SJST
sjst.scst.edu.ly

**S**urman **J**ournal for **S**cience and **T**echnology
ISSN: Online (2790-5721) - Print (2790-5713)

مجلة صرمان للعلوم والتقنية
Vol**6**, No.**1**, Jan. 2024
Pages: 001 ~ 015

# DESIGN AND SIMULATION OF POLYMER NEEDLES TO PRODUCE BY INJECTION MOLDING MACHINE

[1]Samir S. Abubaker , [2]Fathi Etaher Elbakoush , [3]Nizar Ramadan, [4]Salem A. Sultan, [5]Mohamed. R. Budar

[1,4,5] Department of Mechanical Engineering, Janzour College of Engineering Technology, Janzour , Libay.

[2,3]Department of Mechanical Engineering, Surman College for Science and Technology, Surman, Libya.

sanysalum@yahoo.com

الملخص

تتناول هذه الورقة طريقة إنتاج الإبر الصغيرة باستخدام المواد البلاستيكية ( البوليمر) بدلاً من المواد الحديدية شائعة الاستخدام بسبب خواصها الميكانيكية الجيدة، وخصوصاً الفولاذ المقاوم للصدأ ، لأنه يتمتع بمقاومة عالية للتآكل كما أنه شائع الاستخدام في التطبيقات الطبية، لكن هذه المواد باهظة الثمن ويصعب تنظيفها للاستخدام المتعدد. الهدف من هذه الورقة هو تصميم مجموعة ابر صغيرة الحجم ورخيصة من البوليمريمكن استخدامها مرة واحدة في مجال الصحة والجمال. تعد عملية التشكيل بالحقن التقنية الرئيسية لتصنيع الأجزاء البوليمرية ذات ألابعاد الصغيرة القريبة من المليميتر. في هذا البحث بعد ان تم التأكيد على نموذج الإبرة المختار,و التأكد من نتائج تحليل المعاناة والقوة، ووضعها في مصفوفة ,تمت محاكاة مجموعة الإبر بخمس مواد بوليمر مختلفة (PS، PP، PLA، PC، ABS) عن طريق برنامج *Mold Flow Analysis* تحليل تدفق المصهور في القالب, لصنع القالب المناسب لمجموعة الابر,لآلة التشكيل بالحقن الدقيق.

Abstract

This paper study the production of small Needles by using Polymer materials. Ferro materials are commonly used, due to good mechanical properties, stainless steel is preferred for medical use, because it has high corrosion resistance and also a commonly used for medical application, but it is expensive and hard to clean for multiple use. The objective of this paper is to make simple, cheap, and one time use arrays of small scale solid polymer needles for health and beauty use. Micro injection molding process is the key technology for manufacturing polymeric parts with structure dimensions in micron and sub-micron range. In this paper A selected needle model was simulated via the results of suffered and strength analysis, and the array of needles was simulated with five different polymer materials (PS,PP,PLA,PC,ABS) by Mold Flow Analysis to make the right product with the suitable injection mold for the Micro Injection Molding machine .

**Keywords:** *Mechanical behavior, Polymer microneedle. Mold Flow Analysis, Micro Injection Molding*

## I. INTRODUCTION

In the last three decades, Technological development has contributed to the improvement of various industries, as this development has saved a lot of time and effort while increasing productivity, and the following are the effects of technology development on industry Additive manufacturing which includes any work involved in 3D printing , advanced materials, Technological development has contributed to the development of technologies that develop industrial processes, which in turn contribute to reducing costs and accelerating production.Therefore the development of Micro-electro-mechanical systems and materials science, a more efficient and safer traditional transdermal drug delivery like Microneedle (MN) emerges [1-3]. MN technology has received much attention in the medical community and the beauty industry. MNs will play a decisive role in promoting micro-sample analysis, trace injection, blood fluid analysis, sampling and vaccines against influenza. MNs have been demonstrated to be pain-free and potentially low-cost and easy-to use [4]. Generally, MNs should not break when bent slightly, and not rupture when pulled out after piercing the skin. In the world of plastic manufacturing, there is a growing demand for exact and intricate plastic components. To meet this demand, many product designers and engineers are turning towards a revolutionary manufacturing technique – Micro Injection Molding (MIM) [5]. Traditional injection molding methods may not be suitable for producing small polymer components that measure only a few millimeters across. Unlike conventional molding methods, micro molding creates small parts with delicate features, thin walls, micro holes, and tight tolerances. It enables manufacturers to meet the demands for small, exact components while ensuring scalability for high-volume production. MIM is a highly specialized form of injection molding that focuses on creating extremely small components. The process involves the creation of a cavity that matches the desired shape of the part. Micro-structured steel or aluminum molds are precisely machined using CNC and EDM techniques with micron or even submicron scale tolerances [6]. This approach allows for producing components that weigh less than a gram and have dimensions in the range of a few millimeters, thus, there is no room for error in the smallest of details, when it comes to tooling. Nevertheless, with the large number of factors that have the potential to influence production, it’s easier to avoid mistakes if all manpower is fully aware of every process and its detail. Prior to injection molding, Mold Flow Analysis (MFA) is essential. It involves using specialized software to simulate the design of the component. This should happen [7], because the liquid material flows inside the mold significantly impacts how the finished product behaves, this process can help save a lot of time and effort in the long run. MFA is a critical component of the manufacturing process. MFA is used to make the most of available resources and create the best products. This improves the entire injection molding process [8-11].

