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**DESIGN ANALYSIS OF A HYDRAULICALLY POWERED COMPRESSION
MOULDING MACHINE FOR THE RECYCLING OF PLASTIC WASTE**

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ABSTRACT

An estimated 32 million tons of solid waste is said to be generated in Nigeria per annum out of which plastic waste constitute some 2.5 million tons. The plastic menace is very real as they are very ubiquitous: blocking drains, sewers, rivers and streams and even our oceans. One of the major solutions to this menace being explored is the recycling of plastics. Many methods are available for this purpose but the one explored in this work is the use of compression moulding machine. A prototype pilot compression moulding machine was designed to produce electrical Patress from waste plastics using hydraulic press. Different types of plastics: PET, HDPE, PVC and Polypropylene were melted but only Polypropylene melt could cast and pressed to form Patress. The PET Melt solidified into a brittle mass while the HDPE plasticized and the PVC could not be melted using open fire. The Polypropylene melt solidified for 90 minutes in open air but took 20 minutes to solidify when enclosed in a water jacket.

Keywords: Design Analysis, Plastic Wastes, Hydraulically Powered, Compression Mould Machine, Recycling

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1. Introduction

Manufacturing industries are the main sectors that create job opportunities to enhance economic development of a country. In the modern world, one of the main products of manufacturing industries is plastic materials. Plastic materials are non-degradable and are discarded indiscriminately, leading to accumulation in drains, sewers, rivers and the oceans (Alabi et al, 2021). Plastic wastes have become one of the environmental pollutants in the world. Plastic product being used and dumped, contribute about 8.69% of total municipal solid waste generated in Nigeria (Gideon *et al.*, 2014). Recycling is one method that is used to combat and reduce plastic wastes and one recycling method is compression moulding. Compression moulding is one of the manufacturing processes used in the production of thermoplastic and thermoset products in industries.

The operation of the compression mould involves sorting of plastic wastes materials from solid wastes composition which are then mixed with fillers and heated and converted to a polymer in a molten state or plasticized. The polymer is poured into the mould cavity so that the polymer can take the required shape with the help of varying temperature and pressure (Kamal, 2009).

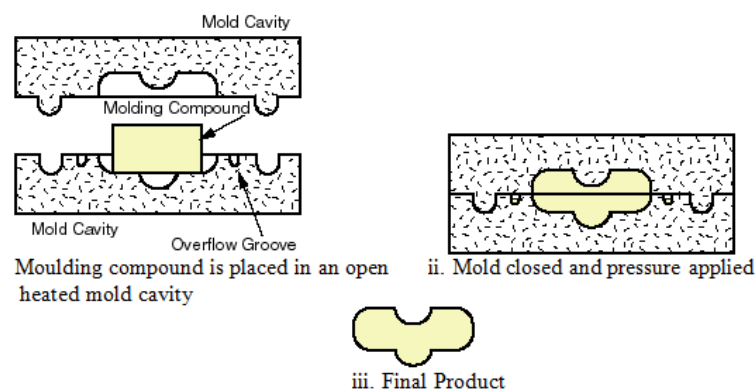


Figure 1: Processes of Compression Moulding Machine

The mould is then closed and pressure is applied to force the materials to fill the cavity. A hydraulic ram is utilized to produce sufficient force during the moulding process. The heat and pressure are maintained until the plastic is cured and sets into a formed solid material (Soffie, 2016). The process schematic is shown in Figure 1.

Compression molding machine offers many advantages to alternative plastic manufacturing methods. These include minimal losses from scrap, mass production possibility, ease of production complex parts and minimal finishing requirements. Compression molding is a high volume, high-pressure plastic molding method that is suitable for molding complex and high strength objects. This process produces complex parts in a wide variety of sizes. With its short cycle time and high production rate, many organizations in the automotive industry have chosen compression molding technology to produce light plastic parts (Formlabs, 2021).

