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A Comparative Study of NAK80 Steel and Beryllium Copper Moulds for Injection Moulding of Polypropylene Material

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Abstract

The project aim to compare the performance of beryllium copper and NAK80 mould insert materials in plastic injection moulding. The experiment involved varying critical processing parameters like melting temperature and injection pressure, and considering design aspects like shrinkage level and weight of the mould part. The choice between BeCu and NAK80 depends on the specific requirements of the application and the relative importance of each factor. BeCu has a better cycle time and weight, making it suitable for high-volume production scenarios. The weight of the sample is better for BeCu, making it more durable. However, NAK80 has a higher shrinkage level, which is generally desirable as it leads to less dimensional change in the final product. Other factors, such as cost and availability, may also play a role in the decision.

1. Introduction

This study is executed the knowledge of Injection moulding is a versatile and efficient manufacturing process used for mass-producing complex-shaped plastic components. The process involves injecting molten plastic into a mould cavity under high pressure, followed by cooling to solidify the desired part. The choice of mold material, traditionally steel due to its strength and thermal conductivity, significantly impacts quality, productivity, and cost-effectiveness. Despite steel's advantages, its complicated machining procedures increase production costs and lead times. Since the 1980s, there has been a focus on using ceramic powders for injection moulding complex-shaped structural ceramics. This process is desirable for near-net shape fabrication. Injection moulding is widely used in various industries, such as aerospace, electronics, medical, and instrumentation, due to its ability to produce products with intricate structures and precise dimensions. Even though the injection moulding process has been around for a while, it is still costly and difficult to optimise the parameters and produce high-quality products by trial and error (Zhang et al., 2019). The quality of injection moulding depends on raw materials, injection machines, mold construction, and process parameters like injection pressure, time, speed, packing pressure, mould temperature, and more. The complexity of the injection molding process, characterized by nonlinearity, time variation, and instability, makes analysing process parameters challenging. Recent research has aimed to optimize these parameters to enhance the overall molding quality of products. Choosing the wrong process parameter setting results in a large amount of scrap, unstable product quality and long lead time for product failure (W. C. Chen et al., 2008).

2. Methodology

First of all, the element that important to consider in this research was methodology. The approaching experiment will use the supplied polymer resin in conjunction with the plastic material selected for the study. The liquid mass flow rate of the material is 50 g/10 min, and its density is 0.9 g/cm3 (Lotte Chemical, 2020). The PP homopolymer material was procured from Lotte Chemical Titan, specifically the TITANPRO PM803 product. The mechanical properties of polypropylene are influenced by the injection moulding process parameters (Wu et al., 2023). Next the mould insert selected is NAK80 and BeCu mould. NAK80 is widely recognized as a representative material in the field of engineering plastics due to its exceptional properties and favorable fluidity during the moulding process. Functional parts have been utilised in diverse industrial applications. A range of appropriate grades and series can be found that are suitable for both processing and the desired performance of moulded parts. NAK80 is a new high-strength plastic die steel with many notable properties, including excellent mirror grinding performance, strong electrical discharge machining performance, higher pre-hardened hardness, and so on (Fu, 2013). Beryllium copper mould are utilised in plastic injection moulding because of their exceptional thermal characteristics, which enable quick heat removal from plastic components produced by injection moulding machines. Coefficient of elasticity, thermal conductivity and temperature expansion coefficient (Mindivan, 2020).

Then, the injection moulding process consists of various process parameters that have the potential to impact the product cycle time, shrinkage part, and weight part. Nonetheless, this study solely took focus on two process parameters. The chosen variables involve melting temperature and injection pressure. Melting temperature is important for plastic flow. Without a specific melting point, it depends on the liquid temperature. The structure and composition of the plastic affects its fluidity. Temperature affects molecular rigidity differently and should be considered for different materials. A more fluid plastic is produced at a higher melting temperature, which can enhance the filling procedure and the moulded part quality (Ye, 2023). The parameter must be explicitly stated and its optimal level emphasised in order to attain the state of PP polymer. In order to attain the appropriate material density and minimise voids or flaws in the finished product, the injection pressure also has an impact on the moulding process's packing and holding stages (Mohan et al., 2016).. Hence, the analysis of parameter setting can also be conducted with regards to the shrinkage and weight of the mould component.

