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DESIGN OF BLOW MOULD DIE FOR POLYPROPYLENE BOTTLE WITH MULTIPLE OPENINGS

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Abstract— ***Blow holding is the forming of a hollow part by blowing a mould cavity shaped parison made by thermoplastic molten tube. Blow moulding is generally suitable for manufacturing thermoplastic products which have only one side open. The present work deals with a die design to produce a bottle having openings at two ends. The product here is a 1500 ml top up bottle used in solar industry with open ends at top phase and bottom phase. The bottle openings had ¾" BSP external thread at one end and ¾" NPT external thread at the other end. The raw material of the product is Polypropylene. Die design includes the numerical analysis of blow pressure, air vent, Orifice size and blow time for better product. The die material was EN8 medium carbon steel. By the reference of journals it was possible to determine the method of parison wall thickness control, properties of EN8 medium carbon steel, Double Dam pinch off design. As per the design specifications, the final CAD is modelled using Pro-E software and structural analysis in Ansys software***

Keywords— Blow moulding, Poly propylene, Air vent, Orifice size, blow time.

I. INTRODUCTION

Blow moulding is a plastic forming process that is especially well suited for the manufacturing of bottles and other simple, hollow-shaped parts. The essence of the process is the formation of hollow parts from a preformed plastic tube. While blow moulding is competitive with other process that can make hollow parts, specifically injection moulding and rotational moulding, blow moulding has some advantages in forming some parts that make it the process of choice for the majority of medium-sized hollow containers. The general steps in Blow Moulding process are shown in the below figure 1

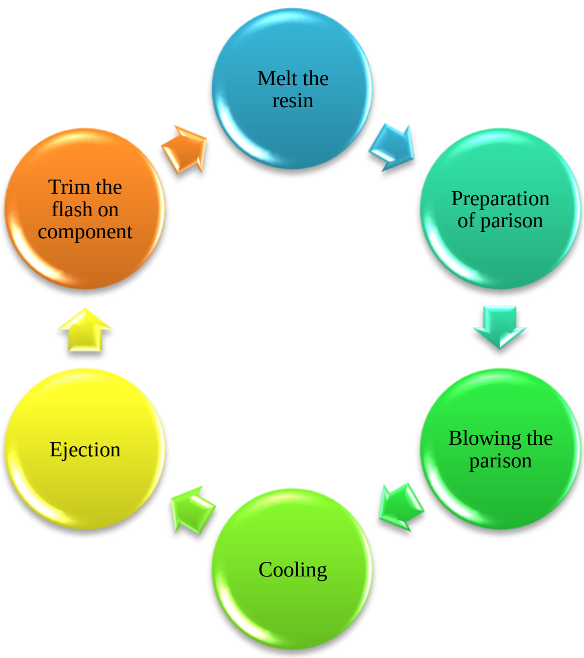


Fig: 1. Illustration of the steps involved in blow moulding process.

Shuichi Tanoue et al, [1] have presented a study on Numerical simulations those are useful for solving various problems that may occur during the moulding process. A multilayer-parison shape at the pinch-off stage in extrusion blow moulding was predicted [1]. H. Tomiyama et al, [2] has made a study on shape analysis of multi layered parison through simulation [3]. Y-L Hsu et al, [4] have described the fuzzy optimization algorithm for determining the optimal die gap openings and die geometry for the required thickness distribution in the blow moulding process is presented. The process modelling is based on a large displacement finite element formulation [5]. N.M. Zarroug et al, [6] have examined the results obtained from combined tension–torsion loading tests carried out on Mild steel (EN8) specimen. Experiments carried out by Meguid et al. [7], to determine the behaviour of thin walled tubular specimen made of Mild steel (En8) under non-proportional straining gave results in good agreement with the von Misses yield condition. The results from the finite element analysis (FEA) were validated against experimental results. Frederick. H. Axtell et al, [9] have made a study related to the shear and elongation rheological behaviours of polyester. The parison extrusion behaviour was studied as the output rate and melt temperature were varied. M/S DuPont polymers [10] have provided the information related to the barrel temperatures, adapter, head and die temperature, parison programming, mould temperature, start-up procedures, purging and shutdown, secondary operations: trimming, welding. It has also provided the mould design guidelines, material shrinkage allowance, blow ratio and pinch off design. Jyh-Cheng Yu et al, [11] has described the type of parison wall thickness controlling system. The proposed strategy is Fuzzy Neural-Taguchi and Genetic Algorithm. Diarddo et al [12] has established a neural network to predict the distribution of parison wall thickness and applied Newton-Rampsons method to obtain the final blow moulded part [13]. HAN-XIONG HUANG et al [18] suggests that in applying the BP network, some modifications, such as using a self-adaptive learning rate coefficient, determining the number of hidden neurons through experimentation, and so on, to the original BP algorithm are carried out to speed up learning. A. Bendadaa et al [28] found that the cooling phase of the extrusion blow moulding process has a large influence on the cycle time of the process as well as on the properties and quality of the moulded products. Musa r. Kamal et al [35] determined the contact temperature and the rate of heat transfer between the mould and the polymer during the cooling stage of the extrusion blow moulding process. The Double Dam pinch off point design was changed to suit the current requirement. The die material properties were taken from the literature review. The clearance value at pinch off point was taken from the above referred papers. The parison wall thickness controlling method by Fuzzy algorithm method is explained. But in this project, the parison wall thickness was controlled by Programmable Logic controller (PLC).The detailed study and the experimental values has helped to know the properties of the selected die material. The study has provided knowledge on parison sagging of Co-polyester polymer.

