Compression Moulding Process – An Overview

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ABSTRACT

Known as one of the oldest plastic processing methods, compression moulding (CM) is widely used in plastic processing plants due to its advantages which are lesser seen in other methods. Though injection moulding is the most widely used process, it lacks in some properties which can be achieved in compression moulding. This process is used to give a desired shape to the plastic with the use of high temperature and pressure. It can be used for thermoplastics as well as for thermosetting. In plastics, Thermosets and composite plastics have low melt flow index and the fact that they require high pressure to cure, compression moulding is most common process selected. The finished product from compression moulding is seen to be tough and hard to sustain various loads applied and the surface can be made smooth as per requirement. The scrap produced (flash) is lesser than injection moulding (runners and gates produced during the process). The process setup includes the plastic preform (either powder or tablets) is usually preheated is placed in the heated mould cavity. Heating of mould is done to catalyze the curing reaction. Pressure is then applied with help of a power press for a certain period of time known as curing time. The part thus takes the shape of mould cavity and is then ejected from the mould with ejector system. For an optimum utilization of this process, various parameters are to be controlled such as part geometry, part material, mould quality, mould temperature, curing time, clamping pressure, breathe cycle, preheating and charge quantity. This paper covers a brief overview of the compression moulding process followed by the controlling process parameters.

Keyword: - *Compression Moulding, Thermoplastics, Thermosets, process parameters, curing, breathe cycle*

1. INRODUCTION-

Compression molding is among the oldest materials processing techniques. In commercial use, compression moulding is the most simple and reliable process. Due to its simplicity and availability, it is most widely used process. Product areas are lighting and electrical devices, closures, transportation, and appliances. Specific items are electrical wall switch plates and receptacles, circuit breakers, bottle caps, buttons, packaging, containers, covers, protective helmets, pump components, gears, brake parts, frames, pulleys, vehicle panels, dishware, and appliance housings, bases, handles, and knobs. [1].

1.1 Nomenclature of Compression Moulding Process

Compression moulding process require following components:-

1. Component raw material

   The material needed to be molded in cavity is required with preprocessing done. Pre-procedures like preheating, addition of any binding agents or reinforcement. Raw material may come in form of powders, resins, sheets or granules. These materials are then needed to be processed before placing them in cavity. Some plastic materials are mixed with binding agents and reinforcements like fibre, or with some other plastics to make a composite. Powders are needed to be tablated in a tablating machine, as this improves the performance and helps to preserve the powder for a long period of time.

Fig 1 Moulding powder.

Fig 2 Preform

2. Mould with desired shaped cavity

A precise and accurate mould is the key element for this process. The mould should be able to withstand tremendous pressure. It should posses following properties:-

- Accuracy and precision – the punch and cavity inserts should meet high accuracy and precision.
- Strength – the mould should sustain the working pressure and it would be better if it work hardens.
- Reliability – it should be reliable for mass productions.
- Alignment – the alignment between the punch – cavity, support pillars – bushings, ejector pins holes should be proper.
- Surface finish – the surface of the punch and cavity should be super finished to achieve the part surface smooth.
- Coating/plating – the punch and cavity surface should be coated or plated with a harder material to reduce wear and tear,
- Hardening – the plates of mould should be hardened to be immune to scratches and wear occurred while regular operation.
- Cost – it should be available at lower costs.

