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Improved Design Fabrication and Testing of a Compression Moulding Machine

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Abstract**—***A design of a compression moulding machine was improved and it was fabricated for the purpose of melting and compression of plastics to form plastic tiles. The major components of the machine encompass; Hydraulic jack, Lever hanger, Lever, Ram, Plunger and sensors. The machine was designed in such a way that it can melt close to 2 tonnes of plastic and does compression in the same chamber. An additional sensor was added to set melting time to avoid manual operations and help with specific time of delivery. The machine was tested for its efficiency. The tray loss (TL) and impurity level (IML) after separation were also measured. The results show that the efficiency of the initial fabricated machine and after optimization are 89.7% and 96.4% respectively. The tray loss pre and after optimization were 9.4% and 0.8% respectively, while the impurity level after fabrication and optimization were 7.1% and 2.9% respectively. This Compression Moulding Machine will solve the problem of plastic pollution and also increases efficiency of Machine.*

Keywords**—** *Compression, moulding machine, fabrication, optimization.*

I. INTRODUCTION

Plastic is a synthetic material made from polymers, which are large molecules composed of repeating subunits. It is created through a process called polymerization, where small molecules called monomers are chemically bonded together to form long chains or networks. Plastics are known for their versatility, durability, and low cost of production. They have high plasticity which means they can be moulded into various shapes, making them suitable for a wide range of applications in industries such as packaging, construction, automotive, electronics, and textiles. Plastics can be rigid or flexible, transparent or opaque, and can have different physical and chemical properties depending on their composition and manufacturing process. Common types of plastics include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), and polyurethane (PU). Each type has its own characteristics and uses. For example, PE and PP are often used in packaging and containers, PVC is used in pipes and vinyl products, PS is used in disposable utensils and packaging foam, PET is used in bottles, and PU is used in foams and cushioning materials. One of the challenges associated with plastics is their environmental impact. Many plastics are non-biodegradable, meaning they do not naturally break down over time. Improper disposal and waste management have led to widespread plastic pollution, particularly in oceans and other ecosystems. About 9.2 billion tonnes of plastic are estimated to have been made between 1950 and 2017 and it means more than half of the figures have been produced since 2004. In 2020, 400 million tonnes of plastic were produced [Orhorhoro et.al, 2016]. If global trends in plastic demand continue, global plastic production is estimated to increase to more than 1,100 million tons by 2050. However, despite the huge value plastics in its various types has on humanity, its inability to decompose faster like other usable by humans is major discouragement. Most plastic produced has not been reused, or is incapable of reuse, either being captured in landfills or persisting in the environment as plastic pollution. Plastic pollution can be found in the entire world's major water bodies, for example, creating garbage patches in all of the world's oceans and contaminating terrestrial ecosystems. Of all the plastic discarded so far, some 14% has been incinerated and less than 10% has been recycled [Ružbarský & Žarnovský, 2013]. Efforts are being made to develop more sustainable alternatives, promote recycling and circular economy practices, and reduce plastic waste through initiatives like single-use plastic bans and improved plastic waste management systems. The essence of this study is to improve the ways of converting plastics into another usable substance in society.

II. MATERIALS AND METHODS

A compression moulding machine was meticulously designed with a keen focus on accommodating the specific temperature needs of different plastic types. When we talk about plastics, it's important to understand that not all plastics are the same. Each type of plastic has its unique melting point, and this can vary considerably from one type to another. Understanding these differences is crucial when designing machinery for moulding, as exposing plastics to inappropriate temperatures can compromise their quality or even make them unusable. Therefore, a significant portion of the design process was dedicated to researching and understanding the various melting points of different plastics. Beyond just the melting points, the machine's overall properties, such as the heating mechanism, were given due consideration. This involved delving into the specifics of the heater's configuration. The heater's design and function are pivotal because it's the primary tool for achieving the desired temperatures. Ensuring it operates efficiently and consistently is of utmost importance. Additionally, the inclusion of a thermostat was another vital design consideration. A thermostat would continually monitor the temperature, making adjustments as needed to maintain the set temperature. This feature is invaluable, ensuring that the plastics are always processed at their optimal temperatures, thereby guaranteeing the production of high-quality moulded items.