The next phase involved the effect of injection moulding process parameter through the experimental on injection of sample cup with different mould. After that, the completion of the injection moulding process, the weight of the plastic cup sample was measured. There are some samples are taken and averaged. This is because to get a more accurate sample value for this study. The purpose is to analyse the weight of factors and parameters of different levels that can affect the weight of plastic cup samples. Then will be measure by CMM machine to generated the shrinkages level of the process parameter.

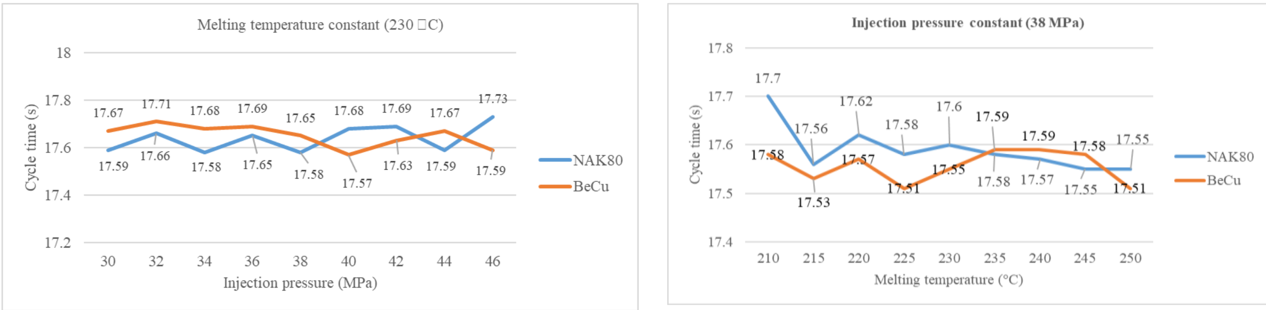
3. Result and Discussion

For a start this discussion is about the result of cycle time of process parameters, part shrinkage and weight from the experiment. The results were gained by doing an experiment using two different moulds which is beryllium copper and NAK80 steel. The polymer resin used in this experiment is PP material. The data that obtained from the experiment was insert into a data sheet or table. Once the data sheet or table was completed, the graph was generated using the data to analyze the cycle time of process parameters. The function to measure the part shrinkage and weight was to analyze the confirmation test.

The figure 1 below show the cycle time in injection molding depends on a processing parameter was setup at the injection moulding machine, including the process parameter was selected on this experiment are melting temperature and injection pressure. NAK80 steel and BeCu are two different materials commonly used for moulds in injection molding, and they have different properties that can affect cycle times.

Next, the figure 1(a) illustrates the comparison between cycle time for NAK80 steel and BeCu moulds. The cycle time for NAK80 steel starts at 17.59s for the first sample cup, fluctuating between 17.66s to 17.58s. It then rises to 17.69s at the 7th injection pressure, then drops back to 17.59 at 44MPa. The cycle time for BeCu mould starts at 17.67s for 30 MPa injection pressure, undulating between 17.71s to 17.68s. A decline pattern starts at 36MPa to 40MPa, marked by 17.69s to 17.57s. The cycle time for NAK80 steel mould is recorded at 17.58s at 34 MPa and 38 MPa, while the highest peak is 17.73s at the final injection pressure. The cycle time fluctuates among injection pressures, with the lowest cycle time for BeCu mould at 17.57s at 40 MPa and the maximum at 17.71s at 32 MPa.