The versatile nature of this technology has made several researchers to work on different designs or techniques to produce compression moulding machines. For instance, Amira, (2016), carried out a mechanical system design of compression moulding machine. The study

emphasized the development of hydraulic system for compression moulding machine in order to make it fast in production of thermoplastics products. Orhororo *et al.* (2016) carried out the design and fabrication of compression moulding machine for plastic waste recycling in Nigeria. The machine consists mainly of threaded screw, hopper, heater, heating chamber, forming chamber, steel frame, and control switch. The raw materials (waste plastics) were loaded through the hopper and heated within a temperature range of 180⁰C-220⁰C and formed under a pressure of 3.77 MN/m². Jagushte *et al* (2017) and Singh *et al.* (2017) designed and fabricated pneumatic compression moulding machines for fiber reinforced polymer (FRP) composites. In their design, temperature of specimen dies can be controlled automatically by using sensors and by using FRL (filter, regulator and lubricator) unit. The low density, high strength and high stiffness to weight ratio, fiber reinforced composite materials are manufactured by the machine at low cost. However, most of these designs did not consider separate melting of polymer to be fed into the mould before compression and further refinement. In this present work, compression moulding machine is designed and this paper is meant to present the problems of producing effective compression in the moulding machine and preparing the materials for compression.

2. Research Methodology

The machine was designed for the compression moulding of thermoplastics, including Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC) and Polypropylene, which are used for many of the plastic containers and grocery bags that constitute the bulk of the plastic wastes. The design considerations include providing means of producing required pressure; heating the plastics to melt or plasticize the scrap and means to open and eject the piece from the mould. The hydraulic jack was selected for the first condition of providing pressure and will be set above the top platen to push down the platen when operated. A set of extension springs were chosen which will open the mould after compression while a lever operated pusher ejects the Partress after compression moulding. The heating posed an initial problem because of the planned use of assorted scrap; hence a separate melting chamber was designed to melt the scrap.

2.1 The Machine

The configuration of the system is shown in Figure 2. It comprised of a frame constructed of U-channel to provide stability and rigidity. The stresses in these members are minimal because the expected compression pressure is low for the production of the plastic. The framed structure carries two platens: the lower platen, which is rigid and carries the mould; and the top platen, which carries the ram and could move up or down. The top platen is suspended with extension springs and supports the hydraulic jack, used to drive it down to apply pressure to the mould. The platen is also equipped with studs to ensure it runs aligned.