In this work, based on a selected mechanical model of MN [12], therefore the strength of a polymer MN was verified, and the structures of MNs were obtained, five kinds of common polymers will be analyzed, which are, Polypropylene (PP), Polystyrene (PS), Polycarbonates (PC), Acrylonitrile butadiene styrene (ABS), and Polylactide (PLA), to satisfy the strength requirements.

**The model of Needle**

In this paper, based on the model of Needle were selected by our previous work [8]. Injection Molding process will be used for producing polymer MN's model. MN shape should be regular and simple. MNs are generally conical, pyramid, cylindrical, and other structures as shown in Figure 1. [9-13], applied ANSYS to analysis the different shapes of MN, the results showed that, truncated pyramid by mechanical stress is generally higher than that of a cone shape MN, but manufacturing process of the trunked conical shape is simpler. That is, the performance of MNs with conical platform shape is better than that of tri-pyramid platform and four-shaped MNs. The structure of the needle body in this paper is a conical flat needle body.

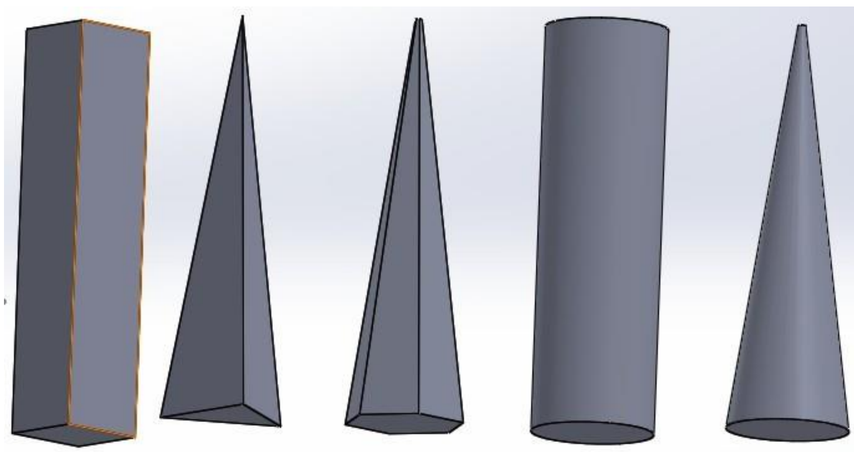


Figure 1. Different shape structure of MNs

The height of 550 µm, base diameter of 250 µm and tip diameter of 50 µm was selected. The model is simply conical frustum model for solid MN, the mechanical model of MN is shown in Figure 2 below.

D1 is the bottom diameter, D2 is tip diameter of needle, and H is the height of MN.

Surman Journal for Science and Technology
ISSN: Online (2790-5721) - Print (2790-5713)
مجلة صرمان للعلوم والتقنية
Vol6, No.1, Jan. 2024
Pages: 001 ~ 015

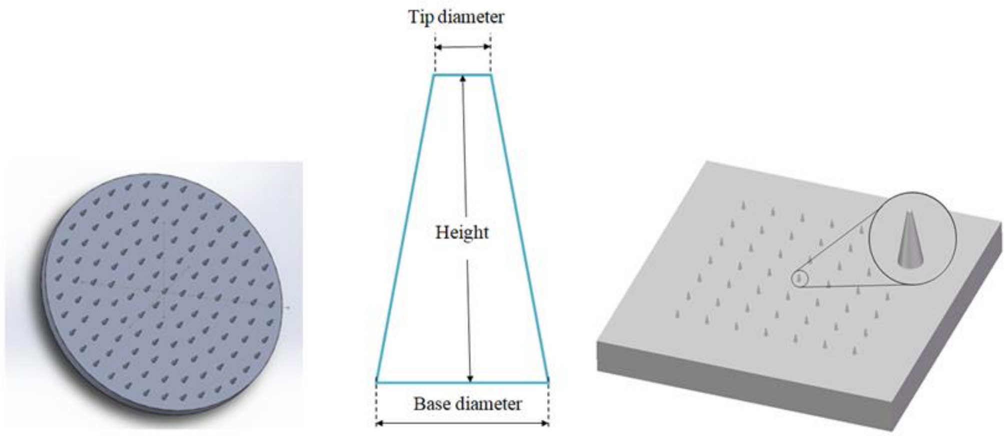



Figure. 2. Mechanical model of MN

To estimate the bending force and maximum strength for the selected model, the below Equation, was applied, thus determine the material can be used for this model [10-14].