The methodology used for this research included the following task namely;

a) Design of compression moulding machine.
b) Engineering drafting of the components and sourcing of required materials using 3D AutoCAD Software.
c) Construction of compression moulding machine using local technology and sourced materials.
d) Evaluation of the compression moulding machine.

Analysis of Improvement in Existing Compression Moulding Machine

Thorough analysis of the existing compression moulding machine was conducted to identify the areas that can be improved. This makes it possible to create a compression moulding machine that is time saving, more accurate and reliable with better efficiency in terms of energy conservation and product yield. The specific improvements carried out are shown in table 2.1 below:

TABLE 2.1: Existing Compression Moulding Machine versus the improved version

SN	Existing Compression Moulding Machine	Improved Compression Moulding Machine
1	Bulky	Small
2	Low temperature range (30-120 ^{0}C)	Higher temperature range (30 - 350 ^{0}C)
3	Longer processing time per batch (5 to 7 hours)	Reduced processing time per batch (60 minutes)
4	Lower production rate - maximum of 2 samples per day	Higher production rate - 1 sample per hour
5	Low compression force - less than 1 ton	Higher compression force – up to of 10 tons
6	High energy consumption rate electric	Energy conserved electric element with higher heating rate
7	Many parts	Reduced components
8	Suitable for melting and moulding of Polyethylene (HDPE and LDPE) plastics only.	Suitable for melting and moulding of Polyethylene, Polypropylene, Polyvinyl Chloride, Polystyrene, Polyethylene terephthalate and Polyurethane plastics

Design Considerations

The following factors are considered in the design of this machine.

i. The machine is designed in a simple way that anyone can operate it with little or no skill.
ii. It is made affordable and with little maintenance cost.
iii. The machine is made up of durable materials.
iv. The machine is designed to melt and compress plastic of high or low melting point.
v. The machine is made portable so that it can be easily transported from one location to another.
vi. Good materials were selected for the construction of the machine based on strength, safety (anti-corrosion characteristics), and durability.

Design Considerations and Calculations

The following considerations and calculations were carried out to select suitable design parameters.

1) *Furnace Dimensions*

I. External casting
Outer total length (L) = 600mm
Outer total breath (B) = 480mm
Outer total height (H) = 430mm
II. Casing Volume, Vs = L x B x H = 600mm x 480mm x 430mm
III HeatingChamber
Length, ***l*** **=** 450mm
Heigh, h = 350mm
Width,*w*=400mm

Surface area, Ac = = 2[(l x w) + (b x h)]
Ac = mm2
IV. Chamber’s Volume, Vc = l x b x h (3)
Vc = mm3
V. Chamber’s Perimeter, Pc = 4 (l + b) (4)

Heating Rate of the Heating Element

Rajput (2008) expressed the equation for calculating the heating rate (H) of electric heaters as:

$P = Q / t$ (5)

Q = Quantity of heat or energy supplied (Joules)
t = time taken to make such supply (sec)

The heating capacity of the coil (element) is 750W = 0.75KW

Watt (W) is the energy consumption rate of one joule per second (1J/s)

*1*W = *1* J/s

Hence, the energy consumption of the heating element = 0.75KW = Q = *750 J/s*

Specific Heat Capacity of the Chamber

The rate of heat flow ‘Q’ and heat transfer per unit mass ‘q’ of a given mass ‘m’ of a sample with the specific heat capacity ‘Cp’ is given by Theodore *et al.*, (2011) as:

$H = Q.t = m.Cp\,.\Theta$ (7)

Where: m. = mass of heat in the chamber (Kg)
Cp = Specific heat capacity of mild steel (J/Kg0C)
Ɵ =Temperature change (K) = (T2 – T1)
Q =quantity of heat supplied (W) = 750W
t = time
H = amount of heat supplied (J)

The quantity of heat required to raise the temperature of the furnace chamber from 25°C to 100°C With a quantity of heat Q, passing through a given mass m, of a sample, the specific heat capacity of the sample as: $m = Q / Cp\,.\Theta$

