PROCESSING OF POLYMERS AND COMPOSITES

ENGINE VALVE
(INLET)

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My aim of the project would be to **“reduce mass, increase stiffness, overcome brittle failure and simplify manufacturing with a fiber-reinforced polymer composite material.”**

STEP-1: Select a component/part and clearly mention the materials.

OUTLET VALVE   INLET VALVE

I am considering only inlet valves for this project because inlet valves see's temperatures of around 400°C whereas outlet valves see's temperatures of around 900°C. Our polymer composite material will mostly melt & fail to meet its function if it sees temperatures of around 900°C. So, I am eying to work & change the material for inlet valve now.

Valves are made from wide range of materias, but I have considered these
Two valves which were made of the following materials:

MATERIALS:

→ Low Carbon steel.

→ Martensitic & Austenitic grades of valve steels.

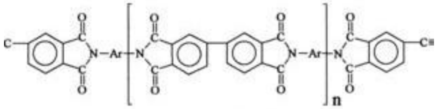
→ Super alloys(nickel, iron–nickel and cobalt alloys; 21-4N valve Steel).

→ Stellite (alloy of cobalt and chromium) for valve tip.

Proposed polymer or polymer composite material:

The polymer composite design comprises of:

- The matrix is a **high-temperature PETI-RFI polyimide resin**.



PETI-5

- **Two-layer braided carbon fiber tube** that incorporates 60 percent axial unidirectional tow for additional axial bending resistance.

- Two small **discs of plain-weave fabric** were added to the valve face to resist the imposed bending loads.

PETI-RFI(Phenyl_Ethynyl_Terminated_Imide-Resin Film Infusion)

❖ High temperature polymer matrix material PETI-RFI is a variant of the high temperature polyimide polymer PETI-5 developed by NASA.

❖ RFI is a process developed by NASA for the desire to use a qualified prepreg resin system for the matrix resin.

PROPERTIES OF MATERIALS

PETI-RFI polyimide resin

Molecular Weight	1250 g/mol
Melt viscosity	below 6.0
Glass transition temperature (*Tg*)	236°C.(220 - 340 °C)
Tensile modulus	3.48 GPa,(1.3 - 4 GPa)
Ultimate Strength	94.4 MPa.
Coefficient of Linear Thermal Expansion	5.5 x 10^{-5} /^{o}C

Density	1.31-1.43 g/cm3
Toughness(Notched Izod Impact at Room temperature)	60 - 112 J/m
Volume Resistivity	14-18 x 10^{15} Ohm-cm
Dissipation factor	18 -50 x 10^{-4}
Shrinkage	0.2-1.2%
Flexibility (Flexural Modulus)	2.48 - 4.1 GPa

DECIDING A MANUFACTURING PROCESS

1. Raw materials(long steel bars) Gets processed in a shearing machine.
2. Cut to required lengths.
3. each part is subjected to upset forging to form head of the valve.
4. Form cavity in the tip of the valve to join it with Stellite.
5. TIG welding to join metals
6. Series of heat treatment process.
7. Shot blasting to clean valve and perform Straightening
8. Ultrasonic inspection to check defects.
9. Clean valves in Alkali bath.

Conventional manufacturing →

- We can observe that in conventional technique, a series of operations(involving machines and technologies) are performed to produce 1 valve.
- We can clearly understand that it's a:
  - time taking process
  - Requires high investment initially & regular servicing of machine in-order to maintain efficiency & throughput.
  - labour cost would be high since skilled staff is required to operate machines
  - High scrap rate.
  - Product consistency & efficiency is not 100% guaranteed unless machines are automated/semi-automated since human errors might lead to part defects.

Considering all these aspects, I wanted to select a moulding manufacturing process that would reduce the above mentioned drawbacks for producing my polymer composite valve which is as or more efficient than the valve produced using traditional conventional process. But which moulding process!?

My options are:

Extrusion Blow moulding v/s **Compression moulding** v/s **Dip moulding** v/s **Casting** v/s **Injection moulding**

Extrusion Blow moulding

Makes hollow parts which are not sufficiently strong to meet the requirements.
So **REJECTED.**

Compression moulding

Has poor consistency, not precise & difficulty in controlling the flashing. So, it's a prolonged, time-taking process.
So **REJECTED.**

Dip moulding

Slow process & controlling the thickness is the toughest job.
So **REJECTED.**

Casting

Not economical for mass production, low fatigue strength & poor surface finish.
So **REJECTED.**

Injection moulding

All the difficulties/drawbacks of the processes being rejected can be overcomed using Injection molding.
So **SELECTED.**