II. METHODOLOGY

Methodology is a systematic approach for the realization of total task. It consists of the following detail:

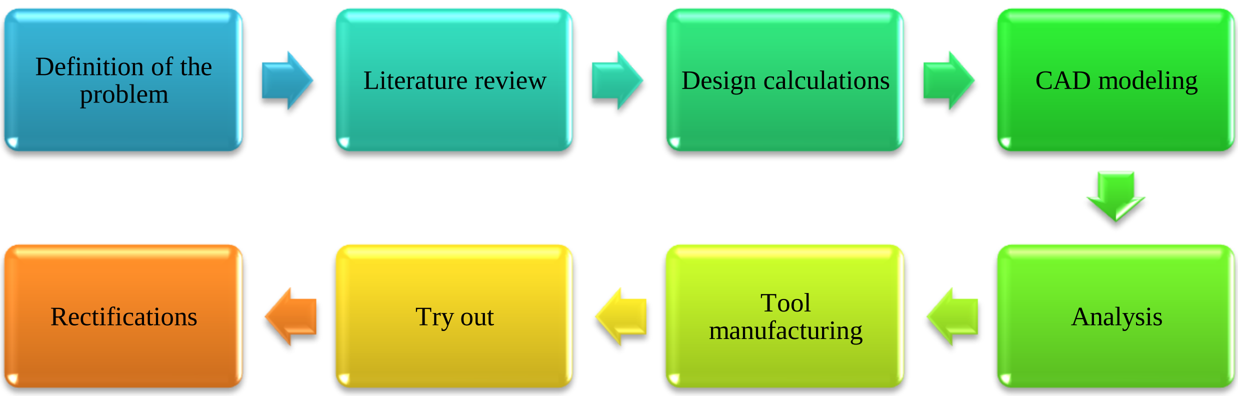


Figure 2: Flow chart of the process

The Primary objective of the project is to design the die for the production of 1500 ml polypropylene bottle having NPT thread and BSP threads at the respective ends. The designed die has to be economical and easy to manufacture. The die has to be designed by considering the shrinkage factor, thermal calculations, blow ratio, pinch off design, air vent design and other parameters