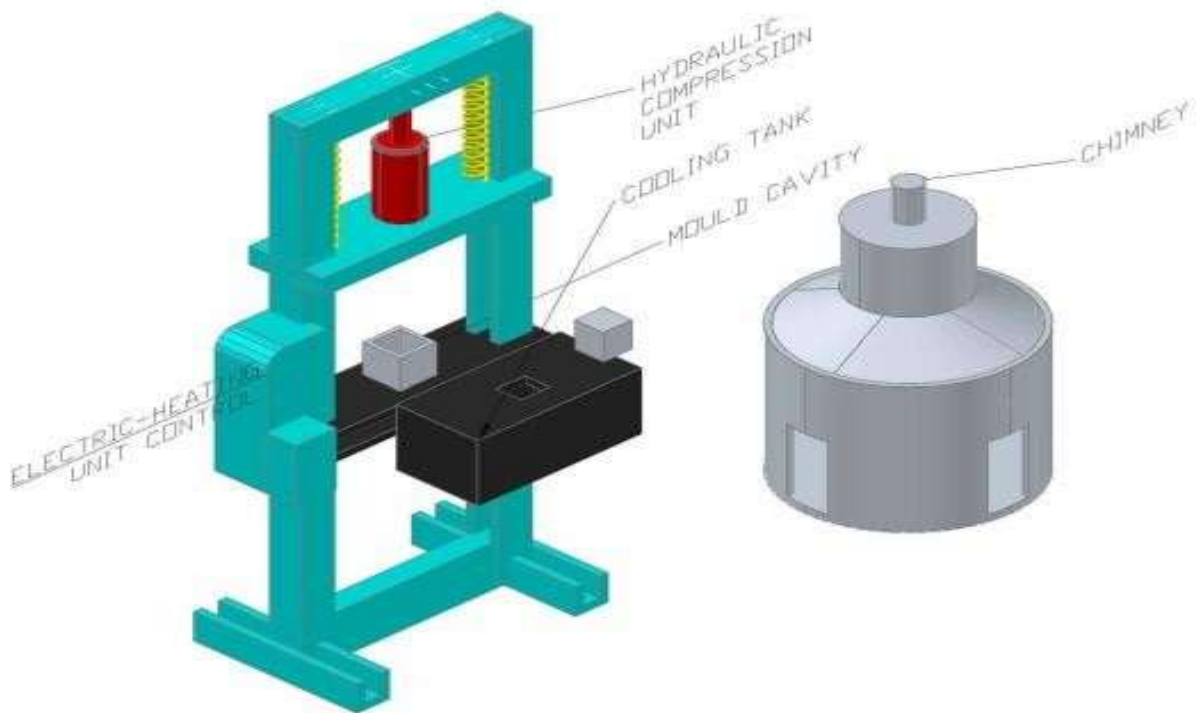


Figure 2: An Isometric View of the Compression Mould making Machine

2.2 Mould Design

The mould is designed for the compression moulding of Patress for electrical wall fittings. The Patress is shown in Figure 3 and it's a simple 85 mm x 85 mm x 40 mm open rectangular box with a 3 mm shell. For this design, a 5 mm shell was considered.

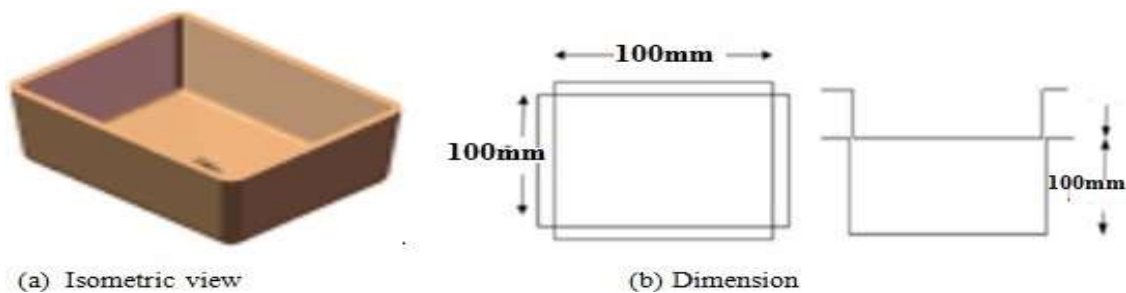


Figure 3: Electrical Patress

Therefore,

Size of mould cavity = 85mm x 85mm x 40mm; volume of mould = 289 cm³

Size of ram = 75mm x 75mm x 35mm

Volume of Patress = 92.125 cm³

During compression moulding, the liquid or plasticized plastic of approximately the volume of the Patress is ladled into the mould and will be pushed by the action of the ram to fill the

annulus between the mould and the ram. The lack of consistency in the initial quantity of plasticized plastic results in flashes between the top platen and the mould.

Height of pre-compression plastic is,

$$h = \frac{\text{volume of patress}}{\text{Area of mould}} = \frac{92,125}{85 \times 85} = 12.75\text{mm} \quad (1)$$

2.3 Compression Pressure and Compression Load

During compression, the ram travels 7.75 mm (12.75mm – 5mm) into the plastic in the mould. The weight of plastic displaced is the buoyancy force on the ram.