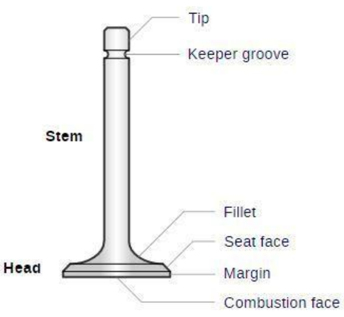
PROCEDURE DURING MANUFACTURING

- Selected manufacturing process is **Injection molding.**
- Idea is to inject the resin into the mould at elevated temperature, but just below the cure temperature. From the reference book-1, I learned that after injecting, placing the mould in an oven would be a best option for complete cure and crosslinking for composite materials.
- My valve has to be made in one piece, so, as of what I learned from my Manufacturing Process Practice course, I would use a Single-cavity Aluminium mould.
- From the reference book-1, I learned that Aluminium mold will be distorted over time due to high cure temperatures, which leads the sealing problems and ultimately results in void formation in parts, non-uniform filling, part lock in the mould.

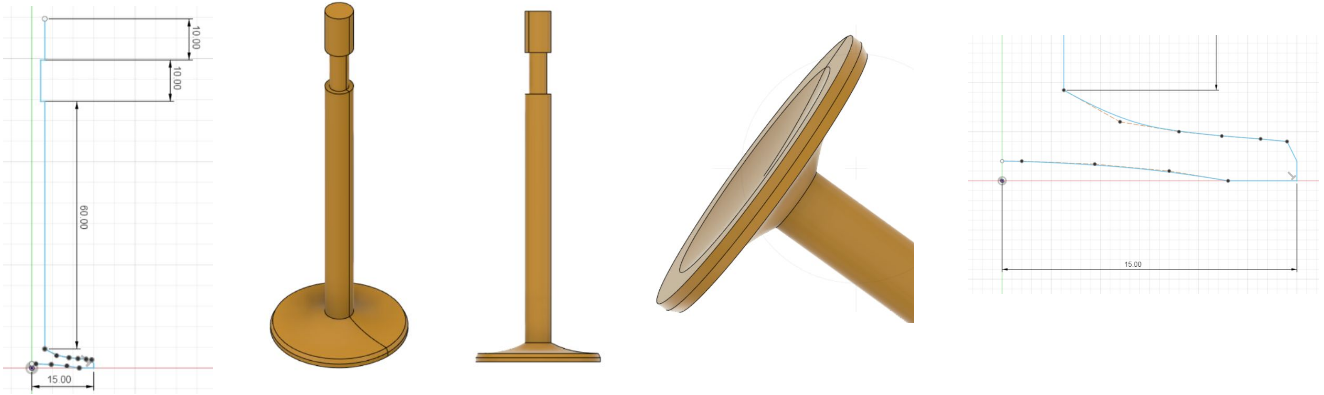
- I selected injection moulding so that all the drawbacks of rejected processes will be overcomed. So, now I have to select a new mould that will have long-life even at high temperatures, & at the same time should possess all the beneficial features from Aluminium mould.
- Now, I have to think of a new mould. Split-cavity Stainless steel mould is my next option, which provides additional benefits like improving filling and wetout, provide great clamp pressures & permit easier part removal.
- One challenge that I can think of is "how to maintain the tiny braid in the correct position within the mould during injection?"
  - The solution to my above question was found in reference book-2. The solution was to use a two-piece preform retention bushing that clamps the braided sleeve at the valve tip end.
  - The bushing has the capability to keep the fibers from washing down the mould & can act to open the braid to force the resin inside.
- Another challenge is "how to add local fiber reinforcement at the valve face?"
  - From reference book-3,the answer to this question is to prepreg dry carbon plain-weave fabric by melting the PETI-RFI onto the fabric.

Please refer the last slide for all the references

SHAPE/DESIGN CHANGE



Conventional intake engine valve (which I used as a reference)



My design for the inlet engine valve in this project using injection molding with head diameter=30mm, stem diameter=7mm and stem length=80mm

Changes in design:

Valves are subjected to cyclic loading due to valve train dynamics.The stem of the valve is under axial repeated loading, it can fail by axial Fatigue. The keeper groove area is subjected to tensile stresses and becomes a critical section due to geometric stress concentrations.

- The length of the keeper groove/spring keeper is increased because Tensile failure is observed to occur in this region if the length/area is small. The increased length & area ensure that a proper amount of spring pressure is applied consistently to prevent valve bounce, and hence reduce severe tensile stresses that could break the valve at keeper groove area.
- The combustion face at the bottom of the Head is changed from flat to non-flat shape so that the closing force of the valve will increase due to this shape making sure that no liquid is seeped out of the valve when its closed ensuring best functioning of the valve.