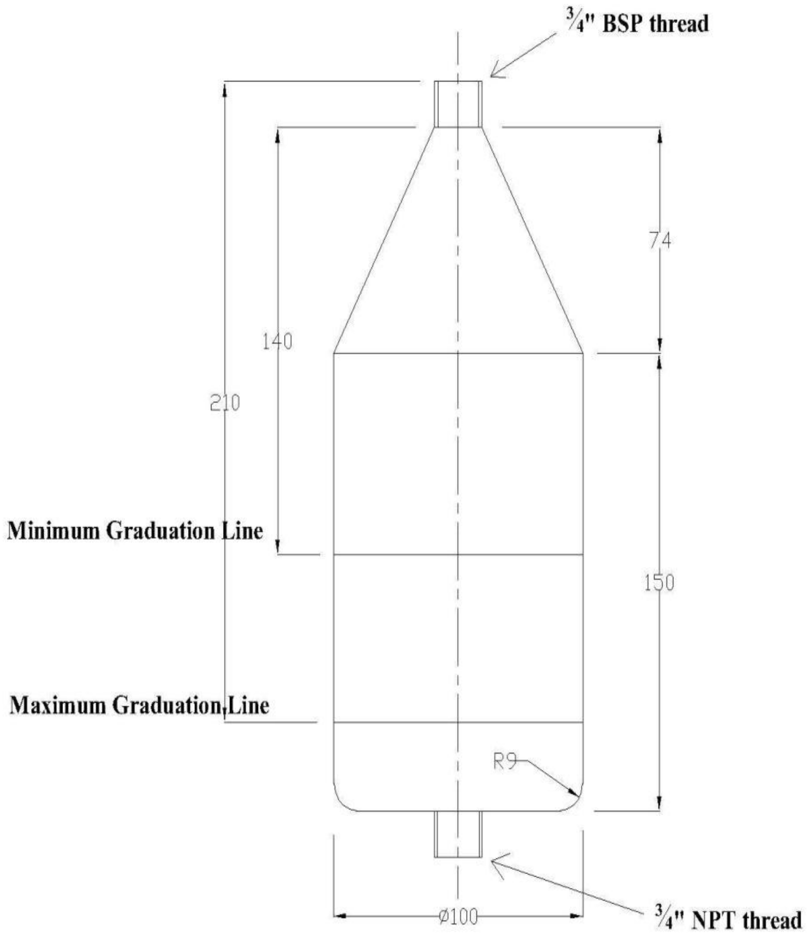


Figure 3**:** Flow chart of the process

III. EXPERIMENTAL STUDIES AND NUMERICAL EVALUATION

The Experimental studies include the numerical calculations and the numerical relations that are to be associated to die design of blow molding process. The formulas used in the case study are referred from Blow Molding Design Guide, Normal C. Lee et. al

3.1. Part details

Material of the product is Polypropylene with the following specifications: Shrinkage: 2 %, Volume of component: 1757 cm^3, Density of material: 0.855 gm / cm^3, Weight of the component: 104 gm, Number of cavities: Single cavity.

3.2 Actual weight of the component.

W=ρ X V *[Reference: Technical Directory on Design and Tooling for plastics, CIPET]*

W = Actual weight of the component, g.

P = Density of plastic material, gm / cm^3 = .855 g / cm^3.

V = Volume of the component, cm^3 = 121.9 cm^3 (outer volume – inner volume of bottle, from CAD model).

W = 0.855 X 116.9

W = 103.455 g

Flash value that is been considered here is 25 percentage.

3.3 Blow ratio

It is defined as the ratio of product outer diameter to the diameter of the parison. Product Outer diameter = 100 mm, Parison outer diameter is determined by the following ratio, **2.5 : 1**, [*Reference: page 187, Blow moulding hand book, Dominick.V.Rosato]*, the required diameter of the parison is, 40 mm. Hence the parison outer diameter is 40 mm.

3.4. Suggestion of Die and Mandrel type to be used.

Die and Mandrel are the tools that are used to form the parison to the required dimensions. There are two types of die and mandrel, they are Diverging type and Converging type. Diverging dies are used often for the parison sizes of 12.7 cm in diameter or less. *[Ref: Blow mould design guide, N. C. Lee]*. Converging dies are used to form the parison sizes of 15 cm in diameter or more.*[Ref: Blow mould design guide, N. C. Lee]* Since the required parison diameter is 40mm, converging type die and mandrel assembly has to be used.

3.5. Air Blow Pressure and orifice size

The air blow pressure required for Polypropylene is between 5.2 to 6.9 bar. *[Reference: Blow mould hand book, Dominck.V.Rosato]* The orifice diameter has to be 6.4 mm, *[Reference: Blow mould hand book, Dominck.V.Rosato]*

3.6. Blow time determination

Volumetric flow of the air within the die is controlled by the line pressure and the orifice diameter. The flow control valves that are located as close as possible to the orifice control linear velocity. Blow time can be determined by using the formula,

Blow time = <u>Mould volume (ft cube)</u> x (<u>Final mod, psi – 14.7, psi</u>)

*[Reference: Table 6.3, page 200, Blow mould handbook, Dominick. V. Rosat*o]

Mould volume of 1757 cm^3 (0.062 ft^3) , *[Ref: Cad model]*.