$\Theta = T2 - T1 = (100-30) + 273.15 = 70 + 273.15 = 353.15$ K
$m = 750 \times 1000/(877.96 \times 353.15)$
$= 2.42$ Kg

The rate of heat flow ‘Q’ and heat transfer per unit mass ‘q’ of a given mass ‘m’ of a sample with the specific heat capacity
‘Cp’ is : $q = Q / m$ (8)

Where:
m = mass of the furnace chamber = 2.42 kg
Q = quantity of heat supplied (W) = 750 W

The rate of heat transfer, q = 750/2.2 = 340.99J/kg

Thermal Conductivity:

Thermal conductivity is the ability of a material to transfer heat. In other words, it is the amount/speed of heat energy transmitted through a material per unit of time per unit of surface area. According to Cengel (2015): thermal conductivity (k) is directly proportional to the heat capacity (C) and the mean free path (λ): $K x C x \lambda$

Using the absolute axial heat flow method: the electrical power supplied over a given length L of the sample is measured and recorded. The thermal conductivity of each of the insulating material were calculated from (Theodore *et al.*, 2011)

Thermal diffusivity

In comparison to its capacity to hold energy from heat, a material's thermal diffusivity determines its capacity for transmitting thermal energy over time. It is the density and specific heat capacity at constant pressure divided by the thermal conductivity. Its SI unit is either m2/s or m2/hr. Thermal diffusivity is calculated as follows:

(xi) α =Thermal conductivity / heat storage capacity = $k/(C_p\rho)$

Where:

k = Thermal conductivity = 1.4949 W/m·K
ρ = Density = 2300 kg/m3
Cp = Specific heat capacity = __ J/kg·K
$\alpha = 1.4949 / (2300 \; x \; 877.96 \; 1.4949)$
$\alpha = 0.7400 \; x \; 10\text{-}6$

Thermal Shock and Thermal Shock Resistance

The thermal stress that occurs at the surface during cooling is referred to the following equation (1): $\sigma th = \frac{E \, \alpha \, \Delta T}{1 - v}$

Where σth: thermal stress

E: the coefficient of thermal expansion: the temperature difference and Poisson's ratio.

α: the coefficient of thermal expansion

ΔT: The temperature differences

V: Poisson’s ratio

Fabrication Procedure and Assembly of Machine frame

Machine frame

The compression moulding machine comprises two parts: the furnace and the stand. The external dimensions of the furnace are 600mm×480mm×430mm, while its internal dimensions are 450mm×400mm×350mm. The stand has a height of 310mm. Mild steel iron was cut to the necessary sizes using an electric hand cutting machine. After accurately measuring and marking the lengths of each stand, the top and bottom bracings were also measured and marked with a scriber. These pieces were then cut with a grinding disc, ensuring precise and clean cuts. An engineering square was employed to guarantee perpendicular and straight cuts. Additionally, the hydraulic jack stand was measured and marked using a sharp scriber. The frame materials were then transported to the welding machine. They were carefully assembled with a few tack welds to hold the materials in place. Once there was confidence in the designed position and orientation of the assembled machine frame parts, a full weld was executed.

