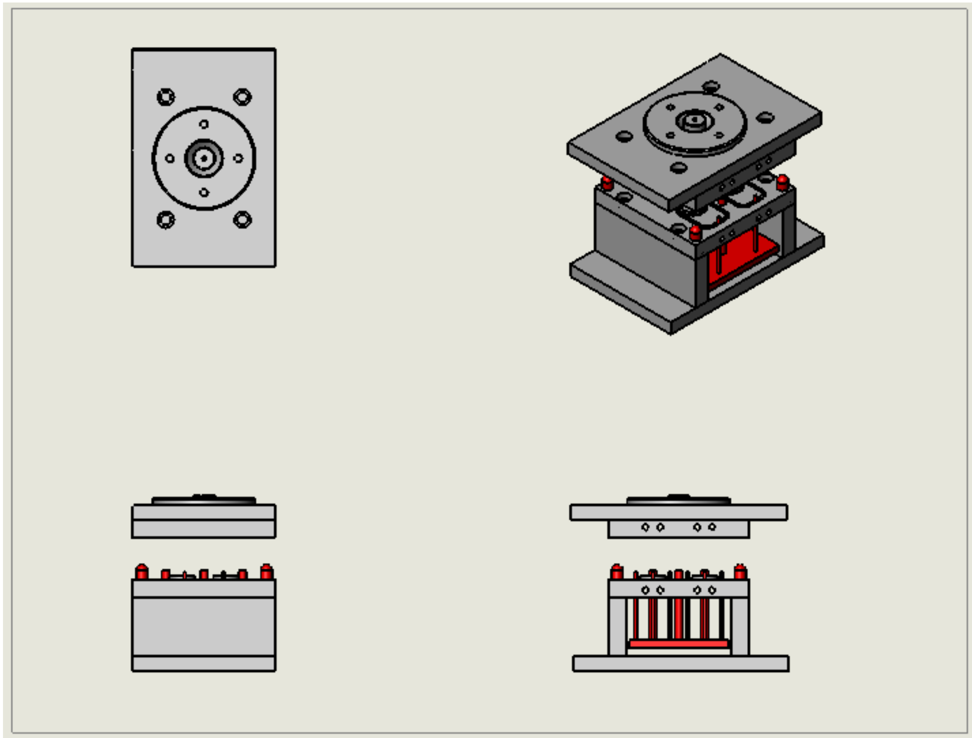

Fig. AIII-13. Projections of assembled mould (solid)