The cycle time of NAK80 steel and BeCu moulds at different melting temperatures as figure 1 (b). The cycle time was taken from an average of 5 sample cups produced from an injection moulding machine using a constant injection pressure at 38MPa. The graph displays the melting temperature and cycle time values in seconds for each mould, with fluctuations in cycle time observed between the first and sixth melting temperature. For BeCu, cycle time fluctuates considerably between 17.58s to 17.51s at 210°C to 225°C, then stabilizes at 240°C and then significantly decreases at 250°C. The minimum cycle time for BeCu is 17.55s and the maximum at 17.70s, with the lowest and highest peak cycle times recorded at 240 and 17.59s at each melting temperature, respectively. The pattern of cycle time decreases moderately from 5th to 8th melting temperature until the final cycle time is considerably reduced at 250 °C. NAK20 steel mould has the highest cycle time, 17.62s, and the lowest cycle time at 250 ºC. Both moulds have minimal and maximum cycle times of 17.54s. Based on the data provided, the BeCu mold generally demonstrates a more consistent and lower cycle time compared to the NAK80 steel mold. The BeCu mould shows fluctuations between 17.58s to 17.51s at 210°C to 225°C, stabilizes at 240°C, and then significantly decreases at 250°C. The minimum cycle time for BeCu is 17.51s, and the maximum is 17.70s. On the other hand, the NAK80 steel mould has a higher cycle time, starting at 17.70s and fluctuating between 17.60s to 17.55s, with the highest cycle time at 17.62s. Therefore, based on the provided data, the BeCu mould appears to be the preferred choice for achieving lower cycle times in injection moulding.



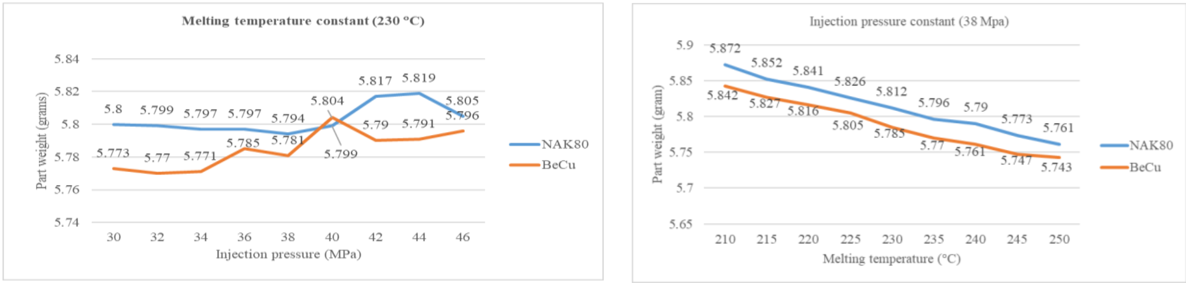
(a) **(b)**

Fig. 1 *(a) melting temperature constant (230 ℃) ; (b) injection pressure constant (38 MPa)*

The figure 2 shown below the choice of mould material, whether NAK80 steel or Beryllium copper, typically has a minimal direct impact on the weight of the sample cup moulded part. The material of the mould primarily affects factors such as thermal conductivity, wear resistance, and ease of machining, but it does not directly determine the weight of the final product.

However, figure 2 (a) represents the lowest part weight of NAK80 steel and BeCu moulds sample cup are 5.794g and 5.770g. Therefore, the highest peak of part weight for NAK80 sample cup is 5.819g, followed by remarkable for BeCu sample cup is 5.804g. Then, the NAK80 and BeCu sample cups reveal different patterns across the injection pressure two times for sure between at 38 MPa to 40 MPa and 40 MPa to 42 MPa. More or less, the trend pattern for NAK80 sample cup moderately decreasing from the 1st injection pressure to the 5th injection pressure, then significantly upward trend until 8th injection pressure before it turns to dropped down at 9th injection pressure. Meanwhile, for the BeCu mould sample cup seems like the trend pattern are fluctuating part weight from 30 MPa to 40 MPa, concluding with rise up at 42 MPa. The best part weight between NAK80 and BeCu is determined by comparing the lowest and highest peak part weights for each material. The lowest part weight recorded for the NAK80 steel mould sample cup is 5.794g, while the lowest part weight for the BeCu mould sample cup is 5.770g. On the other hand, the highest peak part weight for the NAK80 sample cup is 5.819g, and for the BeCu sample cup, it is 5.804g. Therefore, the NAK80 steel mould has a slightly higher best part weight compared to the BeCu mould.