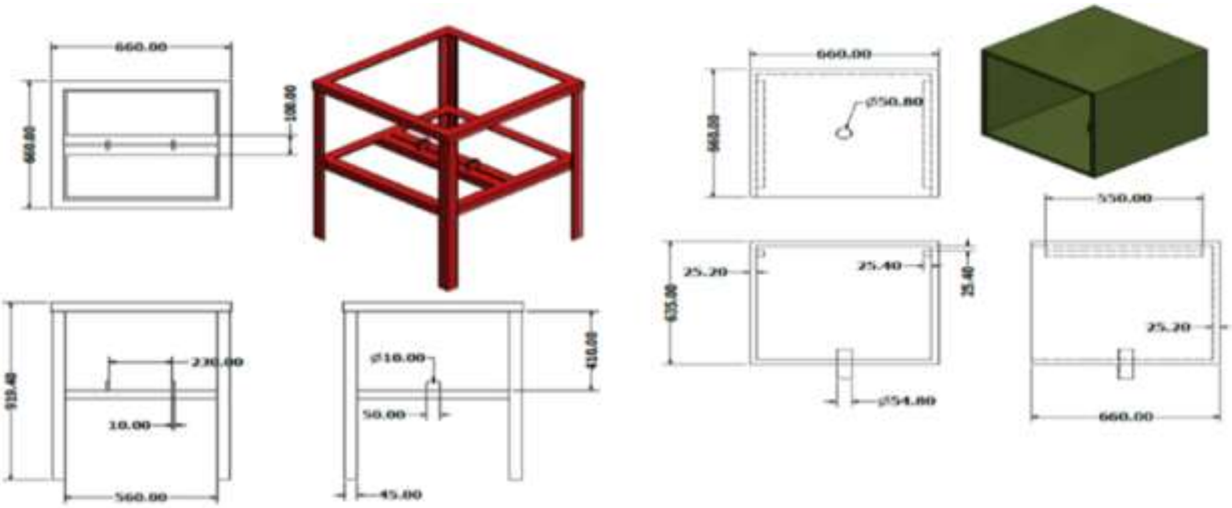

Fig. 2.1: Machine frame

The Mould

The mould of a plastic compression machine is a crucial component that determines the final shape and dimensions of the compressed plastic. the mould has dimensions of 300mm×250mm×200mm. It's constructed from mild steel, a material known for its excellent durability, malleability, and resistance to wear, making it ideal for repeated use without deformation. The choice of mild steel also aids in efficient heat conduction, ensuring uniform temperature distribution during the compression process. This uniform heat aids in achieving a consistent finish and quality in the moulded plastics. Furthermore, the mould's design facilitates easy release of the compressed plastic once the moulding process is complete, ensuring a smooth production cycle.

Hydraulic press

The hydraulic press integrated into our plastic compression moulding machine boasts a capacity of 20 tonnes. This specific tonnage was chosen after meticulous evaluation based on several factors. Firstly, plastics, when heated to their malleable state, require a certain degree of pressure to be accurately shaped and moulded. The 20-tonne press ensures that an optimal and consistent force is applied across the plastic material, leading to high-quality moulded products with uniformity in dimensions and appearance. Moreover, the force provided by this hydraulic press caters to a broad range

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of plastic types, granting the machine versatility in handling various plastic materials.