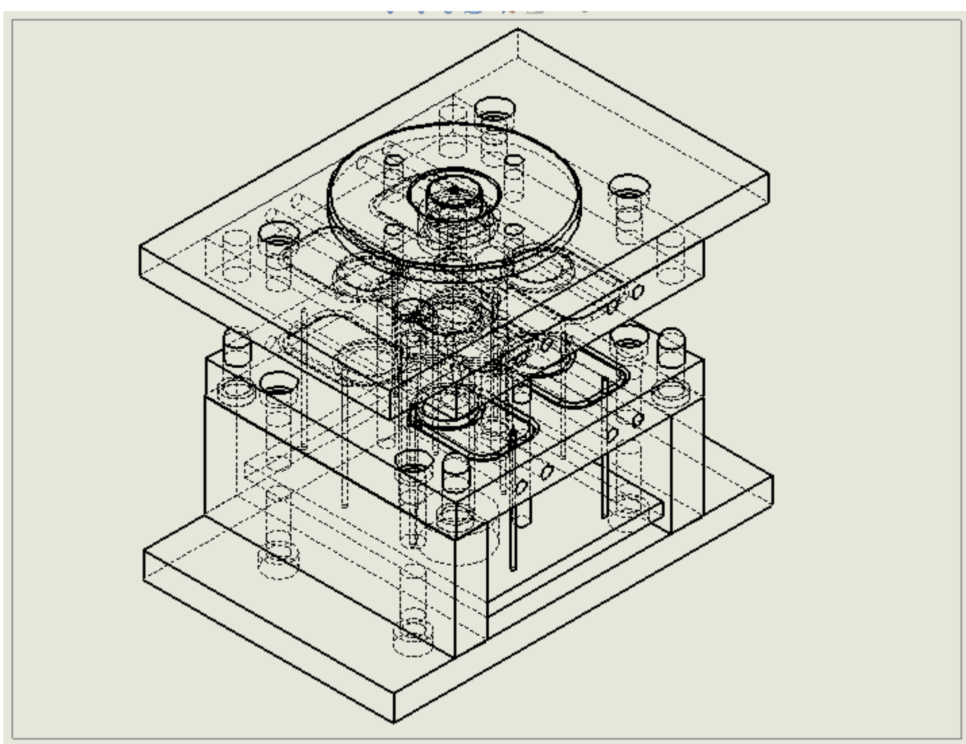

Fig. AIII-14. Pictorial projection of mould assembly (wire frame)

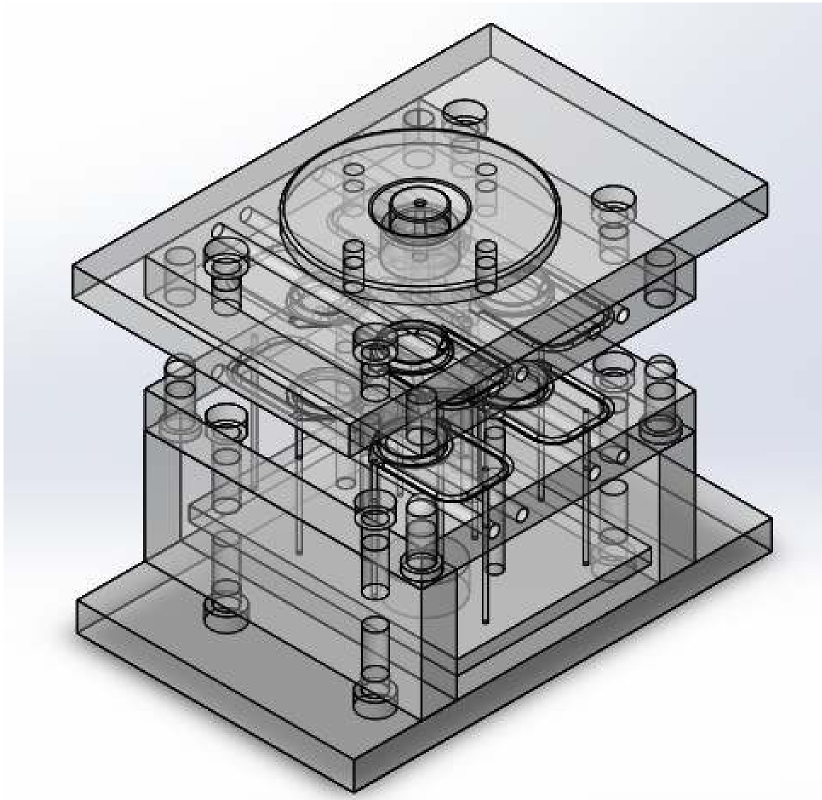

Fig. AIII-15. Pictorial projection of mould assembly (glass)

