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A Study on Resin Flow to Make a Replica Using a Silicone Mold

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Abstract

The replica of silicone mold which can produce the test samples and the market-displayable products without making expensive metallic patterns is advantageous because it incurs less cost than the ordinary method that manufactures the products from the metallic patterns. However, the production of the products using silicone mold should require a technician with professional knowledge about the metallic patterns every time.

Thus we tried to judge whether a forming analysis software for iron molding can be applied to silicon molding in this paper. In other words, this paper suggests a method to use a computer simulator from the designing step of the silicone mold, which is the most important part in making replica using simple silicone molds to the step of pouring the cast. The paper shows that if the know-how of a professional worker is provided in advance, an amateur worker can easily produce silicone molds of the best quality, the defective rate of the products will be decreased, and the replica will have a more complete status. By doing so, we suggested a possibility for reducing the delivery time at the production sites and for improving the product quality.

Key Words : Replica, Resin flow, Forming analysis, Silicon mold

1. Introduction

If products are made by injection molding, mold material cost, mold processing cost and injection cost to use injector are required. Besides if a number of injecting products are not larger than the minimum requirement, we can't even order them.

Thus, in case to need some prototypes of molding or to product goods by small quantity batch production, the unit price had been very high or sometimes they had given up to product them. But as RTV silicon was developed for molding and vacuum forming techniques have grown at present, prototype products or goods by small quantity batch production are usually manufactured by vacuum forming.

But, vacuum forming has the critical disadvantage. As there are difference between injection molding and vacuum forming about material, physical properties of the mold and molding material, only an expert of the vacuum forming can design silicon molds, manufacture them and do forming process that are suitable for vacuum forming.

It means it takes very long time to manufacture products on small quantity batch products because the expert should do all the work from design to molding to be suit for every kinds of shape's properties. So we may give up to keep due date.

Therefore this research suggests unskilled laborers a method to deeply participate in vacuum forming from the beginning as same as vacuum forming experts. By using a computer program, we can replace the know-how of experts.

We performed the modeling product's shape in three dimensions and the injection analysis by a computer program. Then a silicon mold was designed by reflecting the result of forming analysis. Comparing reproduction of the silicon mold and the result of forming analysis, we could prove that unskilled labors were available at work no less than experts when they were helped by the computer program. By doing so, we suggested a possibility to reduce the delivery time at the production sites and to improve the product quality.

This paper is organized as follows: Section 2 shows the elements of forming analysis. In section 3 shows a process to choosing a replica and modeling. And also shows forming analysis and analyzing a result of miniature model. Section 4 is for experiments and results and Section 5 has conclusion.

2. The elements of Forming Analysis

2.1 Filling Analysis

If we analysis filling process, we can use the results diversely. For example, we can predict forming defectives, design a product and a mold that has the best quality, and select proper process conditions according to a material [1-5].

After selecting resin and inputting process conditions, we used the finite element method and the finite difference method to get pressure distribution and calculate three dimensional distribution of temperature on filling process. And we analyzed filling pattern of resin by using the control volume method.

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The purpose of filling analysis is as follows:

① To determine the numbers and location of gates.
② To determine the location and intensity of weld lines.
③ To determine location of air traps.
④ To determine pressure of a mold clamping device on molding process after evaluating the clamping force and injection amount.
⑤ To verify the thickness of products to keep the flowing balance in cavities
⑥ To investigate the necessity of multistage injection
⑦ To adjust balance of runner systems
⑧ To minimize the size of runners
⑨ To inspect whether molding is performed within allowable stress and temperature
⑩ To set the best molding conditions

Filling pattern means time for resin to reach to the location of each parts of a product. At this moment, to keep consistent flow may be the most important. To observe the progress of fluids can predict location of weld lines and air traps.

2.2 Pressure Analysis

We can identify pressure depression from pressure distribution according to time that resin fills at some parts of a mold. The pressure difference of each other parts causes flow of resin on filling process.

Melted resin always flows from the higher to the lower of pressure. Therefore entrance of resin has the highest pressure and the melt front advancement has the lowest one.

Magnitude of pressure or pressure grade is influenced by fluid resistance of melted resin. Resin that has high viscosity needs higher pressure to fill the mold. And high pressure is needed to fill thin parts of the mold, runner that has smaller diameter and parts of which flow length is longer.