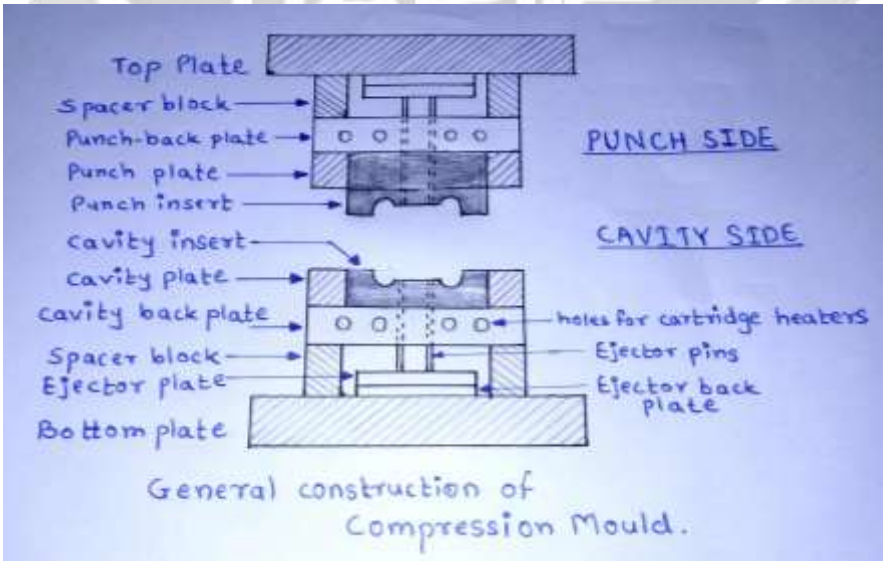

Fig 3 General construction of mould

3. Moulding machine

The machine is the fundamental element of this process. A compression moulding machine is similar to a power press except power press have a fast operation and do not stay for more time at stroke. CM machines stay for a predetermined time when actuated. It is more similar to a UTM machine.

Fig 4 Compression moulding machine

1.2 Process Flow

The process takes place in following steps,

Step-1. Heating the mould

The mould is heated to a certain temperature as per the plastic raw material requirement. Usually the raw material manufacturer suggests the mould temperature. e.g.- for single stage and two stage phenolic moulding compounds, PLENCO suggests the Mold Temperatures should be 165° - 182°C (330° - 360°F).[2]

Step-2. Preheating the plastic

The material can be Sheet Moulding Compound (SMC), Bulk Moulding Compound (BMC), Thick Moulding Compound (TMC) or the material can either be granulated powder or a preform tablet. Preheating is done in a small convection heater. The raw material is preheated to a certain temperature for two main reasons:-

- To remove moisture content as thermoset powder has tendency to absorb moisture from air.
- To reduce the curing time required by material in the mould cavity

Step-3. Placing the plastic in the cavity and mould closing

The preheated plastic is then placed into the mould cavity followed by closing the mould halves together. After closing the mould, breathe cycle is introduced to remove any air bubbles trapped inside. The pressure and temperature is then held for some period of time

Step-4. Curing reaction

Curing is a chemical process employed in polymer chemistry and process engineering that produces the toughening or hardening of a polymer material by cross-linking of polymer chains. Even if it is strongly associated with the production of thermosetting polymers, the term curing can be used for all the processes where starting from a liquid solution, a solid product is obtained. [3]

Step-5. Mould opening and Ejection

After the plastic is cured, the part can be removed from the mould. To remove the part, ejection system is employed. The mould has ejector pins and ejector plates assembled on both halves below the cavity and punch back plates. The plates push the ejector pins which remove the part from cavity.

Step-6. Cleaning of mould

After the ejection, cycle is completed. For next cycle, mould has to be cleaned to remove any dirt, dust, flash from the cavity and punch surface. The cleaning can be done by wiping off with a cloth or by blowing pressurized air on the surface.