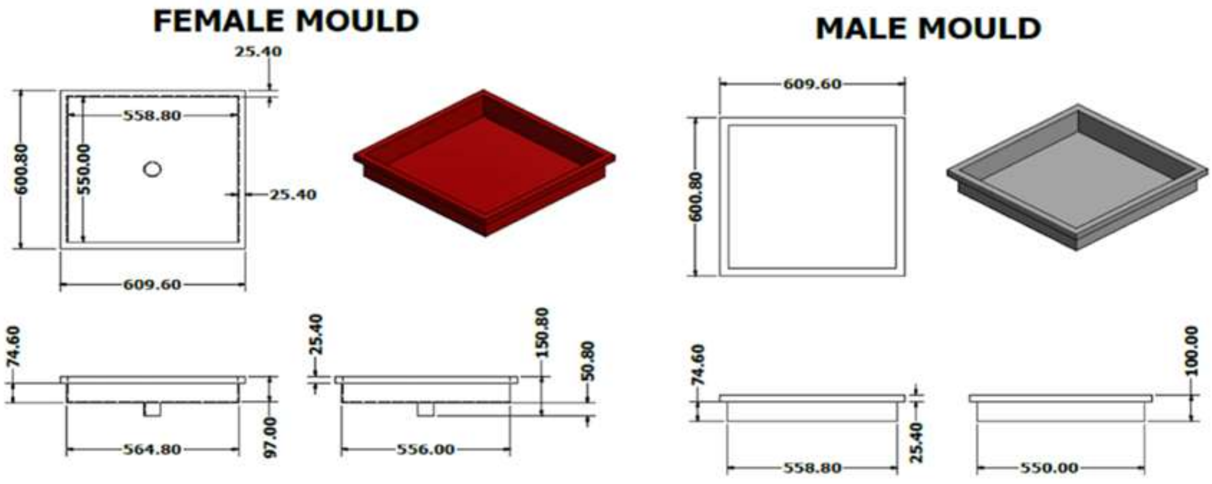

Figure 2.2: Machine detailed dimensioning

This ensures that the machine is not limited to moulding a specific type of plastic, but rather can cater to the diverse needs of the industry. Another pivotal advantage is the precision control offered by a hydraulic system. This allows for fine-tuning of the applied pressure, ensuring the protection of the mould and extending its lifespan. Over-compression, which can damage both the mould and the product, is thus effectively prevented. In addition to these functional advantages, safety is another significant benefit. Hydraulic presses, by their nature, provide controlled and steady force application. This reduces the risk of sudden jerks or movements that might pose safety concerns during the compression moulding process.

Electrical Controller Box

This state-of-the-art component is paramount for our operations, mainly when dealing with processes that require meticulous temperature control. Here's an in-depth look at its features and functionalities:

Electrical Control Box Overview:

The Electrical Control Box serves as the nexus for temperature management within our setup. It's meticulously designed to set, regulate, and monitor temperatures, ensuring that our processes remain within desired parameters, thus guaranteeing optimal outcomes and product quality.

Components of the Electrical Control Box:

- Push Buttons with Indicator Lights: The control box boasts four distinct push buttons, two of which are green and labeled "ON", and the other two, red, labeled "OFF". These buttons are integral for manual overrides and system control. The accompanying indicator lights offer immediate visual feedback, confirming the activation or deactivation status of connected machinery or processes.
- Digital Displays: The two digital screens positioned at the box's lower section provide real-time temperature data. One display indicates the current operational temperature, while the other allows users to set a desired target temperature. This dual-display setup ensures operators can simultaneously monitor the ongoing temperature and compare it with the pre-set target, making timely adjustments if deviations occur.
- Keyed Switch: Positioned centrally above the digital screens, the keyed switch introduces an essential security layer. Its presence ensures that temperature settings and other vital configurations can only be adjusted by authorized personnel, thus minimizing potential disruptions or unintentional changes.
- Robust Enclosure: Encasing these components is a durable metal frame, purposefully chosen to shield the internal elements from external disturbances, such as dust, moisture, or physical impact. Its neutral hue ensures seamless integration into diverse industrial environments.

The Electrical Control Box is a testament to our project's commitment to precision and quality. By integrating this component, we're not only bolstering the efficiency of our operations but also ensuring that our temperature-sensitive processes are consistently maintained at the desired levels, yielding unparalleled results

TABLE 2.2: Materials Selected for Fabrication of Improved Compression Moulding Machine

Sn	Item Required	Qty
1	2" Angle Iron	1
	1" Sq. Pipe	1
	1.5" Plate	1
2	Lagging Materials- fiber	10 kg
3	15 ton Hydraulic Jack	1
4	1.4mm Plate	1
5	1.4mm Plate	1
6	10mm Plate	1
7	10mm thick spring	2
8	Ø2" X 5mm thick Pipe	1
9	Flat bar, 1"sq.Pipe	1
10	5mm Tempered glass	1
11	Ø 3/4 X 5mm thick Pipe	1
12	Hydraulic jack	1
13	Lever hanger	1
14	Plunger	1
15	Ram	1
16	Lever	1
17	Lever hanger	1

Material Selection and Manufacturing Technique

High-quality materials and modern manufacturing techniques were selected to ensure durability and reliability. Sensors and other monitoring tools were incorporated into the design to allow for real-time monitoring of the moulding process. This will help to identify any issues early on and prevent costly downtime. Table 2.2 above contains list of selected materials for the fabrication of the improved compression moulding machine.