Buoyancy, W_p = wt of plastic displaced;

$$W_p = \text{volume of plastic displaced} \times \text{density} \times \text{gravity} = V_p \rho g \quad (2)$$

Where V_p = Volume of displaced plastic, and ρ = density, g = acceleration due to gravity

$$V_p = 75 \times 75 \times 7.75 = 43,593.75 \text{ mm}^3 \quad ; \text{ density of plastic} = 0.94 \text{ g/cm}^3$$

$$\therefore m_p = 43.59375 \times 0.94 = 40.978125$$

$$\text{Buoyancy, } W_p = F_B = \text{Displaced weight} \times \text{gravity} = \frac{40.978125 \times 9.81}{1000} = 0.402 \text{ N} \quad (3)$$

This is the force at the base of the ram or piston. However, in displacing the plastic, the plastic moves up along the annulus against the friction between the plastic and the steel mould. The coefficient of friction between plastic and steel varies with the type of plastic and mould surface finish. However, since we are designing for the worst scenario, we used the maximum friction coefficient between steel and polyethylene. Researches put the coefficients between steel and plastic at between 0.25 and 0.4; we chose 0.4 for our work. Therefore,

$$\text{Friction force, } F_f = \mu \times F_N = \mu \times F_B = 0.4 \times 0.402 = 0.1608 \text{ N} \quad (4)$$

Therefore, total resisting force,

$$F_T = F_B + F_f = 0.402 + 0.1608 = 0.5628 \text{ N} \quad (5)$$

The force determined here is very low because it is based on pure plastic without the introduction of reinforcing fibres. It does not also include the force to overcome the spring force used to open the mould after compression.

2.4 Spring Design

The spring should provide the force to open the mould and return the platen to top position after compression and release of the compression force produced by the hydraulic press. The load to be overcome is made up of the weight of the hydraulic press, the top platen and the ram. We have,

Weight of hydraulic jack = 3 kg, Weight of platen and ram = 4.5 kg; total mass = 7.5 kg. A weight of 10 kg is assumed to give a force of 100 N.

The pressure applied to the mould is

$$P = \frac{F}{A} \quad (6)$$

Where F = Applied force, A = Mould base area

$$P = \frac{F}{A} = \frac{100}{0.075 \times 0.075} = 17.8 \text{ kPa} \cong 20 \text{ kPa}$$

Spring Data:

Spring material: ASTM A227 Hard drawn Wire: - G = 80 GPa, D = 25 mm,

$$S_u = 1510 \text{ MPa}; S_{us} = 0.67S_u; F_s = 1.5 \quad \tau_{all} = \frac{0.67S_u}{F_s} = \frac{0.67 \times 1510}{1.5} = 674.47 \text{ MPa}$$

Where S_u = ultimate stress, S_{us} = ultimate stress in shear, F_s = safety factor, C = spring index, D = mean spring diameter, τ_{all} = allowable stress.

With the allowable shear stress, the diameter of the spring is determined using (7) according to (Ugural, 2006).

$$\tau_{all} = \frac{k_s 8PD}{\pi d^3} \quad (7)$$

where, $k_s = 1 + \frac{0.615}{10} = 1.0615$

$$d^3 = \frac{k_s 8PD}{\pi \tau_{all}} = \frac{1.0615 \times 8 \times 100 \times 25}{\pi \times 674.47} = 10.0193$$

$$d = 2.1544 \approx 2.5 \text{ mm}$$

Therefore, $d = 2.5 \text{ mm}$, $C = 10$

Number of coils:

We use equation for deflection

$$\delta = \frac{8PD^3 N_a}{Gd^4} = \frac{8PC^3 N_a}{Gd} \quad (8)$$

Where δ = deflection, P = Applied load, D = mean coil diameter, d = wire diameter, C = spring index and

N_a = Active number of coils.