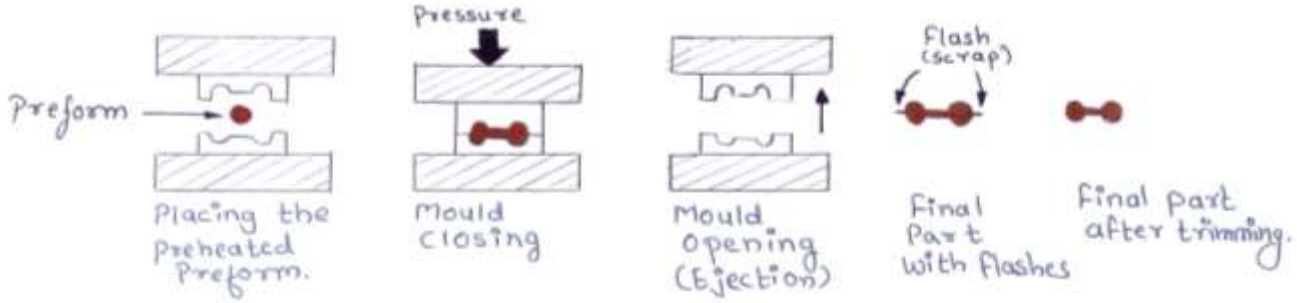

Fig 5 Stepwise procedure of CM process

1.3 Process Parameters

Following parameters should b controlled in compression moulding process:-

I. Part Geometry

The part to be molded should have a specific shape and size. Bigger the part, bigger the mould has to be made and higher the pressure requirement. The design should be correct and satisfying the need of application. Poor design leads to poor performance. CM cannot handle very intricate designs, thus part should be designed accordingly.

II. Shot Size

The amount of raw material required for a part is known as shot size. It is determined from the weight of part required. Shot size is oftenly taken a bit more than the requirement to ensure complete filling of cavity. Flashes (scrap) are expected in final part as it indicates complete filling of cavity. It is oftenly considered by trial and error basis. Low shot size leads to incomplete filling of cavity.

III. Part Material

While selecting the process, part material is the main factor. Viscosity of plastic is deciding factor. Very viscous plastics are harder to compress and require high pressure and temperature. Melt Flow Index is the factor considered in plastics, it is the test done on plastics to determine the viscosity when plastic is melted. The test consists of melting of the plastic in a small cylinder covered with heater element. Then the piston

pushes the plastic after melting as a predetermined weight is placed above it. after some time weight of displaced plastic is taken and MFI is calculated. Depending on the Melt Flow Index, the plastics can be classified as:-

1. Low melt flow index

   These plastics have low viscosity and hence have less fluidity. These require severe pressure to flow and cover each and every corner of the mould cavity. For these plastics use of compression moulding is must as it is best suitable process

2. Medium melt flow index

   These types of plastics have medium fluidity. They may or may not be processed by compression moulding method. These have a medium viscosity and do not require high pressures and temperatures.

3. High melt flow index

   These have a great fluidity and lowest viscosity amongst above. Injection moulding is best suitable for these plastics and requires lowest time to cover mould cavity. Cycle time is usually lower of these plastics.

Apart from Melt Flow Index, the type of plastic is also necessary. Whether the plastic is a thermoplastic, thermoset or a composite of plastic and some kind of additive and reinforcement (fibre matrix) is also a question discussed while selecting the process.

IV. Mould Quality

In order to achieve a smooth finish on the part, the cavity surface should be super finished and coated with a hard material to reduce its wear and tear. The mould should pass the overall quality parameters like alignment, strength, stress concentration, fits, limits, tolerances and allowances should be considered with high accuracy. The mould should be made of optimum quality material according to international standards like HASCO, DME, DMS, DESOUTTER, UDDFORM, etc. coating/plating should be done to reduce wear and tear.

V. Mould Material

CM process involves use of high pressure presses. To sustain this pressure, heavy duty metals are used. There are many metals from which moulds can be made. Preferably materials like P 20 steel, S 7 steel, AI QC7 and AI7075 are used. [4]

AISI Designation Description	Hardness Rc	Hardening Temp (°F)	Tempering Temp (°F)	Heat Treatability	Compressive Strength	Corrosion Resistance	Wear Resistance	Toughness	Machinability	Polishability	Weldability	Thermal Conductivity
4140	30-36	1500	1200	10	4	1	2	8	6	5	4	5
P20	30-36	1600	1100	10	4	2	2	9	6	8	4	5
420SS	35-40	1885	1050	10	4	8	3	9	4	9	4	2
P5	59-61	1575	450	6	8	2	8	6	10	7	9	3
P6	58-60	1475	425	6	6	3	8	7	10	7	8	3
420SS	50-52	1885	480	8	6	7	6	6	7	10	6	2
440SS	56-58	1900	425	7	8	8	8	3	6	9	4	2
BECU	36-42	625	NR	7	2	6	1	1	10	9	7	9

Fig 6 Metals used in moulds and their properties.