$$\sigma_{\max} = \sigma_2 \left[ \frac{16H}{27(D_1 - D_2)} \sin 2\alpha + 1 \right] \le [\sigma]$$

Materials with yield strength above this value for $F_b$ (bending force) 3.1 *mN, and* $\sigma$ ( maximum stress) 8.3*MPa* can be used safely [10]. Table 1.shows the Mechanical properties of some polymers could be used in this experiment

Table 1. Mechanical properties of polymer

| Material | Young's modulus(GPa) | Poisson' ratio | Tensile strength( MPa) | Density (g/cm$^3$) |
|---|---|---|---|---|
| PP | 1.5-2.0 | 0.45 | 40-60 | 0.85- 0.95 |
| PS | 3.0-3.6 | 0.35 | 30-100 | 0.96-1.04 |
| PC | 2.0-2.4 | 0.370.39 | 55-75 | 1.2-1.22 |
| ABS | 2-3 | 0.394 | 41-45 | 1.04-1.08 |
| PLA | 3-4 | 0.36 | 40-60 | 1.21-1.43 |

Therefore, materials with strength above this value can endures the forces needed to pierce the skin with the pressure of 3.183 Mpa [11-15], without buckling and breaking the needle. Figure 3, illustrate the effect of height, base, and tip diameter on the maximum stress (pressure).

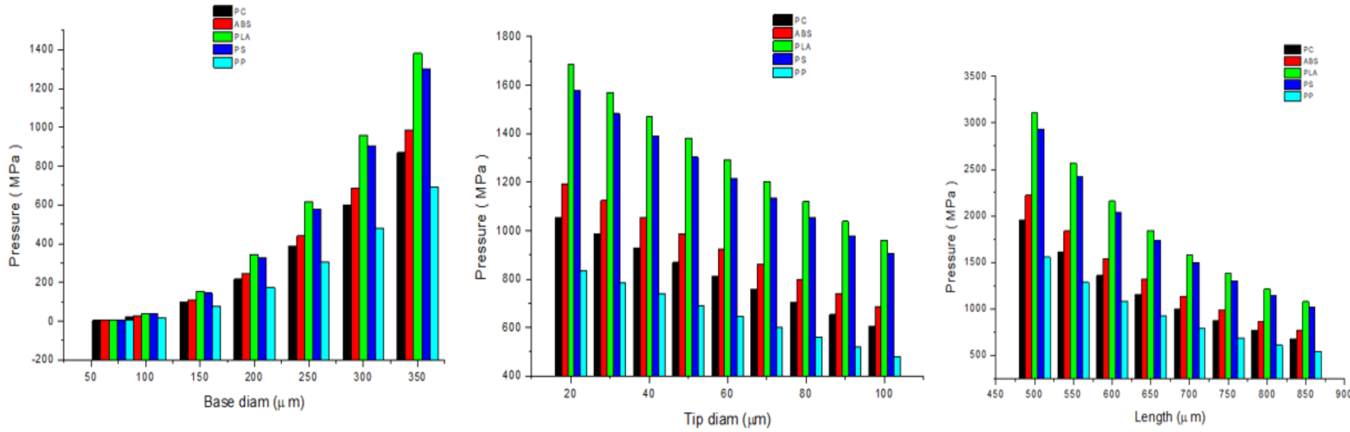



Figure. 3 The effect of MN's tip diameter ,base diameter & length on pressure

## The Array of Needels

Needels number and interspacing ‘MNs density’ is an important parameter in designing any MNs array. Increasing the number of MN increases skin permeability and improve the efficiency of transdermal drug delivery [13-16] . Although it has been shown that increasing the density of a MN array can led to an increase in the rate of transdermal drug delivery From designer to another MNs numbers may vary from 10-to 400 [16]. The increase of efficiency of penetration illustrated that, a high needle density is needed, [17-20], [14], observed lower drug permeation results for very high MNs array densities.

In this paper, based on the previous experience mentioned, the manufactured mold parts with Injection molding process should have the shape and size of the MNs array as shown in Figure 4, which has the specifications shown in Table 2.