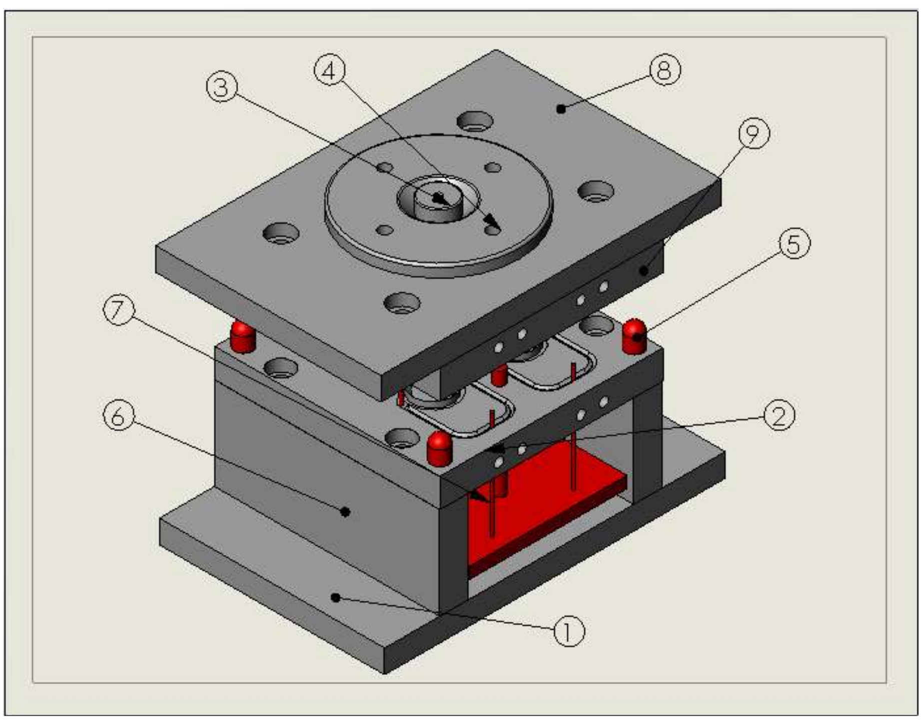

Fig. AIII-16. Pictorial projection of mould assembly with part numbers

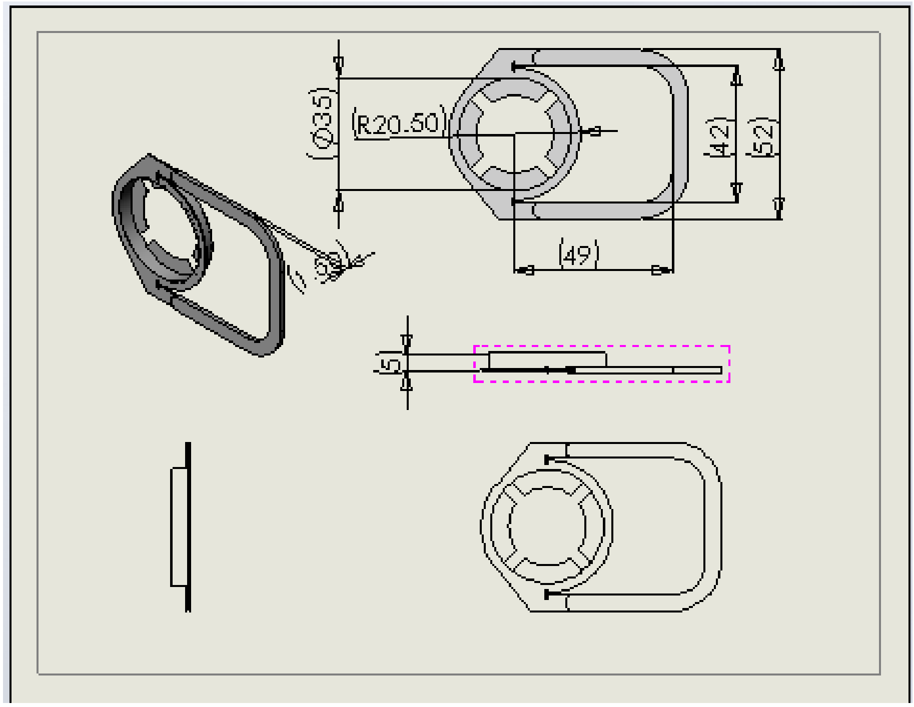

Fig. AIII-17. Pictorial representation of handle

Table AIII-18. Bill of materials/quantity

Item no.	Description/name	Quantity
1	Base Plate Female	1
2	Face Plate Female	1
3	Sprue Bush	1
4	Locating Ring	1
5	Locating Pin	4
6	Ejection Pin	12
7	Face Plate Support	2
8	Ejection Plate	1
9	Base Plate Male	1
10	Face Plate Male	1
11	M-14 Allen Bolts	4
12	M-8 Nipples	4
13	M-8 Bolts	4

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/12079