International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 6, Issue 11, pp 99-104, November-2022

https://doi.org/10.47001/IRJIET/2022.611013

The Making of Injection Molding Machines for Shoe Insoles from Silicone Rubber Composite Materials

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***Abstract* - The injection molding machine is one of the most significant and rational forming methods available for processing plastic materials. An injection molding machine has three basic components. Injection unit, mold, and clamping system. The injected unit, also called a plasticator, prepares a precise melt of the plastic and through the injected unit transfers the melt to the next component which is the mold. The clamping system closes and opens the mold. Injection molding machines are commonly used for the manufacture of plastic-based products, but in this study, the basic materials were changed to silicone rubber and talc composites Silicone rubber is used as matrix and talc as filler. Due to the different mechanical properties that exist between plastic and silicone rubber, some parts of the injection molding machine need to be changed and the parameters that affect this tool must be considered. Parameters that need to be considered are the dimensions of each part of the tool, temperature, pressure, and time.**

Keywords: Injection Molding, Talc, Silicone Rubber, Insole.

I. INTRODUCTION

Rubber is widely used for industrial manufacture, either as a finished or raw material. Rubber is divided into two, namely natural rubber and synthetic rubber, one example of synthetic rubber is silicone rubber. Silicone rubber is a thermoset elastomer that exhibits relatively high elongation, consistent high-temperature performance, low sensitivity to ultraviolet (UV) radiation, and favorable biocompatibility, and is available in a wide range of hardnesses. Due to its good bio-compatibility, silicone rubber is increasingly being used. in biomedical applications (Meunier, L. et al. 2008).

An injection molding machine (IMM) is a machine that uses an injection system to inject material into a mold or molding unit. An injection molding machine is a machine that uses thermoplastic materials, so far the development of this machine has been related to increase power efficiency, processing speed, and durability. This machine performs certain important functions: (1) plasticizing: heating and melting of the plastic in the plasticator, (2) injection: injection of the plasticator under controlled volume shot pressure of the melt into a closed mold, with compaction of the plastic starting at the walls of the mold cavity, (3) after filling: maintaining the injected material under pressure for a certain time to prevent backflow of melt and to compensate for the decrease.

II. RESEARCH OBJECT

2.1 Injection Molding Machine

The parts contained in the injection molding machine are: (1) hydraulic pump: to apply pressure and move the injection cylinder, (2) injection cylinder: pushes the injection screw so that the injection process occurs through the gate, (3) injection screw: a place the plastic material is heated and becomes melted plastic, then injected into the mold, (4) mold: the mold to be formed, (5) clamp cylinder: functions to press the mold so that it can be closed during processing, and open when the process is complete (Injection Molding Handbook, 2000).

The injection pressure value is the actual compressive strength that occurs during the injection process, generally the pressure used in silicone rubber is 1 – 10 Mpa (Bont M, Barry C, Johnston S, 2021), to calculate the strength of the actual pressure value at the time of injection is the following formula

$$P_{spesifik} = P_{hydraulic} \times \frac{A_{Piston}}{A_{Plunger}}$$

The size of the plunger also affects the capacity that can be injected into the mold, the things that affect capacity are the length of the hydraulic stroke and also the size of the plunger. The calculation used to calculate the injection capacity is the following formula

$$V_{injeksi} = \pi \times r^2 \times maximum\ stroke\ hydraulic$$

Determination of the number of cavities is the determination of the maximum number of cavities based on the maximum injection capacity that can be carried out by an injection machine based on the weight of the runner and the product. The formula for finding the number of cavities can be seen in the formula below.

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$$qty\ of\ cavity = \frac{Sw \times 0{,}8}{Wm}$$

2.2 Composite

Composite is a combination of two or more materials on a macroscopic scale to form a new, higher quality material (Jones, 1999). Mixing the two materials with different properties is expected to provide a material that is superior to the previous material. Composite components consist of filler and matrix

Composite material has better properties than metal, this composite material has high tailorability, good fatigue, high strength/weight and Young's modulus, higher density than metal, corrosion resistant, has heat and sound insulating properties, and can be used as a good electrical barrier, and can also be used to patch damage due to loading and corrosion.