Table 2 Specifications of MNs array

| Type of array | Interspacing | The number of MNs |
|---|---|---|
| Circle | 1.5mm | 121 |
| Square | 1.5 mm | 121 |

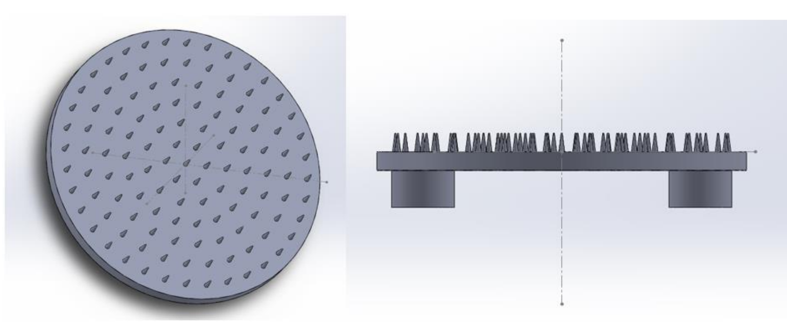


Figure. 4 Circular MNs array

## II. ANALYSIS AND SIMULATION BY AUTODESK MOLD FLOW

Moldflow simulation can be used to simulate the effects of different design approaches and the effects that they will have upon both the production process and product performance. Often, the expense of developing a product prototype can be avoided by running state of the art simulation and analysis on our product, before a single mold is even made. This can save valuable time and money and helps to ensure that the final product will meet the technological limitations and environmental stresses of production and final product use.

Many aspects of injection molding can be analyzed, from gate and runner sizes to identification of potential weld line locations and air traps, wall thickness enhancements to achieve uniform filling, and injection pressure requirements. As well, mold flow shows the filling, packing and cooling during a molding cycle, and how molding process parameters influence molded-in stress, which, can lead to shrinkage and warpage.

All this information is illustrated to the user before a mold is built. Generally, mold flow provides these benefits, analyze the performance of product design in real world conditions, allows users to create a higher quality product, by adjusting the design to correct unexpected product design limitations, and reduce or avoid the need and expenses related to the development of product prototypes.

*Runner number and its impact on molding process and quality of product*

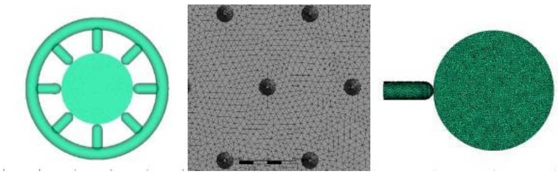
The mold plays a vital role, not only affects the quality of final products, and have a certain impact on the entire molding cycle. This paper utilize MFA software to analyze the effect of the number and position of runners on the molding process and the quality of the product. For the number of runners, the three models shown in Table 4 are set.

Table 3 the runner number and type of analysis

| Type | Number of runners |
|---|---|
| A | Eight runners |
| B | Three runners |
| C | Single runners |

The Moldflow analysis procedure starts with following steps:

*Modeling*, and *Meshing*, the overall runner size of the three groups of products are Ø35×55mm, the model structure is shown below in Figure 5. Models were established with Solid works, namely: eight runners, three, and single MN model.



(a) Eight runner (b) Single runner

Figure. 5 The results of meshing

*Setting parameters,* setting up the injection inlet; Material parameters shown in Table 4, the machine shown in Figure 6, belongs KASAH Company in Krimia region, it's specification as shown in Table 5. The analysis selected is the filling, holding pressure etc.

Table 4. Parameters of selected material

| **Material** | **Melt temperature** | **Density** | **Pre-drying** | **Mold temperature** | **shrinkage** |
|---|---|---|---|---|---|
| PS | 150-180 ˚C | 0.98 g/cm$^3$ | 3.5 hours | 60-80 ˚C | 0.5-0.6% |
| PP | 100-165 ˚C | 0.91 g/cm$^3$ | 3 hours | 60-90 ˚C | 0.1-0.4% |
| PLA | 170-240 ˚C | 1.3 g/cm$^3$ | 5 hours | 20-100 ˚C | 0.3-0.4% |
| PC | 280-31 ˚C | 1.2 g/cm$^3$ | 3-5 hours | 80-110 ˚C | 0.5-0.7% |

Table 5. Specification of the injection-molding machine" Battenfeld (Ecopower) 55"

| **Item** | **Unit** | **Value** |
|---|---|---|
| Mold clamping force | kN | 550 |
| Diameter of Screw Stem | mm | 22 |
| Screw stroke | mm | 110 |
| Screw diameter ratio | (L/D) | 20 |
| Max. theoretical injection volume | cm$^3$ | 41.8 |
| Maximum injection pressure | bar | 2871 |
| Screw Rotation Speed | min$^{-1}$ | 500 |
| Maximum screw torque | Nm | 150 |
| Injection rate | cm$^3$/s | 152 |
| Ejection force | kN | 25 |

The mould was designed for the use of Micro injection machine. The clamping device of the injection-molding machine is a high dynamic servo motor driven by the double elbow structure to achieve high-speed and high precision injection requirements.

Figure. 6 Injection molding machine type (Battenfeld Ecopower 55/130H B6)

## III. RESULTS OF SIMULATION

*Deformation*

The deformation can be divided into deformation caused by uneven cooling, orientation factors, and deformation caused by uneven shrinkage. The sum caused by these factors is called the sum of all deformation, and the results are shown in Figure 7.