Deflection of spring from top rest position to end of compression = 100 mm (mould = 50mm and top clearance for product release = 50mm)

$$\delta = \frac{8PD^3 N_a}{Gd^4} = \frac{8PC^3 N_a}{Gd}$$

$$N_a = \frac{Gd\delta}{8PC^3} = \frac{80 \times 10^3 \times 2.5 \times 100}{8 \times 100 \times 10^3} = 25 \text{ Coils}$$

The spring constant, $k = \frac{P}{\delta} = \frac{100}{100} = 1$

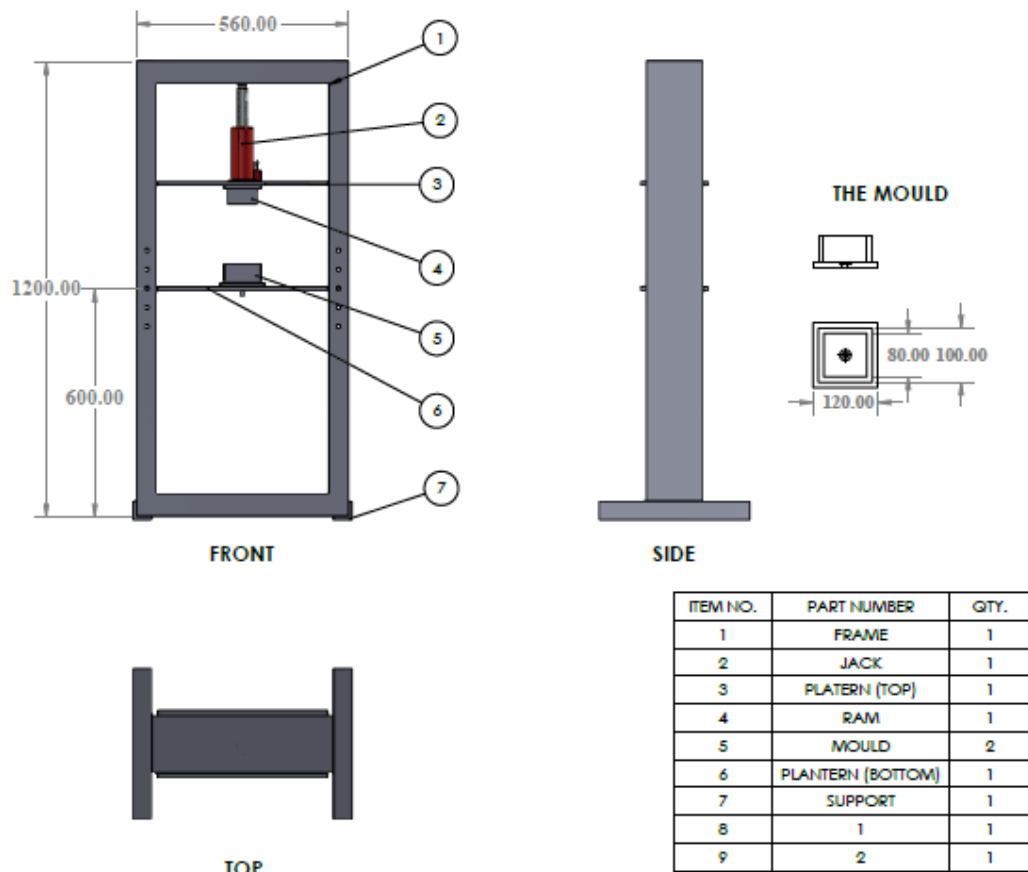


Figure 4: An Orthographic View of the Compression Mould making Machine

2.4 Frame Design

Finite Element Analysis (FEA) was carried out to determine the stresses on the frame section. The FEA was carried out in ANSYS Workbench 11 to determine the maximum stress developed in the press. Figure 4 shows the component meshing.