TABLE 2.3: Melting temperature of plastics

Name	Degree °c
Polyethylene (HDPE and LDPE)	115°c-135°c
Polypropylene	160°c-170°°c
Polyvinyl Chloride	100°c-200°c
Polystyrene	240°c
Polyethylene terephthalate	250°c-260°c
Polyurethane	200°c-400°c

III. RESULTS AND DISCUSSION

In this endeavour, the main objective was the design and construction of a mini compression moulding machine, with a focus on assessing its performance capabilities. The essence of this project lies in the creation of a machine that streamlines the manufacturing process of plastic products, tailored to specific moulds. Central to its functionality is a melting chamber, which plays a pivotal role in liquefying the plastic to fit the designated mould. In addition to this, a car jack is ingeniously employed to apply the necessary pressure, compressing the resin once it reaches its molten state. One of the critical phases of this project involved the meticulous selection of materials. After careful consideration, polypropylene was chosen due to its ability to maintain the integrity and quality of the final product. This selection was crucial as it directly impacts the effectiveness and reliability of the compression moulding process. Upon the completion of the machine's construction, it underwent rigorous testing, particularly focusing on two primary aspects of compression moulding. These tests were instrumental in evaluating the overall performance of the machine. One of the key objectives of these tests was to identify any potential defects in the final product. Furthermore, these tests were essential in determining the optimal melting parameters, specifically concerning temperature and time. The aim was to achieve a perfect melting point that would not only ensure the quality of the final product but also enhance the efficiency of the production process.

Effect of temperature testing

The initial experiment was conducted using a set of three trials, each employing a distinct temperature setting while maintaining a constant time duration. As depicted in Figure 4, the outcomes of these three trials were quite revealing. Specifically, the trials demonstrated that the resin did not achieve a fully melted state at the temperatures of 200°C and 225°C within a span of 15 minutes. This observation is particularly noteworthy given that the melting point of polypropylene, the material used in this experiment, is around 160°C. A plausible explanation for this phenomenon could be the influence of ambient temperature on the machine's operational heat during the testing phase. The absence of refractory materials surrounding the oven, which are typically used to minimize heat loss, might have contributed to this outcome. However, a significant deviation was observed in the third trial. Here, it was found that the resin could be completely melted at a temperature of 250°C. This result strongly suggests that a temperature setting of 250°C is sufficient to melt the resin, compensating for any heat loss to the surroundings. In other words, despite the potential heat loss, a temperature of 250°C proved to be effective in achieving complete melting of the resin within the same time frame of 15 minutes. The detailed analysis of these temperature-based tests, as illustrated in Figure 3.1, provides a comprehensive understanding of the thermal behaviour of the resin under varying conditions.