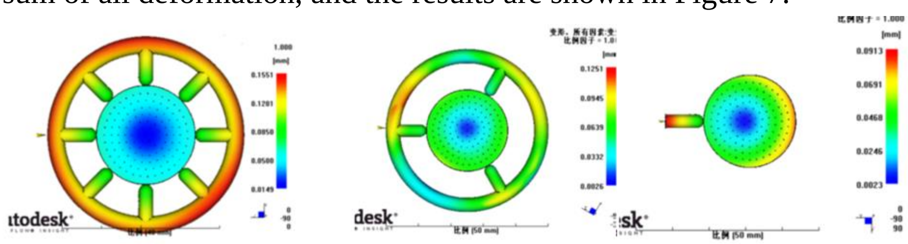


Figure. 7 Deformation caused by all factors Deformation

The simulation results show that, as the number of runners decreases, the deformation of the product gradually increases. Among them, the deformation value of the eight-channel microneedle product with the smallest deformation value and the single flow microneedle product with the largest deformation value is 0.012 mm. Among the three major factors that cause deformation of the product, shrinkage occupies the dominant position. Therefore, during the molding process, the mold temperature should be appropriately increased to reduce the deformation.

Surman Journal for Science and Technology
ISSN: Online (2790-5721) - Print (2790-5713)
مجلة صرمان للعلوم والتقنية
Vol6, No.1, Jan. 2024
Pages: 001 ~ 015

*Filling time*

The shorter the filling time, the shorter the time required for the melt to fill the cavity and the higher the production efficiency [18]. The injection molding time obtained by Moldflow simulation, can clearly show the expansion of the melt flow front, the image reduction polymer in the mold shows the expansion of the melt flow front, and the image reduction polymer in the mold, the flow and filling process in the cavity, the simulation results of the some of the sets of models are shown in Figure 8.

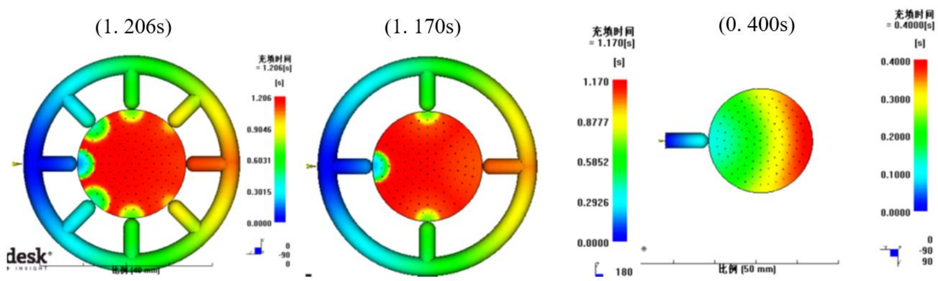



Figure. 8 Fill time

The simulation of filling time results shows that, except for a single flow channel model, the filling time of the five groups with annular flow channels is very small, the filling time is basically between 1.1 and 1.2s, and the filling time of a single flow channel model is 0.4s. Compared with the first five models, the filling time is reduced by about 60%. Under large-scale production conditions, a single flow channel product can greatly shorten the production cycle and increase production.

It can be seen, from the simulation results of the filling time, that the injection molded product with the single runner will have a slow flow phenomenon at the inlet of the branch passage closest to the main flow channel, and it is almost in a stagnant state, because the melt enters the center of the cavity from the branching passage. The plastic parts of a single runner are completely free of this condition, so the performance of a single flow path product is better.

*Time to reach the ejector stage*

The time to reach the desired temperature and ejection stage basically determines the production cycle, and the time simulation results of the three groups of models reaching the ejection step are shown in Figure 9.

Surman Journal for Science and Technology
ISSN: Online (2790-5721) - Print (2790-5713)
sjst.scst.edu.ly
مجلة صرمان للعلوم والتقنية
Vol6, No.1, Jan. 2024
Pages: 001 ~ 015

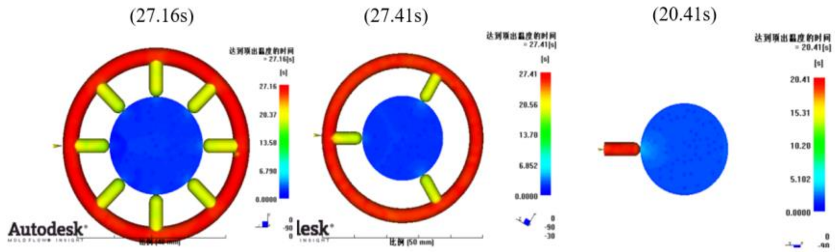



Figure. 9 Cycle time

The simulation results of the injector temperature show that the overall size of the injection molded part is thin, and the annular flow path belongs to the thickest part of the whole product, and the proportion of the entire part is large, and there is no annular flow. Compared to a single runner product, a multi-channel product with an annular flow path takes longer, whether it is the filling phase, the pressure holding phase or the cooling phase, and the time required for the product with the annular flow path reaches the injection temperature of about 27 s. The single flow channel is only about 20s, which shortens the molding cycle and improves production efficiency.