PARAMETERS:

We have various important parameters that has to be taken care of in order to produce engine valve feasibly without any defects using injection molding.

"Cycle time, fill time, cooling time,cooling channel length & diameter,runner length & diameter, gate pressure & diameter, injection time, injection speed, injection pressure, holding pressure, melting temperature, mould temperature."

We will be look into **formulations** for few of the above mentioned parameters:

Note: All the formulas, assumed values are taken from various numerical problems of the Reference books 4,5

1)Cooling Capacity and Cooling Channel Diameter Calculation:

The inputs will be shot weight(M, assumed), decomposing temperature of polyimide(Hm) is 520°C, preheated temperature of the resin(Hr) is 50°C and cooling cycle time(C) is 20 seconds.

$M = 0.07\text{kg} = 70 \text{ grams}$

$H_m = 520^\circ C$

$H_r = 50^\circ C$

$C = 20$ seconds

$$\text{Cooling capacity } (Q) = \frac{M(H_m - H_r)}{C} = \frac{0.07(520-50)}{20} = 1.645 \text{ kg.}^\circ\text{C/sec}$$

Volume of flow required to remove heat

$$V_f = \frac{Q}{20.95} = \frac{1.645}{20.95} = 0.0785 \text{ kg/s}$$

$$\text{Cooling channel diameter} = \sqrt{\frac{76.3 \times Q}{\pi}} = \sqrt{\frac{76.3 \times 1.645}{\pi}} = 6.322 \text{ mm}$$

2) Cooling channel length calculation

Using Poiseulle's equation, we will be calculating the channel length. Injection pressure(P, assumed), radius of channel =6.322/2= 3.13mm, we will use water as the coolant which will have viscosity of 0.001 at 25° C and flow rate as 0.0785 which we calculated earlier.

Pressure $(P) = 70{,}000$ Pa

Radius of channel $(r) = 3.16$ mm $= 0.00316$ m

Viscosity of coolant $(\eta) = 0.001$

Flow rate $(V_F) = 0.0785$

Length of cooling channel, $\boxed{L = \dfrac{P\pi r^4}{8\eta F}}$

$$L = \frac{70{,}000 \times 3.14 \times (0.00316)^4}{8 \times 0.001 \times 0.0785}$$

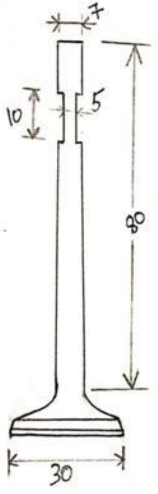
$L = 0.0349$ m

$L = 34.9 \approx 35$ mm

3)Gate Diameter and Gate Pressure Calculation

In a numerical question in reference book 5, Gate diameter was asked to calculate. There the Area of the part was calculated and two empirical factors (N,C)=(0.6,0.4).

So, I will use those same empirical factors here to find answers in my case.



Emperical factors

$N = 0.6$ & $C = 0.4$

Area of part (A) =

First, Area for the cylindrical stem which is of 70mm length & diameter 7mm.

$2\pi r(h+r)$

$\Rightarrow 2 \times \pi \times (3.5)(70+3.5)$

$\Rightarrow 1616.35\ mm^2 \longrightarrow (1)$

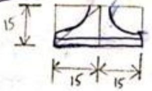
Now, the thin section (ie) keeper groove

$2\pi r(h+r)$

$\Rightarrow 2 \times \pi \times (2.5)(10+2.5)$

$\Rightarrow 196.35\ mm^2 \longrightarrow (2)$

Head of the valve



Now, the area for head of the valve.

We will consider the head as 2 squares & calculate 2 squares areas

Square 1 $\Rightarrow 15 \times 15 = 225\ mm^2$

Square 2 $\Rightarrow 15 \times 15 = 225\ mm^2$

image-3.1

$\Rightarrow 196.35\ mm^2 \longrightarrow (2)$

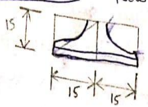
Head of the valve

Now, the area for head of the valve.

We will consider the head as 2 squares & calculate 2 squares areas

Square 1 $\Rightarrow 15 \times 15 = 225\ mm^2$

Square 2 $\Rightarrow 15 \times 15 = 225\ mm^2$



Now, we will half the areas of both the squares to get approximated area of head part in both the squares

Square 1 $\Rightarrow \frac{225}{2} = 112.5\ mm^2$

Square 2 $\Rightarrow \frac{225}{2} = 112.5\ mm^2$

Now we will add areas of both the halved squares (3)

$112.5 + 112.5 \Rightarrow 225\ mm^2$ (approx) is the area of the head of the valve.