We need to keep even pressure grade to get satisfied quality of a molded product. If there are fluid congestion, over-packing that causes flash, under-packing that causes over shrinkage, uneven pressure grade can be observed.

So it is good to avoid the big pressure change on filling process. As pressure change on filling process influences amount of volumetric shrinkage of each part, the pressure change amount of inner part of the mold should be minimized.

2.3 Weld Line

A weld line happens when two more fluids meet with each other during filling process. Sometimes after the two fluids merge, it flows continuously. In that case, we call it a meld line.

The weld lines are the weakest parts and have possibility to be broken from some stress. They cause to happen to appearance defectives on high glossy resin. But location of the weld lines can be controlled considerably by changing locations of gates, product thickness, size of gates and runners.

We can predict the property and strength of weld lines by observing their temperature before two more melt front advancements meet. It is known if temperature difference between them is less than 10 degrees, the quality of weld lines are good [6].

2.4 Forming analysis of Replicas

We performed the mold forming analysis by using the C-MOLD that is a commercial software. Its governing equation is consisted, based on the linear point-elasticity theory, basic continuous equation, the equation of motion and the equation of energy.

Because this research was performed on assumption that the density of the high molecular material doesn't change as time passed, the material could be regarded as Newtonian fluid. Thus it can be analyzed by the following equation (1)

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

But as the melted high molecular resin is continuously given restriction pressure on injection compression, we were able to regard that its density changed as time passed. Thus we analyzed it by the equation (2).

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \qquad (2)$$

In this research, we scanned and modeled an object in three dimensions and analyzed it by changing types of the gates. Fig 1 is a three-dimensional model for molding.

We used a C_MOLD software that was developed by CIMP (Connell Injection Molding Program). It is a total analysis solution of three dimensional simulation from design to production for injection molding [3,4].

Also it ensures various data bases. It supports analysis of recharging and post recharging, cooling process of thermoplastic resin with C-Flow, C-Pack, C-Cool and of thermosetting resin and rubber with C-Gas flow. Structure analysis by residual stress and other factors is supported with C-Pack and C-Warp.

The basic analysis process is as shown in Fig 2. If the all constraints - process, quality of the product, requirements of productivity etc - are satisfied, the analysis loop will be finished [7].

In this paper, the purpose to analyze injection molding is to design the mold that minimize the product defectiveness as sink marks etc by having minimum air traps and weld lines through gate control process of a replica feature. At the same time we make distribution of uniform pressure that minimizes unstable stability of production which was caused by shrinking of molding material and the distribution of temperature inside the mold is uniform while it is cooling. Therefore we can get

maximum quality.