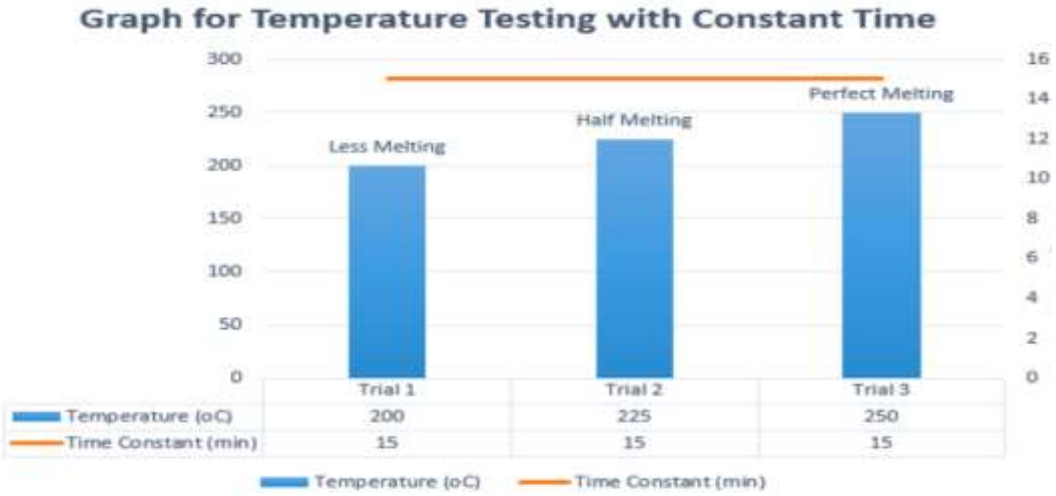

Fig. 3.1 Analysis of the temperature testing with time

Effect of time testing

The second experiment involved varying the duration while maintaining a constant temperature, using polypropylene samples across three trials. As depicted in Figure 3.1, each trial was conducted at a steady temperature of 250°C, but with different time settings. The results of Trial 1 indicated incomplete melting of the resin after 5 minutes at 250°C. A similar issue was observed in Trial 2, where the resin did not fully melt even after 10 minutes, indicating that the time allotted was insufficient for the granules to melt completely. However, Trial 3 yielded a complete melt of the resin, achieved with the same temperature of 250°C over a period of 15 minutes. The findings from this time analysis testing are presented in Figure 3.2.

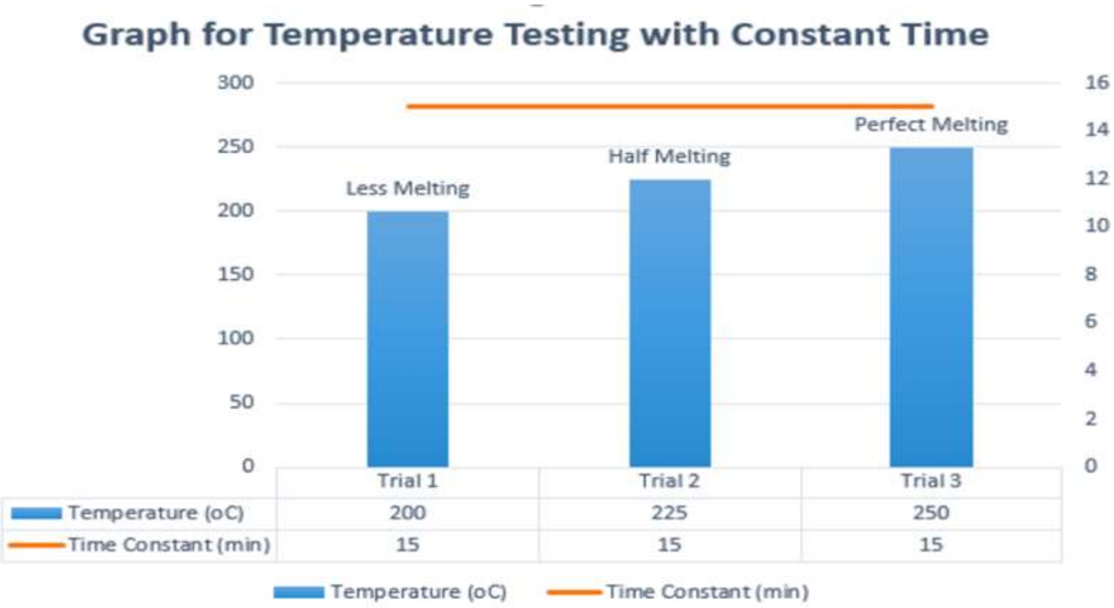

Fig. 3.2 Analysis of the temperature with time

IV. CONCLUSION

The result of the experiment shows that the machine can melt resin material a temperature at the maximum temperature of 250^{O}C, at duration of 15 minutes, this a breakthrough for the research as resin materials are known to withstand a high temperature rate. The melting of the material could be due to the absence of refractory materials surrounding the oven, which are typically used to minimize heat loss, might have contributed to this outcome. The time trial on the material shows that absolute and effective melting is achieved at 15 minute. So, it can be recommended that when using the machine to melt resin material. The comprehensive analysis of temperature and time variations has provided a vivid understanding of the compression moulding machine's behaviour. The results emphasize the importance of an optimal temperature setting, with 250°C being identified as effective in achieving complete melting within a 15-minute timeframe. Furthermore, the experiments underscore the need for careful consideration of time duration, as insufficient time allocation led to incomplete melting in earlier trials. Base of the observed result on how the machine melt the resin material, it can be recommended that the machine is suitable to melt all types of plastic, due to it ability to reduce heat loss during heating.

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