Upon analysis, the minimal part weight shown in figure 2(b) for NAK80 steel mould is 5.761g at 250°C melting temperature. While, the maximum part weight noted at 5.872g at 210°C melting temperature. On other hand, the lowest part weight for BeCu mould is 5.743g, at 250°C then the highest peak hits was recorded at 5.842g which is 210°C melting temperature. In summary, the graph highlights the decreasing pattern starting at 1st to the 9th melting temperature and the experiment compared the part weight of NAK80 steel and BeCu moulds are a downward trend for concluding for both moulds. The best part weight in injection moulding is determined by the lowest recorded part weight, as it indicates a more precise and consistent manufacturing process. In the context provided, the lowest part weight for the BeCu mould is 5.743g at 250C melting temperature. Therefore, based on the data presented, the BeCu mold would be preferred for achieving the best part weight in injection molding.



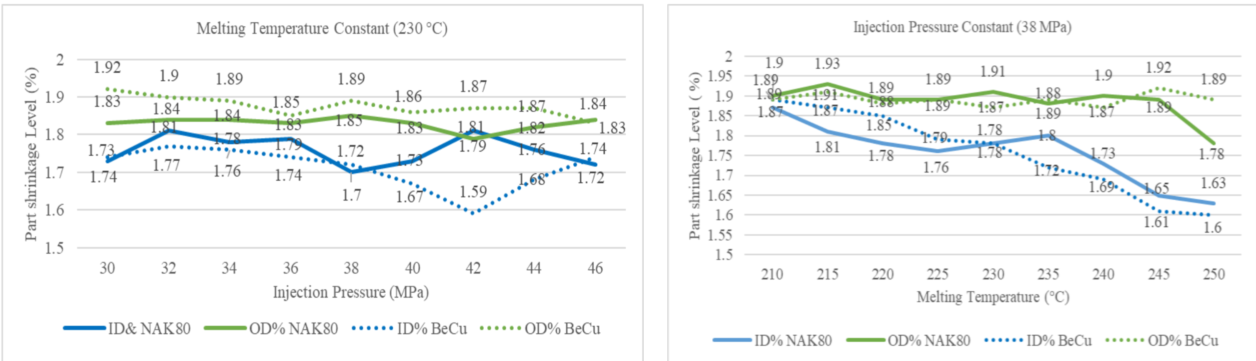
(a) **(b)**

Fig. 2(a) *melting temperature constant (230 ℃) ; (b) injection pressure constant (38 MPa)*

The figure 3 shows the part shrinkage in injection moulding can be influenced by the type of mould used, whether it be Beryllium copper or NAK80 steel, but it is not the only consideration. A variety of process parameters and the properties of the plastic material being utilised are the main factors influencing part shrinkage. On the other hand, the mould material thermal conductivity, cooling effectiveness, and other characteristics may indirectly cause part shrinkage.

In the provided data at figure 3(a), it is observed that NAK80 had a lower inner diameter shrinkage level of 1.70% at 38MPa injection pressure compared to BeCu, which had a lower inner diameter shrinkage level of 1.59% at 42MPa injection pressure. Similarly, NAK80 had a lower outer diameter shrinkage level of 1.79% compared to BeCu, which had a lower outer diameter shrinkage level of 1.84%. Therefore, based on the data, NAK80 generally exhibited lower shrinkage levels compared to BeCu, indicating that it may be considered better in terms of shrinkage for the given parameters.