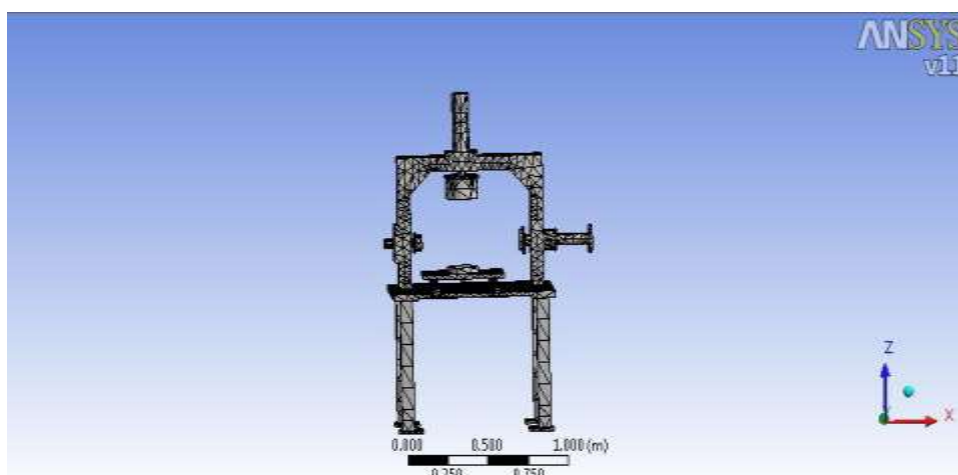


Figure 5: Cores Meshing of Geometry Performed on the Press.

The Finite Element Analysis was carried out using a maximum load of 23000N applied on the base plate due to action of actuator. This mean hydraulic press can hold a load of 20kN which is higher than the forming strength ($10\text{-}34\text{N/m}^2$) used for the waste plastic under consideration.

2.5 Construction

The fabricated compression moulding machine is shown in Figure 6



(a) Without a Water Reservoir



(b) With a Water Reservoir

Water Jacket

Figure 6 Picture of the Fabricated Compression Mould Machine

2.6 Experimentation

The testing of the fabricated machine was carried out by first sorting of the plastics. This was necessary to ensure the workable ones for the product were used. Figure 6 shows part of sorted plastics.



Figure 7. Part of Sorted Plastics: (a) PET Bottles (b) Cream Bottles of HDPE (c) PVC Pipes

The sorted plastic feedstocks were weighed and prepared to be fed into the heating chamber for melting to take place. The various sorted plastics represent Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC), Figure 7a – c.



Figure 8. Melting of Feedstock in Wood Fired: (a) Polypropylene melt charge (b) PVC melt charge and (c) Melted PET charge

Different heating methods were experimented to melt the plastics. These included open wood fire using our designed heating chamber, open frying pan on open fire, gas fire and improvised double boiler. The PET bottles melted in open fire (Figure 8c) but solidified to a very brittle mass-like slag (Figure 8b). The PVC could not melt in the frying pan over open fire (Figure 8b). The HDPE melted but also formed a hard mass. It was only the Polypropylene (chairs, Figure 8a) that melted and was used to cast the Patress.

As soon as the plastic melted, the molten plastic was transferred to the mould. The molten plastic was placed in the lower mould of the hydraulic compression mould and load was exerted on it to compress it under pressure to form a given pattern of the Patress. After compression, the relief valve was released and the hydraulic plunger disengaged to enable removal of the compressed plastic product from the mould. The compression of the molten plastic is shown in Figure 9.



Figure 9: Casting and Compression of Mould

The formed plastic pattern is ejected upon solidification after about 90 minutes in air. In order to reduce this cooling time, a water jacket was designed and constructed to provide a water reservoir. This helped to reduce the curing temperature and time.

3. Results and Discussion

The maximum stress, σ_{max} on the frame is computed as 49MPa with the application of 23kN force. The stress on the cross beam, σ_b is computed as 0.83MPa which is far below the yield

stress, σ_Y which is obtained as 250MPa. The spring used for mould opening has a spring constant, $k = 1$, spring diameter, $d = 2.5\text{mm}$, coil diameter, $D = 25\text{mm}$ and number of coils, $N_a = 25$.

The Polypropylene melts were cast and pressured to form as-cast Patress. The finished formed compression mould plastic product is shown in Figure 10. The finished product is either suitable for use with its output finish or further finishing may be carried out on it to input other desired configurations as may be necessary.



Figure 10 Finished Formed Compression Mould Plastic Products

The data collected during the test are presented in Table 3 and Table 4. These include weights of the plastic feed stocks, the formed product weight, curing time and melting temperature of the plastic.