Final mould air pressure = 6.9 bar = 100.07 psi *[Ref: table 6.1, page 198, Blow mould handbook, Dominick. V. Rosato]*.

Fill rate = 0.013 ft^3 / sec.

Therefore, Blow time is 27.7 sec, (28 sec)

3.7. Die material selection

Die material is selected based on the thermal conductivity and the strength of the die material. The step involved in determining the amount of deserved thermal conductivity is,
To determine the amount of heat that has to be discharged, it is done by equation,

$$Q = m \times C \times (\Delta T)$$

Where, Q = Heat transfer rate (Watts)
m = Mass of polypropylene processed in one hour (grams)
C = Specific heat of PP (J/gK),
ΔT = Temperature difference (K)

Therefore the values are:
Cycle time per component = 35 sec
m = component weight including flash x number of products per hour (13650 grams per hour)
C = specific heat of PP = 1.7 j/gk
T = (160 – 30) + 273 = 103 K

By equating, we get
Q=**663.9 Watts or J / sec**

To determine the required thermal conductivity of the die material, this Q value is equated to the heat conductivity equation.

Q = K A dT/dX

Where, K = Thermal conductivity of the material (W/mk),
A = Area of the die,
dT = Temperature difference,
dX = Depth of the die.
The actual value of the concern parameters are: A = 0.0243 m^3, dT = 103 K, dX = 0.09 m,
Therefore,
K = $\frac{663.9\ X\ 0.9}{243\ x\ 103}$ =23.8 W/mk
Hence EN8 material is been used.

3.8. Mould cooling calculations

Heat to be transferred from mould per hour (Q):

Q = n X m X q_b ***[Reference: Technical Directory on Design and Tooling for plastics, CIPET]***

Where, Q = Heat to be transferred per hour (cal/hr);
m =Mass of the plastic material passed into the mould per shot (g) = 130 g,
n = number of shots per hour (105 shots/hr);
q_b = Heat content of plastic material, for polypropylene = 130 cal/g;
Q = 130 X 105 X 130 = 1774.5 K Cal /hr
Therefore amount of heat removed by cooling water is;
Q_d = 0.5 X Q = 0.5 X 1774.5
= 887.25 K Cal/hr

3.9. Amount of water to be circulated per hour to dissipate heat (m_w)

Amount of water to be circulated to remove 50% of Heat is calculated as;

Qd **= M x S x T x K**

M = Qd **/ (S x T x K)**

[Reference: Technical Directory on Design and Tooling for plastics, CIPET]

Where, K= Thermal conductivity of water; K = 0.65 for direct cooling, K = 0.5 for indirect cooling,
T_{out} = Outgoing water temperature ^oC;
T_{in} = Incoming water temperature ^oC;
$S_{W =}$ Specific heat of water,
$m_{w =}$ Amount of water required to remove 50% of heat.
Assuming a reasonable temperature difference of Tout-T_{in} = 5 ^oC for water
$\frac{887250}{5\ x\ 0.65}$ = 273000 g/ h = 273 kg/ hr, = 273 litres/ hr, = 4.5 litres / minute.

3.10. Reynolds number calculation

Effective cooling of the mould is achieved by creating turbulence in the fluid flow across the cooling channels. The state of turbulence is determined by the Reynolds's Number as stated below

Re = (7740 VD)/γ or (3160 Q)/D γ

[Ref: Blow mould hand book ,Dominick .V.Rosato]

Where, Re = Reynolds number,
V = fluid velocity, ft/s = 2.81 ft/sec = 0.85 m/sec,
D = diameter (in) of the cooling channel = 0.5",
γ = kinematic viscosity in centistokes = 1,
Q = coolant flow rate in gpm,

Therefore, Re = $\frac{7740\ x\ 2.81\ x\ 0.5}{1}$ = 10874.7

The Reynolds number is greater than 10000, hence the flow is considered to be turbulent. If the Reynolds number is less than 2100 then the flow is considered as laminar flow. If the Reynolds number is greater than 3000, then the flow is considered as transition flow.