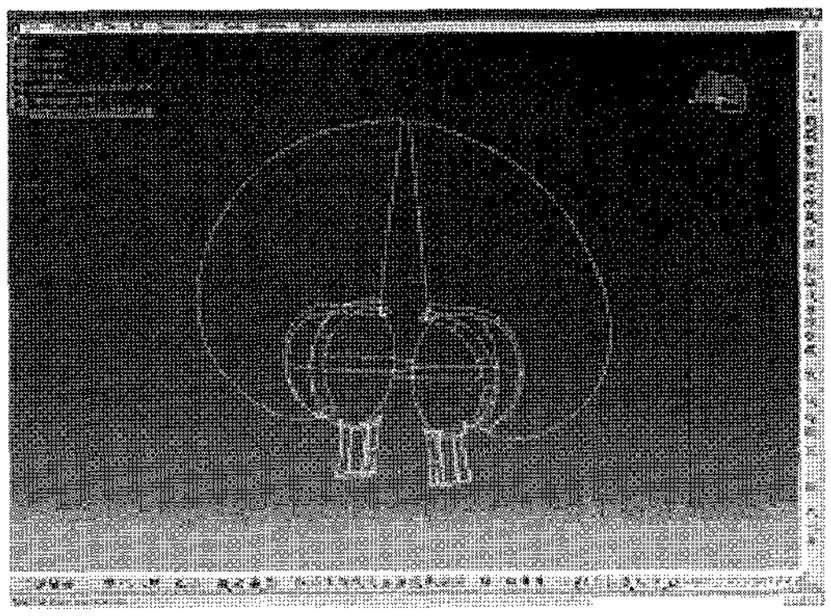

Fig. 1. A three-dimensional geometrical model

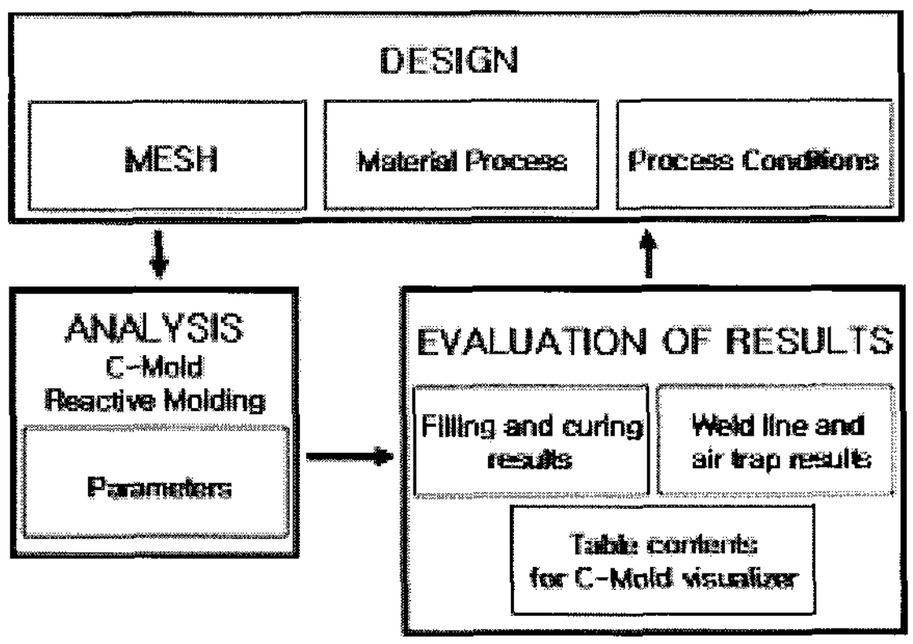

Fig. 2. C-MOLD reactive molding design cycle

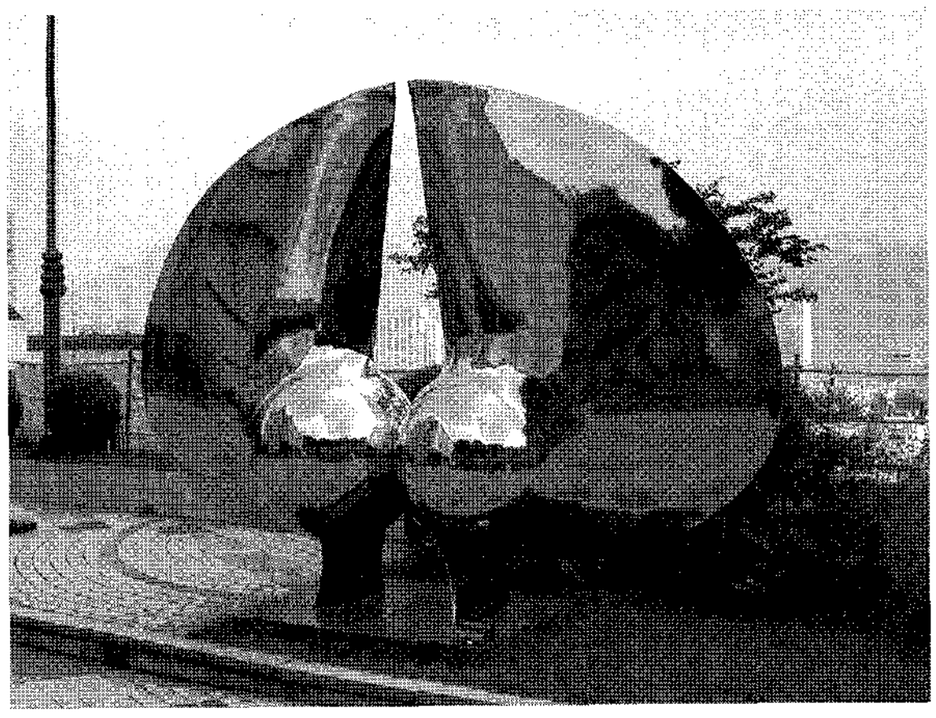

Fig. 3. A Moonshin's work, Concord

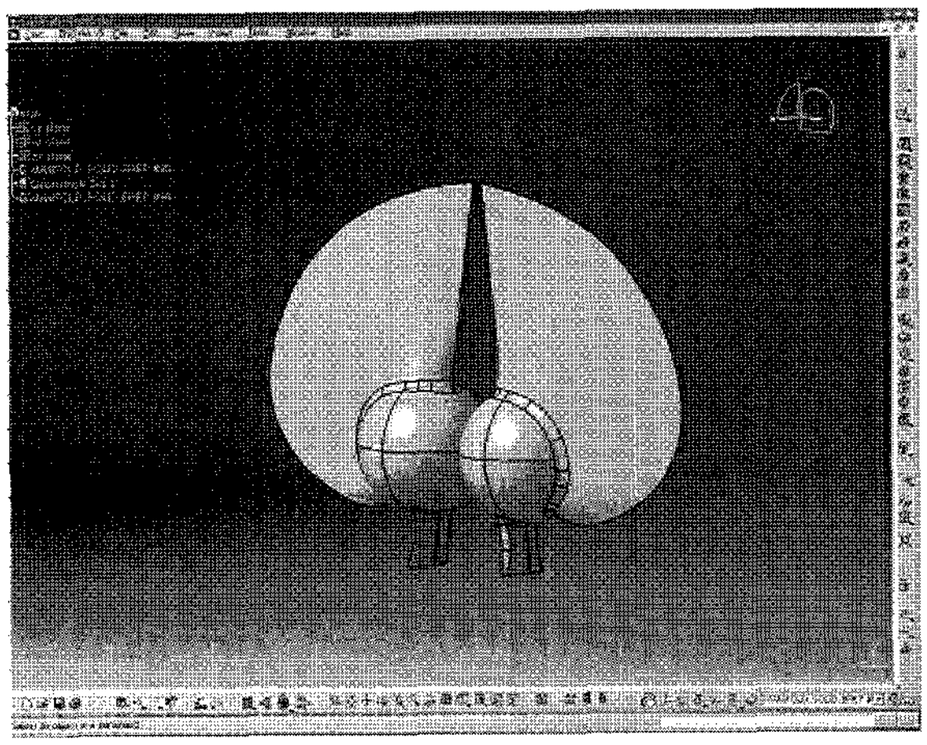

Fig. 4. Modeled Concord by CATIA V5

3. An Target Object Selection for Replication and Modeling

3.1 An Target Object Selection for Replication

3.1.1 An Target Object Selection for Replication and to Design Feature

We selected a sculpture, Concord, which was sculptured at 1988 by Sin Moon as shown in Fig. 3. He is the world famous sculptor who was born in Masan Gyeongnam Korea.

This work locates in the Moonshin gallery of Masan is made of stainless steel. It is very tall and totally curvilinear object. So it is not easy to make a three dimensional model.

After scanning the object at several angles by using an untouched potable three-dimensional digitizer, Vivid910 by Minolta, we removed the noise of the scanned data and made surface model through arranging them by using RapidForm2006 which is made by the INUS cooperation. And then the surface modeled object [8] was converted to a solid modeled one by using CATIA V5 as shown in Fig. 4 [9].

3.1.2 Making a Miniature of the Target Object

To make a replica, we had to make a master model of which size is 1/10 than the original one. To make a miniature, we used a rapid prototyping system, Rapid Meister 6000II by CMET that uses UV laser. Because its layer thickness is 0.03mm, it is easy to sand surfaces of the output after ray prototyping.

And after sanding surfaces of the product and spray painting it with surface primer repeatedly, we accomplished the mater model as shown in Fig. 5 [10].

3.2 Forming Analysis of the Miniature

3.2.1 Establishing Alternatives

After comparing and analyzing melt front advancements, weld lines and air traps of the mater model, its safety was verified by the structure analysis. And we tried to minimize the product defectiveness - weld lines, air traps and sink marks etc - through gate control process. The next step is to consider dimension stability by shrinking, uniform cooling and stabilizing molecular orientation. And then forming analysis process is performed to design the most suitable product and mold.