The matrix used is silicone rubber and the filler used is talc, where silicone rubber is an elastomer (rubber-like material) that consists of silicon itself, which is a polymer containing silicon along with carbon, hydrogen, and oxygen. Silicone has outstanding thermal and thermo-oxidative resistance. Silicone is also much more susceptible to electromagnetic radiation and particles (UV, alpha, beta, and gamma rays) than organic plastics. This allows its use in fields such as aerospace (low and high-temperature performance), electronics (electrical insulation), healthcare (excellent biocompatibility), or in the building industry (resistance to weathering) (Shit and Shah, 2013)

Talc is a hydrosilicate of magnesium that has a chemical composition of Mg3Si4O10 (OH)2 or H2Mg3 (SiO3)4. Talc exhibits high functionality of several excipients because it has been used as filler, lubricant, and glidant in pharmaceutical formulations as well as in cosmetic formulations as an anticaking agent, abrasive, absorbent, opacifying agent, bulking agent, skin protectant, and slip modifier (Nikitakis et al., 2006) Physical properties of talc can be seen in the table below.

Table 1: Physical properties of talc

No.	Propertiest	Description
1	Particle size distribution	Two typical values >99% through 74 µm (200#) or >99% through 44 µm (325#)
2	Solubility	Practically insoluble in water, dilute acids, alkalis and organic solvents
3	Density	Bulkdensity 0,5 g/cm^3 ; Tapped density 0,8g/cm^3
4	refractive index	1,54-1,59
5	Specific Gravity	2,7-2,8
6	Hardness	1,0-1,5
7	Hygroscopicity	Talc absorbs significant amounts of moisture at 25 C and a relative humidity of over 90%

2.3 Machining Process

The machining processes carried out in this study were using CNC milling machines, milling machines, and lathes, CNC machines using the G-code obtained from the CAM results then entered into the Mach3 Milling software to then carry out the machining process using the TU 3A CNC machine. The machining process using milling machines and lathes is carried out with the reference dimensions of the machine drawings that have been made before of the unit. The NPHR value can be calculated with the following formula.

2.4 Data Collection

The authors conducted a literature study and field study to analyze the parameter of Injection Molding Machines. There are several sets of data needed to calculate dimention of machines. The data will be calculated using the formula that has been obtained, and the final result can present the design of the injection molding machine and the finished result of the injection molding machine experiment.

III. RESULTS AND DISCUSSION

3.1 Injection Molding Machines Design

It is known that the hydraulic cylinder used in this study has a piston diameter specification of 30 mm, pressure of 100-150 bar and has a maximum stroke length of 70 mm. Based on the specifications of the hydraulic cylinder, the actual pressure required during injection, the calculation of dimensions on the injection molding machine can be determined by assuming that the plunger or pusher on the injection unit has a diameter of 50 mm, then the calculation of the actual pressure during the injection process is as follows.

$$A_{piston} = \frac{\pi \times d^2}{4}$$

$$A_{piston} = \frac{\pi \times 30^2}{4}$$

$$A_{piston} = 706{,}5\ mm^2 = 7{,}065\ cm^2$$

$$A_{Plunger} = \frac{\pi \times d^2}{4}$$

$$A_{Plunger} = \frac{\pi \times 50^2}{4}$$

$$A_{Plunger} = 1962{,}5\ mm^2 = 19{,}625\ cm^2$$

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$$P_{spesific} = P_{hydraulic} \times \frac{A_{Piston}}{A_{Plunger}}$$

$$P_{spesific} = 150\ bar \times \frac{7{,}065}{19{,}625} = 54\ bar$$

The material requirements in this study required approximately 120 grams, so it is necessary to take into account the injection capacity of the material. Based on the specifications of the hydraulic cylinder and assuming that the plunger size is 50 mm, the calculation of the capacity of material that can be injected is:

$$V = \pi \times r^2 \times maximum\ stroke\ hydraulic$$

$$V = \pi \times 25^2\ mm \times 70\ mm$$

$$V = 137.444\ mm^3 = 137{,}444\ cm^3$$

The calculation above shows that the capacity of material that can be injected is 137.444 cm^3. If converted into weight, then the weight of the material that can be injected is

$$m = V \times \rho_{sr}$$

$$m = 137{,}444\ cm^3 \times 1{,}14 \frac{gr}{cm^3}$$

$$m = 156{,}68\ gr$$

The weight of the product that can be injected is 156.68 grams, so the number of cavities can be calculated using the following formula

$$qty\ of\ cavity = \frac{156{,}68\ gram \times 0{,}8}{120\ gram}$$

$$qty\ of\ cavity = 1{,}044$$

The results of the above calculations show that the number of cavities in the mold is 1 piece.