In the comparison of inner diameter shrinkage levels,as shown figure 3(b) NAK80 exhibited a lower shrinkage level of 1.63% at 250°C, while BeCu had a slightly higher level of 1.60% at the same temperature. Similarly, for the outer diameter shrinkage, NAK80 showed a lower level of 1.78% at 250°C, compared to BeCu's level of 1.87%. Therefore, based on the data provided, NAK80 demonstrated lower shrinkage levels, indicating better part quality compared to BeCu.



(a) **(b)**

Fig. 3 *(a) melting temperature constant (230 ℃) ; (b) injection pressure constant (38 MPa)*

The Equation 1 was used to calculated the shrinkage percentage of inner diameter and the Equation 2 was used to calculated the shrinkage percentage of outer diameter.

$$Outer\ shrinkage = \frac{diameter\ of\ cavity - outer\ diamter\ of\ sample}{diameter\ of\ cavity} \times 100\% \quad (1)$$

$$Inner\ shrinkage = \frac{diameter\ of\ core\ \ - outer\ diamter\ of\ sample}{diameter\ of\ core} \times 100\% \quad (2)$$

4. Conclusion

In conclusion, the investigation into the effect of processing parameters on the cycle time of injection-moulded parts has revealed crucial insights into the manufacturing process using NAK80 steel and beryllium copper moulds. The study emphasized the significant role of certain processing parameters in influencing cycle times, including melting temperature and injection pressure, for both types of moulds. Furthermore, the comparison of part shrinkage and weight between NAK80 steel and beryllium copper moulds in polypropylene injection moulding underscored the material-dependent differences that impact the final properties of moulded parts.

On other hand, a comparison of these project reveals interesting insights. In injection moulding, cycle time refers to the total time it takes to produce one complete cycle of moulding, including the injection, cooling, and ejection phases. So we can conclude the preference for shorter or longer cycle times depends on various factors and goals of the manufacturing process. Futhermore, a shorter cycle time is preferred because it allows for faster production, higher output, and reduced manufacturing costs per part of outcomes. Shorter cycles mean that the moulding machine can produce more parts in a given time, leading to better equipment utilise and increased overall efficiency. Based on the result, BeCu sample cup is often chosen in injection moulding that contribute to shorter cycle times. Shorter cycle times directly translate to increased productivity and higher throughput. Manufacturers can produce more parts in a given time frame, leading to improved efficiency and cost-effectiveness.

For the weight of mould part is also depends on various factors in injection moulding. Both heavy and light parts have their own advantages and considerations. Reached from the result, BeCu moulds have consistently shown lower part weights across the range of melting temperature and injection pressures tested. This provides valuable insights into the performance of different moulds under varying melting temperature and injection pressures. At various melting temperatures, the BeCu mould consistently yields lower part weights compared to the NAK80 mould. Other than that, the BeCu mould consistently produces lowest part weights, indicating its ability to handle varying injection pressures with precision. In the context of injection moulding studies, the best mould for achieving optimal part weight is determined by the lowest recorded weight of the mould part. The geometry and thickness of the part also play a significant role. However, based on the results, BeCu is preferred for its strength and durability. BeCu is less dense than steel, which means parts made from BeCu can be lighter. This is due to the fundamental property of density, which determines the mass per unit volume of a material.

Typically, a lower shrinkage level is preferred in injection moulding. This is because lower shrinkage helps in achieving more accurate and consistent part dimensions, which is critical for meeting tight tolerances and maintaining the desired part geometry. Manufacturers often aim to control and minimise shrinkage to produce high-quality parts that meet design specifications. Based on the data, NAK80 generally exhibited lower shrinkage levels compared to BeCu, indicating that it may be considered better in terms of shrinkage for the given parameters. It is because, minimise of shrinkage contributes to greater consistency in part dimensions across multiple production runs. High shrinkage can result in warping or distortion of the final product, leading to dimensional inaccuracies and potential functional issues. Therefore, minimizing shrinkage is important to ensure that the final products meet the required dimensional specifications. Controlling shrinkage can have a positive impact on the mechanical properties of the moulded parts. Parts with less shrinkage are less likely to warp or deform, resulting in better overall mechanical performance.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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