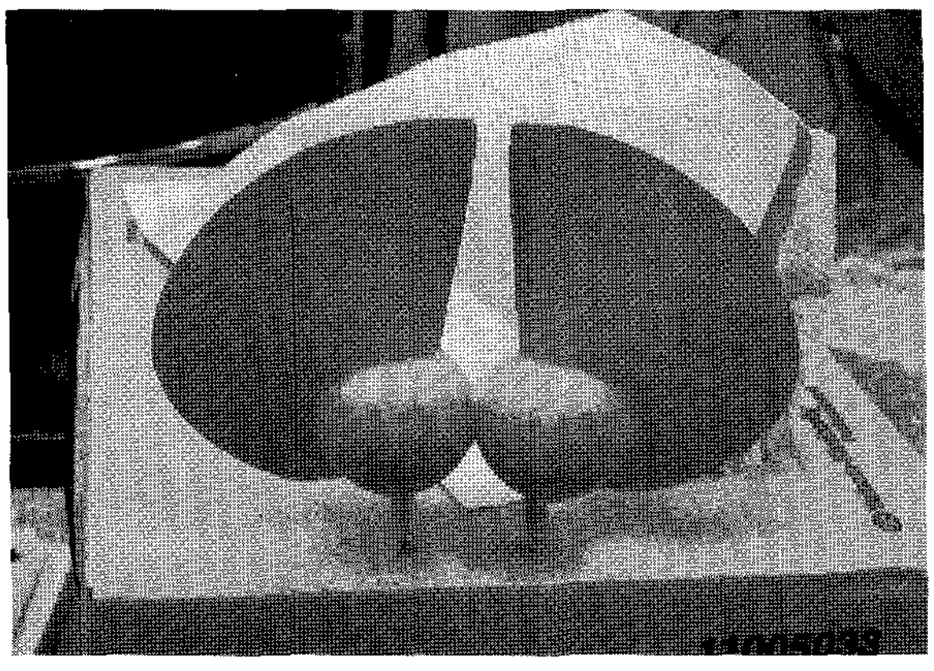

Fig. 5. Master model

To analysis the forming process, we should consider locations and number of gates roughly at first. We can get the basic idea from simple duplication by gravity. In that alternative, gates are located at the highest position, that is, the opposite direction of the gravity. The reason is that air is pushed up the opposite direction of the gravity because density of molding material is higher than air.

This principle is equally applied on forming process by using a special purpose machine. This is because molding material that are poured inside the mold in the machine is gathered at lower position because of gravity. In some cases it is poured from the gate to the runner, but in this research, we assumed an inexperienced man worked and he followed guides of the analysis software about the all of gates.

The C-MOLD that we adopted as the analysis software suggested three alternatives of gates as follows:

Alternative 1: a gate at center position of one part of symmetric replica

Alternative 2: a gate at lower position of the replica

Alternative 3: two gates at lower position of the replica

3.2.2 Forming Analysis for the Replica

Forming analysis for the miniature was performed about air traps, weld lines, pressure, filling time according to the gate locations. The forming simulation is performed according to the equation 2 in the C-MOLD. We totally presented the results as shown in figures and a table. Fig 6, 7 and 8 show the result of the alternative 1, 2 and 3 respectively.

A small yellow circle at the center of the replica image is the gate and smaller sky blue circles and red line segments at the outer area of the replica are air traps and weld lines respectively in Fig 6. Dark gray color nearby the gate location is originally blue color and represents that pressure is lower. Another dark gray area at right top of the replica is originally red color and means higher pressure.