3.11. Plating:

Since the required finish material is transparent and priority is given for aesthetic looks, the surface finish of the die has to be very fine. There should not be any stretch marks, dents or false impression on the product. Hence the inner wall of the die is been coated with chromium up to 20 to 40 microns

IV. Mold Drawing and 3D models of the profiles

The figure 4 shows the 2D drawing of the mold half with cooling channels and pinch off point in figure 5

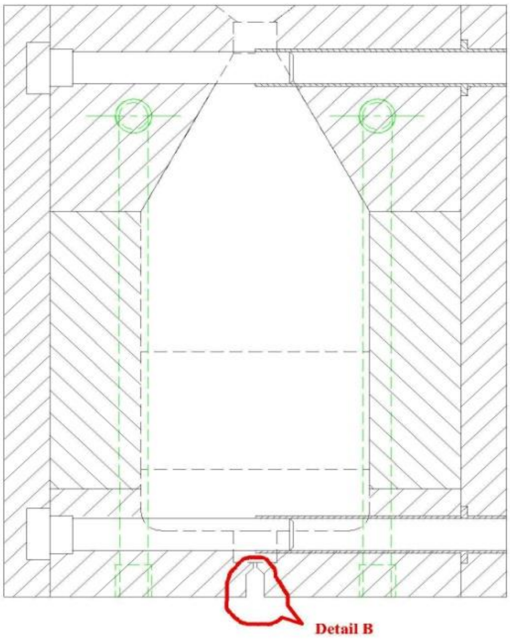


Fig 4: 2D drawing of the mould half (sectional view)