VI. Temperature Control

1) Mould Heating

In compression moulding, mostly used plastics are thermosets. These require heating provision to cure unlike thermoplastics which require cooling for solidification. To heat the mould, various types of heaters can be used. Following are some types of heating systems which can be employed [5]:-

1. Heating and cooling channels (flowing oil or water)
2. Jet impingement (heating by flame)
3. Infrared heaters
4. Inductive heating
5. Resistance heating
6. Cartridge heaters
7. Surface heaters
8. Ceramic heaters
9. Carbon fibre heating layer

2) Preheating

The thermosets are required to be preheated before placing into the mould. This helps in many ways. Preheating is done to achieve following advantages [6]:-

1. Reduced the cycle time.
2. More fluidity to get inside difficult corners than with cold preform
3. Reduced moisture content absorbed by material. Moisture is unwanted in plastic

VII. Clamping Pressure

Clamping pressure is the pressure exerted by the press in order to squeeze the plastic to cover the mould cavity. The machine needs to force the plastic to each and every corner of cavity to acquire the desired shape and size. The pressure should be specifically calculated such that it should not be too high or too low. Too high pressure will start to damage the mould and results in severe wear and tear. Too low pressure on the other hand, will result in improper filling of cavity and inaccurate thickness and depth of the part. As per PLENCO, the formula of clamping pressure is as follows [7],

Clamping pressure required = area of part at parting line * effective pressure required by material
e.g.:- for circular part,

Clamp pressure required (in tonnes) = $\boxed{\mathbf{R^2 * \pi * T/in^2}}$

Where,
R = radius of the part at parting line (inches)
T/in²**:-** Effective tonnage required by material

Sample problem: -
Find the tonnage required for a part measuring 76mm in diameter made of Bakelite with effective pressure of 3 T/in². The mould has 4 nos of cavities. Assume Factor of Safety of 10%.

Given: - D = 76mm, ∴ R = 36mm ≈ 1.4960 in
T/in² = 3
n = 4
FOS = 10%

Solution: - $1.4960^2 * \pi * 3 * 4$
∴21.0928 * 4
∴ 84.3712 tonnes + 10%
∴ 84.3712 + 8.43712
= 92.8090 tonnes

Therefore, the pressure requirement of machine to mould the parts is **92.8090 tonnes**. As standard machines are available in market, a 100 ton machine would be suitable for moulding.

VIII. Curing Time

Curing time is the time taken by plastic to completely solidify and harden. The word curing is used for thermosets only as these plastics go through an irreversible chemical reaction. While for the thermoplastics, process is reversible as they solidify when cooled and melt when heat is provided. Thermoset curing can vary according to size and materials. According to size, curing can take anywhere from few seconds for small sizes to an hour for large sizes. According to thermoset materials, curing time varies based on the chemical composition.

IX. Breathe Cycle

When the pressure s fully applied and the mould closes completely, there are chances of blow holes creating inside the cavity. This can ruin the surface of part also the cavity may or may not be filled completely. To eliminate this, breathe cycle is introduced. Breathe cycle is nothing but just a degassing phase added to cycle time before completely applying the pressure. This removes any vapour, air, gas trapped inside the cavity. The breathe cycle is almost always used with phenolics and other formaldehyde molding compounds, and mostly in compression molding [8].