*Air cavitation*

The air cavitation affects the performance of the product. There are many reasons for the formation of air pockets, such as mold defects, unreasonable injection molding process, injection-molding materials do not meet molding requirements, and product structure design is unreasonable. The fewer the number of cavitation in the product, the better is the product. The cavitation distribution of of models was analyzed. The analysis results are shown in Figure10.

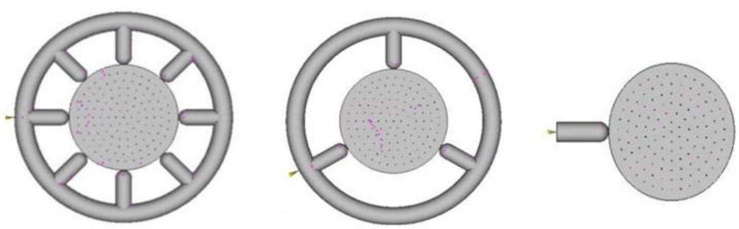


Figure.10 Air Cavitation

The results of cavitation simulation show that in addition to these evenly distributed cavitation, the gathered air pockets not only affect the aesthetics of the products, but also affect the strength of the products. Therefore, the performance of the single flow channel product is better.

*Volume Shrinkage*

The volume shrinkage affects the actual size of the article, making the article smaller than the cavity size. Severe volume shrinkage can cause deformation or even cracking of the product. Therefore, the greater the volume shrinkage, the greater the negative affect the product. The simulation results of model volume shrinkage are shown in Figure 11 below.

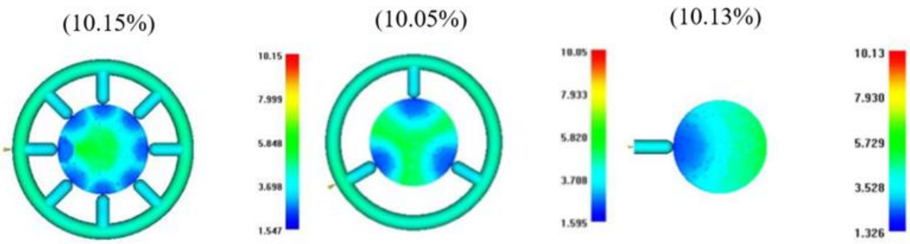



Figure. 11 Volume shrinkage

The volume shrinkage simulation results show that the volume shrinkage is about 10%, and the difference is no more than 0.13%. It can be seen that the material factor affecting the volume shrinkage of microneedle products is the material factor. The effect of shrinkage is negligible.

*The weld lines*

The cavity has multiple shunts and the structure of the product is complex, which will cause weld marks of the injection-molded products, and the weld marks have the same appearance as the air pockets, which not only affects the appearance of the products, but also affects the strength of the products. The simulation and results of models weld lines are shown in Figure 12.

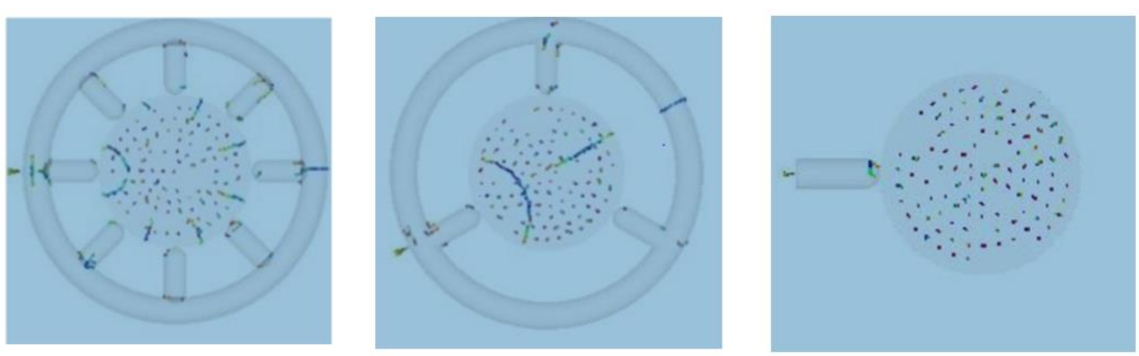


Figure.12 Weld lines

The results of the weld line simulation show that in addition to the evenly distributed weld marks of the tip of the needle, the multi-channel structure with annular flow passage forms

a long weld line due to the existence of multiple runners. From the road to the second runner, the number of welds is decreasing, and there is no obvious weld mark in the single runner except the needle. The existence of multiple shunts directly leads to the appearance of long weld lines, which not only affects the appearance of the product, but also affects the strength of the product. Therefore, the performance of the single-flow product is better.
Influence of MNs array structure on molding process and product quality
Common microneedle arrays are distributed with circular arrays and square arrays. This part will examine the effect of different microneedle array structures on product quality under the same molding process conditions. The two models shown in Table 6, namely the circular array model and the rectangular array model, were set in this study. The circular array model is a model in which the MNs are radially evenly distributed; the rectangular array model is a model in which the MNs are arranged in parallel with each other and at equal intervals. In both models, the specific shape and size of the microneedles are identical.