The injection molding machine design is divided into several parts, including the hydraulic unit, injection unit, molding unit, and clamping unit. In the planning process, a CAD design process is carried out in parts, and after that, the process of assembling the parts into the entire injection molding machine will be carried out. The next process is making 2D machine drawings and CAM making so that the machining process can be carried out.

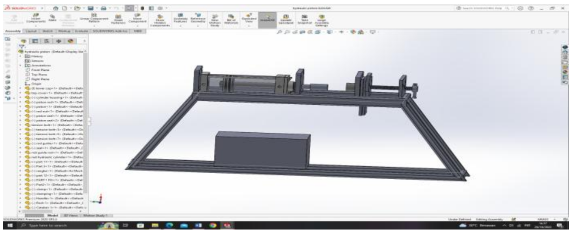

Figure 1: Injection molding machines design

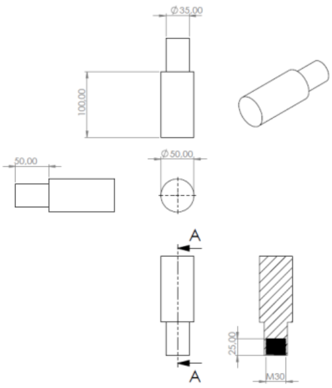

Figure 2: Machine drawing of plunger

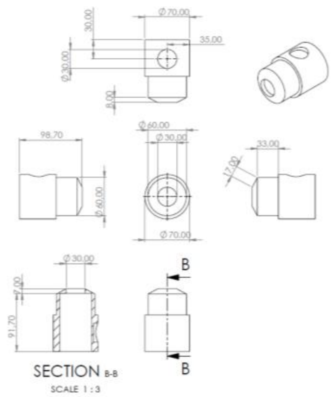

Figure 3: Machine drawing container

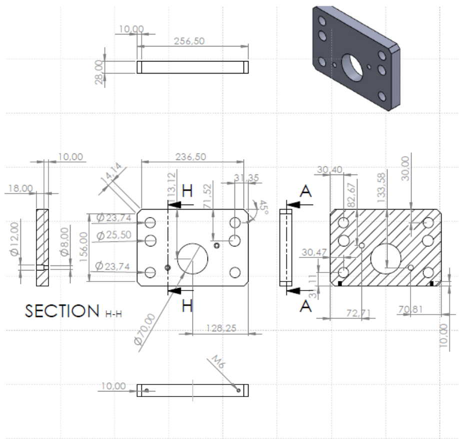

Figure 4: Machine drawing crutch

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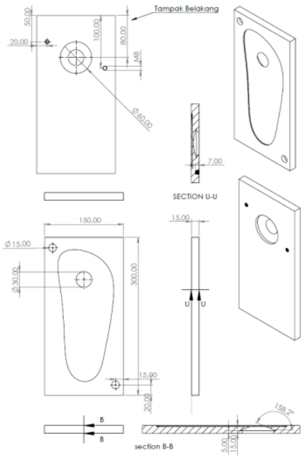

Figure 5: Machine drawing mold

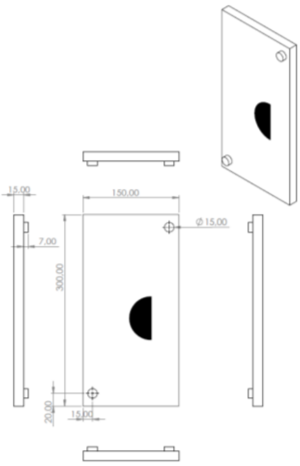

Figure 6: Machine drawing mold

3.2 Machining Process

After doing the calculations, the next step is to carry out the design process using Solidworks 2020 software. This process is carried out to get the 3d design results as a reference, 2d designs, or machine drawings so that lathe and milling machining processes can be carried out, as well as G-code results to be transferred into a CNC machine (Computer Numerical Control).