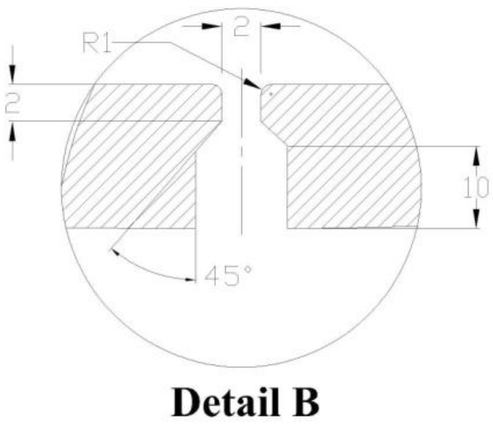


Fig 5: Figure shows the designed Pinch of point

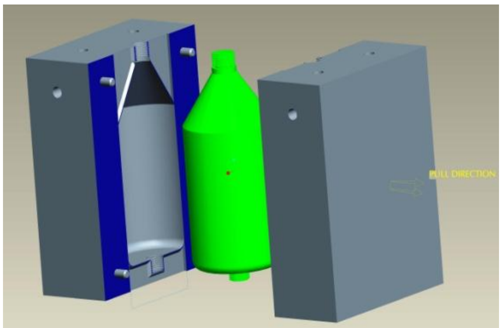


Figure 6: Mould Assembly

Figure 7: Part model

Figure 8: Part model

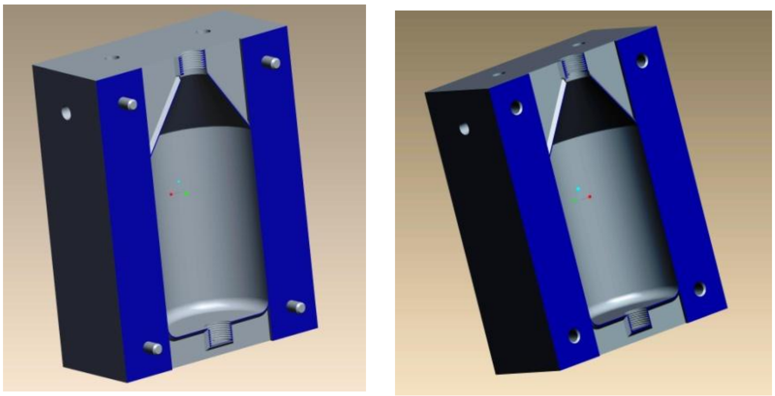
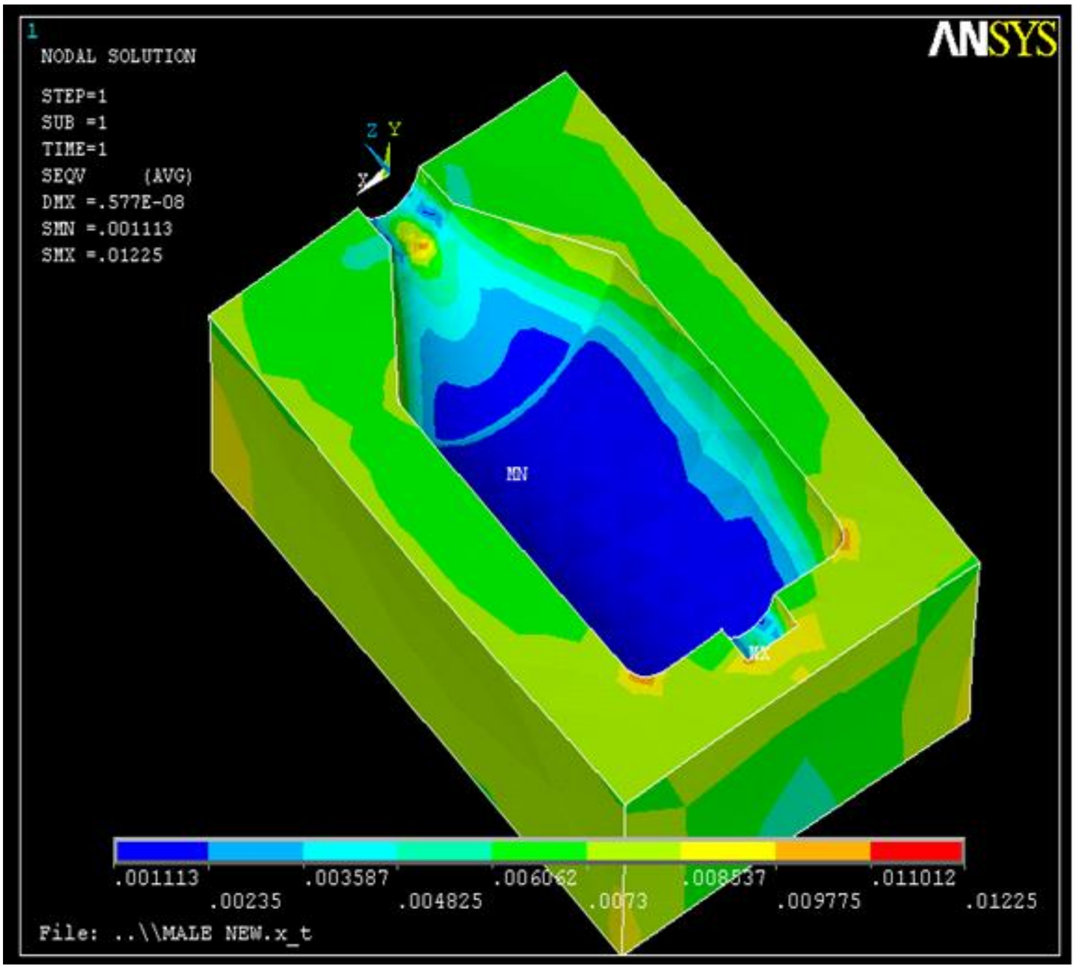


Figure 9: Mould halves

V. FINITE ELEMENT ANALYSIS

The CAD model of the blow moulding die which is modelled in Pro-E software and stored in part files is saved in the format of parasolid. Once the model is created is created and stored, it is then imported to ansys software. After the component is meshed, the subsequent load is applied on the component. This pressure load is determined by dividing the load applied (clamping force) with projected area of the die. The projected area of the die is determined or taken from Cad model



After subjecting the die to the compression load, the maximum stress induced in the die was 0.1225 Mpa and the minimum stress induced was 0.001113 Mpa. The designed die is safer and it can even be subjected to higher clamping force.

VI. CONCLUSION

The Polypropylene bottle of 1500 ml having the density of 0.855g/cm^3 with shrinkage allowance of 2% is designed and the component is of 104gms with 50 % of flash weight and the die is of single cavity. The Blow ratio is 25:1, parison diameter of 40 mm is to be extruded. The parison is to be blown at 5.2 to 6.9 bar. The blow time is 28 sec with cycle time of 35 seconds and the 4.5 liters/ minute flow of water is needed to cool the die by 50% of generated heat. The newly designed pinch off point with adequate clearance squeezes the parison and retains the blow pressure and has effective weld line.

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