Total area of the valve $\Rightarrow (1) + (2) + (3)$

$\Rightarrow 1616.35 + 196.35 + 225$

$\Rightarrow 2037.67\ mm^2$

Gate diameter, $d = NC\sqrt[4]{A} = (0.6)(0.4)(2037.67)^{1/4}$

$\boxed{\text{Gate diameter}, d = 1.6125}$ mm

image-3.2

~~From a~~

From a numerical example in Reference book, the length of gate (l) was given as 0.064m & width of the gate (w) as 0.0025m. The thickness of the gate (h) was calculated, & the result was 6.4mm

Now we will take these values & apply it in our case.

$L = 64\ mm$, $w = 2.5\ mm$, $h = 6.4\ mm$

Flow rate $(Q) = 1.645$ (Calculated earlier)

Viscosity $(\eta) = 0.001$ (Already mentioned earlier as viscosity of coolant)

$$\text{Gate Pressure}, \Delta P = \frac{12 L \eta Q}{w h^3} = \frac{12 \times 64 \times 0.001 \times 1.645}{2.5 \times (6.4)^3}$$

Gate Pressure $\Delta P = 1.928 \times 10^{-3}$ Pa

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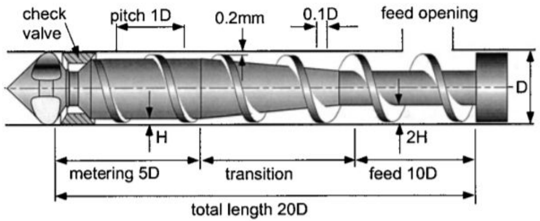
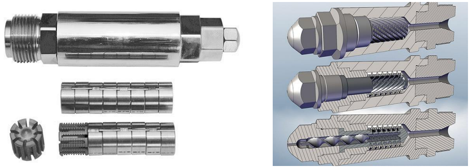
MACHINERY:



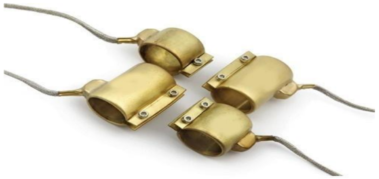
- Split-cavity Stainless steel mould.
- Hydraulic clamping system to open & close the mold.
- Mixing Nozzle- Ensures consistent & uniform dispersion of the resin, coolant; ensures homogeneous & consistent melt overall; molten resin can be injected at desired high pressures unlike gap-filter machine nozzle, screen-pack nozzle.
- Band Heaters- We melt & raise the temperature of the resin in barrel to around 300°C.
  Nozzle band heater- We use this to increase the temperature of resin to around 320-350°C before injecting it into the mold at high pressures.
- Extruder screw with following dimensions:
  (Taken from reference 5 & 6. I don't know how to determine the dimensions of extruder. So I used dimensions of the extruder used for injection molding of polyimide in the references 5 & 6. So, I have taken those values for my project as well.)

Parameters	All dimensions are in mm
Outer diameter	19
Pitch	15
Pitch angle	14.11
channel width	11.5
Flight width	3
Channel depth(feeding zone)	3.9
Channel depth(metering zone	1.4
Compression ratio	2.79
Flight clearance	0.05
pitch-diameter ratio	0.8
aspect ration(metering zone)	0.12
number of parallel flights	1
MSM18B004- ARETI NAVEEN	



Mixing nozzle

Band Heater



Nozzle Mixing heater

REFERENCES:

Reference book-1⇒Fundamentals of modern manufacturing, Mikell Groover

Reference book-2⇒ Manufacturing & processing of Natural filler based polymer composites, by Jagadish, Bhowmik, Sumit.

Reference book-3⇒Light weight polymer composite structures, by Sanjay Mavinkere Rangappa, Lothar Kroll.

Reference paper⇒ https://patents.google.com/patent/EP2767687A1/en

Reference book 4⇒ Understanding Injection molds by Hans Gastrow

Reference book 5⇒ Injection Mould Design : An Introduction And Design For The Thermoplastics Industry by by Pye R G W

Reference paper 6⇒ Melt-processable injecting molding thermosetting polyimide: Synthesis, characterization, fusibility, and property; T. Kuroki A. Shibuya M. Toriida S. Tamai

THE END

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