Figure 7: Milling process

Figure 8: Lathe process

3.3 The Making of Composites

The process of making composite materials was carried out by mixing RTV 497 silicone rubber with talc powder. The composite is made with silicon rubber matrix RTV 497 with the additive used, namely talc powder. Manufacture by adding talc powder additives with composition variations of 10% and 20%. The talc is mixed with silicone rubber and then stirred for 2 minutes and the hardener is added according to the recommended product which is 3-4%, with the total amount needed to make one shoe insole being 120 grams.

The next stage of weighing each material is the process of mixing each material to be used, starting with the process of mixing silicone rubber and talc by stirring using an electric drill for 2 minutes. After that is mixing with the hardener for 2 minutes, the hardener in the mixture functions as a reagent for silicone rubber which was originally liquid and then turns into a solid.

3.4 Injection Molding Machine Experiment

The next process of making shoe insoles using an injection molding machine is an experimental tool that has been made before. In this study, 4 variations were used to conduct experiments on injection molding machines, namely variations in temperature, composition, and pressure, for temperature variations in this study using 2 temperature variations, namely 75^{o}C and 100^{o}C, this temperature variation was carried out because it accelerated the process of hardening the material or hardening silicone rubber is by raising the temperature during the hardening process in the mold. The pressure variations used in this study were 150 bar and 100 bar, pressure variations were carried out to determine how much pressure is needed to inject with silicone rubber material. The variation of the composition that was carried out was 10% and 20%, to determine the good material characterization. The stages carried out in this experiment are as follows:

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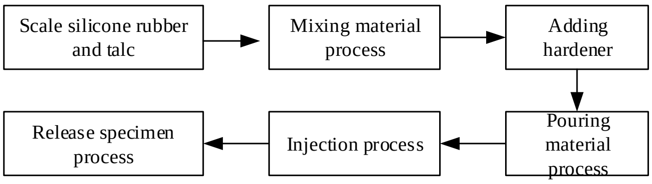

Figure 9: Experiment process diagram

The results of the experiment obtained 4 samples from variations in temperature, pressure and composition used, namely variations with a temperature of 75^{0}C and a pressure of 150 bar, a temperature of 100^{0}C and a pressure of 150 bar, a temperature of 75^{0}C and a pressure of 100 bar. It was found that each variable affected the outcome of the printed shoe insole, along with the results of each variation used.

Figure 10: Temperature 100^{o}C, Pressure 150 bar, Talc Composition 20%

Figure 11: Temperature 75^{o}C, Pressure 150 bar, Talc Composition 20%

Figure 12: Temperature 75^{0}C, Pressure 100 bar, Talc Composition 20%

Figure 13: Temperature 75^{0}C, Pressure 150 bar, Talc Composition 20%

Figure 14: Temperature 75^{0}C, Pressure 150 bar, Talc Composition 10%

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IV. CONCLUSION

From this study, several conclusions were obtained regarding the topics based on the data and calculations that have been described, such as:

1. The mold design process uses Solidworks 2020 software which is used to create 3D designs, machine drawings and G-codes.
2. The machining processes used in the manufacture of injection molding machines are non-conventional machining, namely CNC (Computerized Numerical Control) machines and conventional, namely lathes and milling machines. The machining processes carried out are milling, drilling, drilling and tapping processes to manufacture the entire aluminum-based injection molding machine.
3. The working principle of an injection molding machine with the basic ingredient of silicone rubber is by mixing the material and then putting it in a liquid state and then hardening it on the mold using high temperatures to speed up the hardening process.
4. Experimental results of injection molding machines with silicone rubber and talc composite materials:
   - In terms of process, temperature and pressure affect the results of the material being made, temperatures that are too hot result in porosity so that the optimal temperature is 75^{0}C, and pressure that is too small causes the material not to harden thoroughly due to the long time the material spreads throughout the mould, for that the pressure is optimal is 150 bars.
   - In terms of time, the injection molding machine has succeeded in shortening the time it takes to manufacture shoe insoles with a production time of approximately 50 minutes.

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Citation of this Article:

Yusuf Umardani, Sulistyo, Achmad Widodo, Satriyo Adhi Nugroho, “The Making of Injection Molding Machines for Shoe Insoles from Silicone Rubber Composite Materials” Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 6, Issue 11, pp 99-104, November 2022. Article DOI https://doi.org/10.47001/IRJIET/2022.611013

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