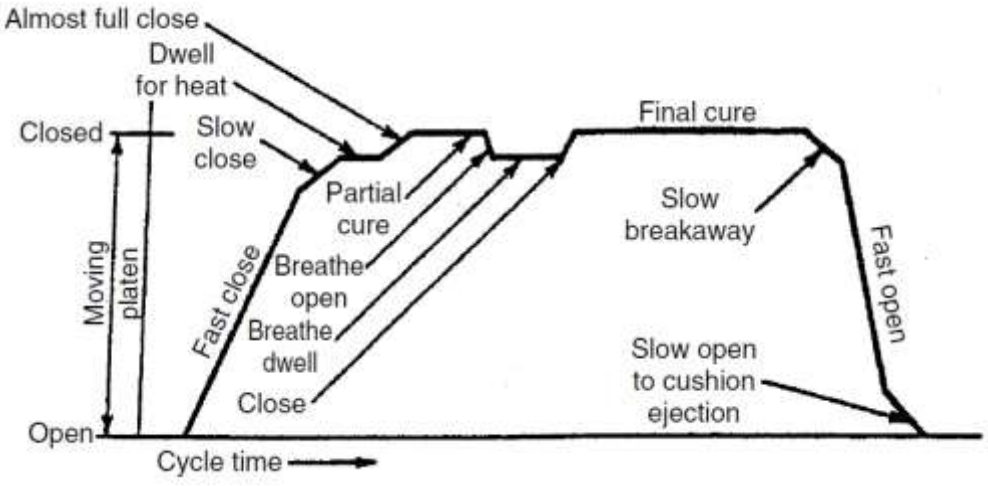

Fig 7 Breathe cycle

X. Shrinkage

After ejection of part from mould, it has a tendency to shrink. Due to this, the final part may differ than intended dimensions. To eliminate this, a shrinkage allowance is considered in manufacturing of the mould. Dimensions of cavity are taken more than the actual design.
e.g.:- shrinkage of two stage phenolic compression moulding compound "04349" is 0.0026 m/m [9]

2. ADVANTAGES

Compression moulding comes with some good advantages. Some advantages are enlisted below:-

1. Low running cost.
2. Good dimensional stability.
3. Density of part is uniform.
4. Shrinkage of part is uniform throughout.
5. No degradation of fibers during flow of plastic.

6. Great impact strength of part.
7. Uniform flow of plastic in entire cavity.
8. Warping and internal stresses are minimal.
9. Shorter lead time.

3. DISADVANTAGES

Compression moulding has some disadvantages too. Some of them are as enlisted below:-

1. Initial cost is high.
2. Uneven parting lines are available.
3. Flash (scrap) produced cannot be recycled.
4. High cycle time as curing time is more.
5. Not suitable for complex parts as material may not flow in intricate gaps.

4. APPLICATIONS

Compression moulding is still used widely in following applications

1. Dinnerware like plates, bowls are made of melamine by compression moulding process.
2. Handles of utensils like cookers, pans are made using CM process.
3. In earlier times, door knobs were made with this process.
4. Television, telephone housings.
5. Radio housings.
6. Electrical parts like switches, switch boards, insulators.
7. Body and interior panels of cars, vans, etc.

5. PROBLEMS OCCURING IN COMPRESSION MOULDING PROCESS

While performing the process, there can be some issues regarding the part. Following problems can occur if the processing parameters are not followed correctly as per PLENCO. [10]

1. Bulge on opposite side of insert.
2. Cure blister
3. Dull appearance
4. Excessive flash
5. Flow lines
6. Procure or hard spots
7. Mould stains
8. Mottled surface appearance
9. Short shot
10. Orange peel
11. Shrinkage
12. Sink marks
13. Skin blisters
14. Sticking in mould
15. Burn mark
16. Warpage

6. CONCLUSIONS

The compression moulding process is one of the non-conventional processes in plastic engineering sector. The process is most suitable for low melt flow thermosets. The parts can possess great surface finish and strength with less warpage. The fiber degradation during flow is minimal with great dimensional stability. The density and shrinkage throughout is uniform. The process can perform best if following parameters are controlled.

1. Part geometry – a good design leads to a good product.
2. Shot size – to properly fill the cavity, proper shot size is necessary. To be taken a bit more than part weight.
3. Part material – proper selection of process depends on part material.
4. Mould quality – ensure optimum quality mould is used to get optimum quality part.
5. Mould material – strong mould lasts longer and gives appropriate part quality.
6. Temperature control – mould heating and plastic preheating should be done properly.
7. Clamping pressure – pressure to mould should be calculated properly to avoid improper part thickness.
8. Curing time – mould holding time depends on curing time. Complete solidification requires proper time.
9. Breathe cycle – to avoid blow holes and air gaps, breathe cycle should be employed.
10. Shrinkage – plastic shrinks after cooling, proper allowances should be considered in mould manufacturing.

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