Table 6. Structure of array and type of analysis

| **Type** | **Array structure** | **Analysis type** |
|---|---|---|
| I | Circular array | Filling - holding pressure - holding & cooling |
| II | Rectangular array | Filling - holding pressure - holding & cooling |

(1) Modeling and dividing the mesh

The circular array and rectangular array microneedle model were established by Solidworks, and analyzed by single flow microneedle model. Dividing the mesh into multiple pieces are needed, therefore it can done then texture individually. Generally, we want to divide the mesh into pieces that can be unfolded into approximate square or rectangle shapes. The meshing results of the two groups of models are shown in Figure 13.

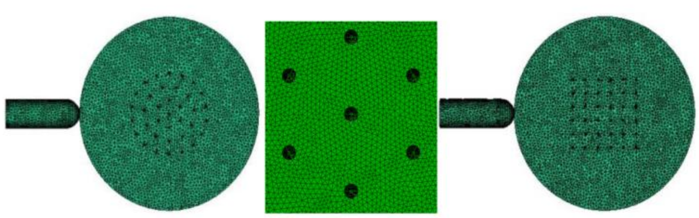


Figure. 13 Meshing of micro -needle model with different array

(2) Setting parameters

Set the injection inlet, the material parameters and machine specifications are consistent with the previous simulation, as shown in the previous tables. Select the analysis type as filling, holding pressure - holding & cooling phase.

(3) Results study

The comparison of some of the more intuitive characterization quantities, like Deformation, Filling time, Air cavitation, Volume Shrinkage, and Weld marks (lines) can be find in the appendix.

Compared with the circular MNs array, the simulation results show that the rectangular MN array has smaller deformation value, relatively shorter filling time, and relatively lower product shrinkage; rectangular MNs array is slightly better than circular MNs array. However, the advantages are not obvious. Therefore, the distribution pattern of the MNs array has little effect on the quality of the product, thus consider all the results mentioned before and the power of the machine, the MNs mold for MNs array will be made the eight runner with circular array like target product in Figure 14 shown below.

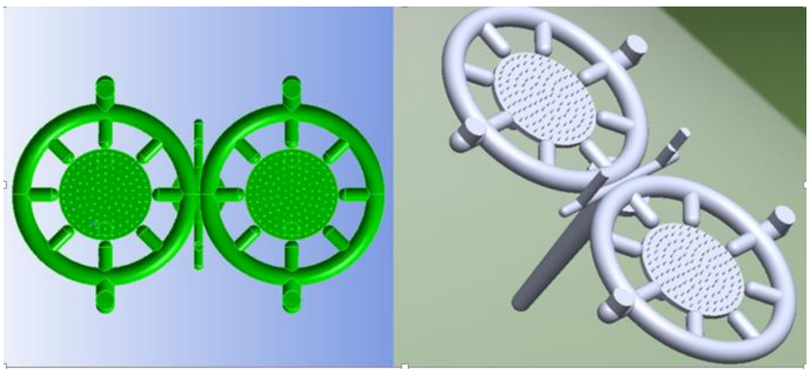


Figure. 14 MNs array as a target product

## IV. CONCLUSIONS

In this paper, based on the selected MN model, the main forces and stresses that a MN suffered was calculated, and analyzed for different polymer materials PS, PC, ABS, and PLA. The results shows that all suggested polymer materials applied for this designed model can be used for MNs array, and satisfy the requirements for safe use of MNs. The production used MIM, starts with the production the mould, thus, MFA used to simulate the effect of the number of melt runners on the forming process and product quality and the effect of the MNs array structure on the molding process and product quality. Compared with the number of runners, a single flow runner without annular flow channels is more conducive to product filling, product deformation and shrinkage. It is smaller; and there are not a large number of concentrated air pockets and obvious weld marks on the product. Therefore, based on the simulations, the single runner MN has better quality and better performance. Moreover can reduce filling, holding pressure, cooling time, and greatly reduce molding cycle.

## V. REFERENCES

[1] Al Mamun, Abdulla, et al. "Design and evaluation of in-plane silicon microneedles fabricated with post-CMOS compatible processes." *Sensors and Actuators A: Physical* 336 (2022): 113407.