Table 3: Melting and Cooling Data for Selected Polypropylene Cooled in Air

S/N	Feedstock Weight W_1 kg	Melting Time t_m (min)	Melting Temperature T_m °C	Product Weight W_2 kg	Solidification Time t_s (min)
1	2	17	200	1.2	87
2	3	17	200	2.4	89
3	4	20	220	3.5	90
4	5	25	225	4.4	90

Table 4: Melting and Cooling Data for Selected Polypropylene Cooled in Water

S/N	Feedstock Weight W_1 kg	Melting Time t_m (min)	Melting Temperature T_m °C	Product Weight W_2 kg	Solidification Time t_s (min)
1	3	17	201	2.4	15
2	5	17	200	4.0	15
3	1	20	220	0.9	18
4	4	25	250	3.6	20

The melting temperature ranged from 200°C to 250°C while the melting time was dependent on the weight being melted. The solidification time was reduced from about 90 minutes to 20 minutes by the introduction of the water jacket. The reduction of solidification time is presented graphically in Figure 11.

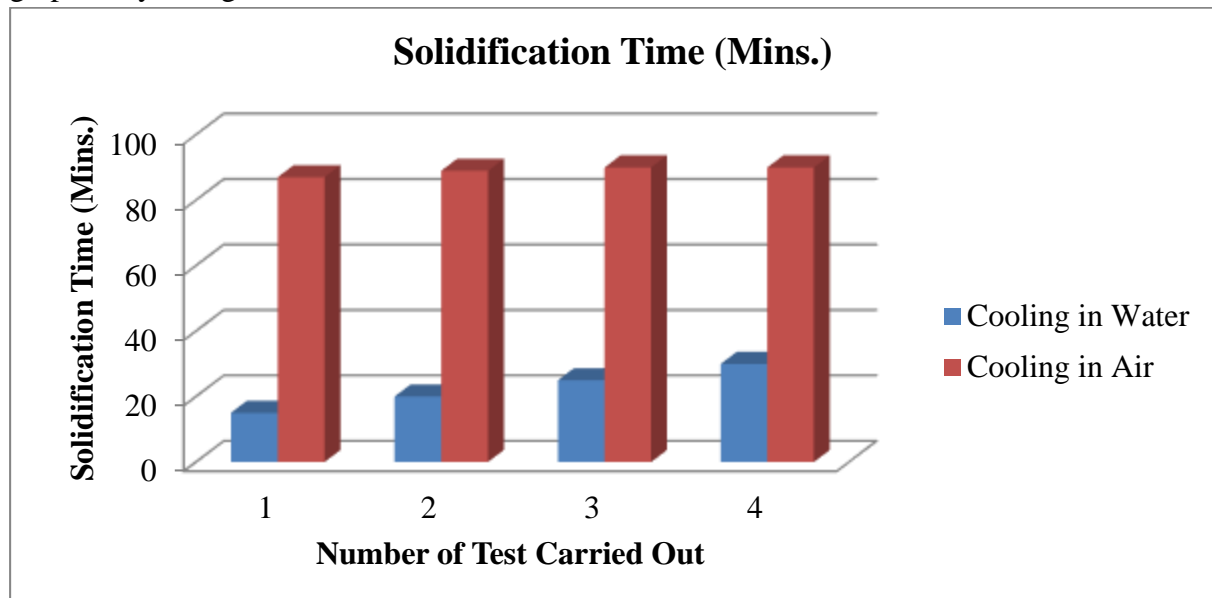


Figure 11: Bar-Chart Showing Comparative Analysis of Solidification Time

4. Conclusion

In this project work, a compression moulding machine for the processing of recycled plastics using waste polymer materials was successfully designed and fabricated. Different plastic materials were melted to provide feedstock for the moulding and compression but only Polypropylene form mouldable melt that was used to cast/compress Patress. A cooling reservoir with water as the coolant was used to reduce the curing time from 90 minutes to 20 minutes. Investigation into other plastics showed that PET, HDPE and PVC could not be recycled as melted plastics as they form brittle mass or are not meltable as with PVC.

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