[2] Abubaker, S. S., N. R. Ramadan, S. A. Sultan and M. R. Budar (2023). "INVESTIGATION OF THE EFFECT OF TEMPERATURE AND TIME OF CASE HARDENING ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURE OF LOW CARBON STEEL (AISI 1020)." Surman Journal of Science and Technology 5(2): 028-036.

[3] Ramadan, N. and H. ALFARES (2020). "Optimize and Improve of The Welding Nugget in The Resistance Welding Process of Carbon Steel by Means of Surface Response Method." Surman Journal of Science and Technology 2(3): 018-007.

[4] Kim, Y.C., Park, J.H. and Prausnitz, M.R., 2012. Microneedles for drug and vaccine delivery. Advanced drug delivery reviews, 64(14), pp.1547-1568.

[5] Tomiyama, Tetsuo, et al. "Development capabilities for smart products." CIRP Annals 68.2 (2019): 727-750.

[6] Ablyaz, Timur Rizovich, Evgeny Sergeevich Shlykov, and Karim Ravilevich Muratov. "Improving the efficiency of electrical discharge machining of special-purpose products with composite electrode tools." Materials 14.20 (2021): 6105.

[7] Lai, Jiing-Yih, et al. "Design Analysis and Modification of Ribs and Tubes on Thin-Wall Parts for Mold Flow Analysis." (2021).

[8] Ramadan, N. and K. ali Osman (2021). "Isothermal Transformation Temperatures and Its Effect in Hardiness of Pearlite Eutectic Steels R350HT Rails." Surman Journal of Science and Technology 3(1): 028-036.

[9] Ramadan, N. and A. Boghdadi (2020). "Parametric optimization of TIG welding influence on tensile strength of dissimilar metals SS-304 and low carbon steel by using Taguchi approach." Am. J. Eng. Res 9(9): 7-14.

[10] Samir, S. Abubaker, Yajun Zhang, and Liqun Dong. "Design and Simulation of Solid Polymer Micro Needles Array." In 2018 7th International Conference on Energy and Environmental Protection (ICEEP 2018), pp. 1318-1321. Atlantis Press, 2018.

[11] Nagarkar, Rigved, Mahima Singh, Hiep X. Nguyen, and Sriramakamal Jonnalagadda. "A review of recent advances in microneedle technology for transdermal drug delivery." Journal of Drug Delivery Science and Technology 59 (2020): 101923

[12] Abubaker, Samir Sghayer, and Yajun Zhang. "Optimization design and fabrication of polymer micro needle by hot embossing method." International Journal of Precision Engineering and Manufacturing 20 (2019): 631-640.

[13] Park, Jung-Hwan, Mark G. Allen, and Mark R. Prausnitz. "Polymer microneedles for controlled-release drug delivery." Pharmaceutical research 23, no. 5 (2006): 1008-1019.

[14] Stoeber, Boris, and Dorian Liepmann. "Arrays of hollow out-of-plane microneedles for drug delivery." Journal of microelectromechanical systems 14, no. 3 (2005): 472-479.

**S**urman **J**ournal for **S**cience and **T**echnology
ISSN: Online (2790-5721) - Print (2790-5713)
مجلة صرمان للعلوم والتقنية
Vol**6**, No.**1**, Jan. 2024
Pages: 001 ~ 015

[15] Ramadan, N., M. M. Embaia and H. M. Elhamrouni (2023). "LASER BEAM WELDING EFFECT ON THE MICROHARDNESS OF WELDING AREA OF 304 STAINLESS STEEL & LOW CARBON STEEL." Surman Journal of Science and Technology 5(1): 018-030.

[16] Ramadan, N., K. Tur and E. Konca (2017). "Design and Simulation of an Apparatus for the Post-Weld Controlled Accelerated Cooling of R350HT Head Hardened Rail Joints."

[17] Shikida, Mitsuhiro, Yoshihiro Hasegawa, Muhammad Salman Al Farisi, Miyoko Matsushima, and Tsutomu Kawabe. "Advancements in MEMS technology for medical applications: Microneedles and miniaturized sensors." Japanese Journal of Applied Physics 61, no. SA (2021): SA0803.

[18] Yan, Guang, Kevin S. Warner, Jie Zhang, Sanjay Sharma, and Bruce K. Gale. "Evaluation needle length and density of microneedle arrays in the pretreatment of skin for transdermal drug delivery." International journal of Pharmaceutics 391, no. 1-2 (2010): 7-12.

[19] Ramadan, N., K. Tur and E. Konca (2017). "Process design optimization for welding of the head hardened R350 Ht rails and their fatigue: a literature review." International Journal of Engineering Research and Development: 2278-2800.Tarbox, Tamara Nina. "Dissolving and coated microneedles as useful drug delivery platforms." PhD diss., 2022.

[20] Layluk, Vatchara, and Kittiphat Rattanachan. "Poor-Man Injection-Compression Moulding Technique." Journal of Positive School Psychology (2022): 3613-3621.