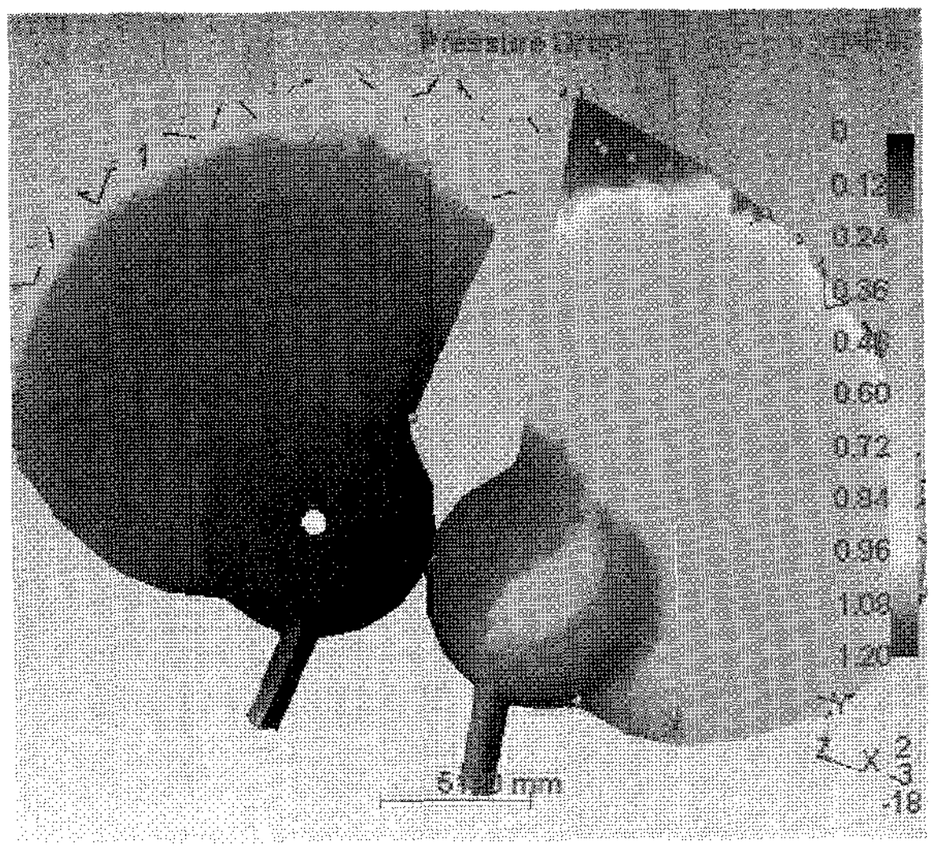

Fig. 6. Collective Result on alternative 1

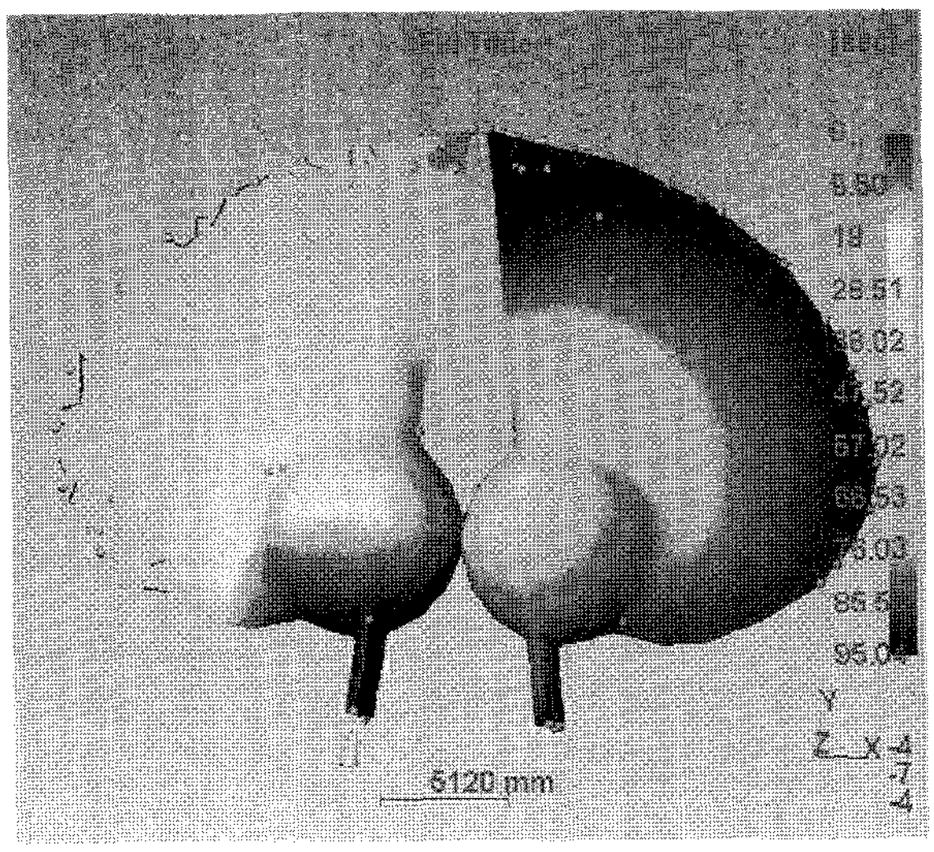

Fig. 7. Collective Result on alternative 2

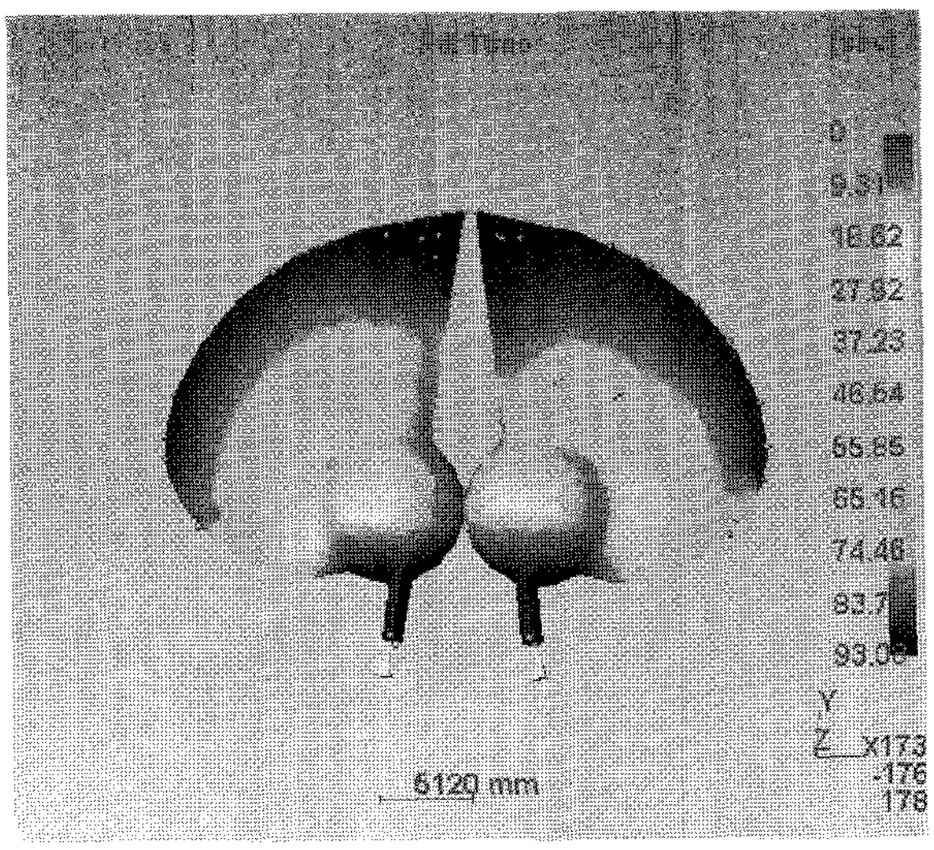

Fig. 8. Collective Result on alternative 3

A corn or corns at bottom of the replica represent the gates in Fig 7, 8. Smaller circles and line segments at the outer area of the replica are air traps and weld lines respectively, too. Dark gray color nearby the gate location is originally red color and represents that filling is shorter. Another dark gray color at outer area of the replica is originally blue color and means longer filling time.

Table 1. Collective Results

alternatives according to gate locations	alternative 1	alternative 2	alternative 3
# of air traps	34	38	36
pressure discrepancy in the mold	1.20Mpa	1.56Mpa	1.22Mpa
pressure distribution in the mold	uneven	uneven	even
filling time	93.77sec	95.04sec	93.00sec
distribution of molding material on time	uneven	uneven	even

Table 2 is shown the collective results. The difference of numbers of air traps or of pressure in the mold was not high according to the gate locations, and of filling time in mold was less than 2 seconds.

But that pressure distribution is not even in the mold means that density of molding material is not same. Because the amount of shrinking is not same when molding material shrinks after hardening, surface illumination is not similar. It means the product is a defective.

Moreover if the distribution of molding material on time is not even, it causes difference of bonding strength after hardening. The product becomes easy to be broken for the stress from outside [11].

Therefore if we select the alternative being pressure in the mold and the distribution of mold material on time is almost uniform, quality of the silicon mold and the product would be better. So, we adopted the alternative 3 that has two gates at lower part of the replica.

4. Experimental Result

Though the C-Mold is made on the assumption that molding material is iron, our case was that molding material was silicon. So, we should make a real replica and compare it with the master model.

The master model was buried in clay and poured RTV silicon on the clay and hardened it during 24 hours at first. And two gates were made at the bottom of the master model as shown in Fig 9.

After making the two gates, we painted release agents and assembled the molds and injected the molding material. A prototype of replica as shown Fig 10 had almost no shrinking and no air bubble with naked eye inspection.

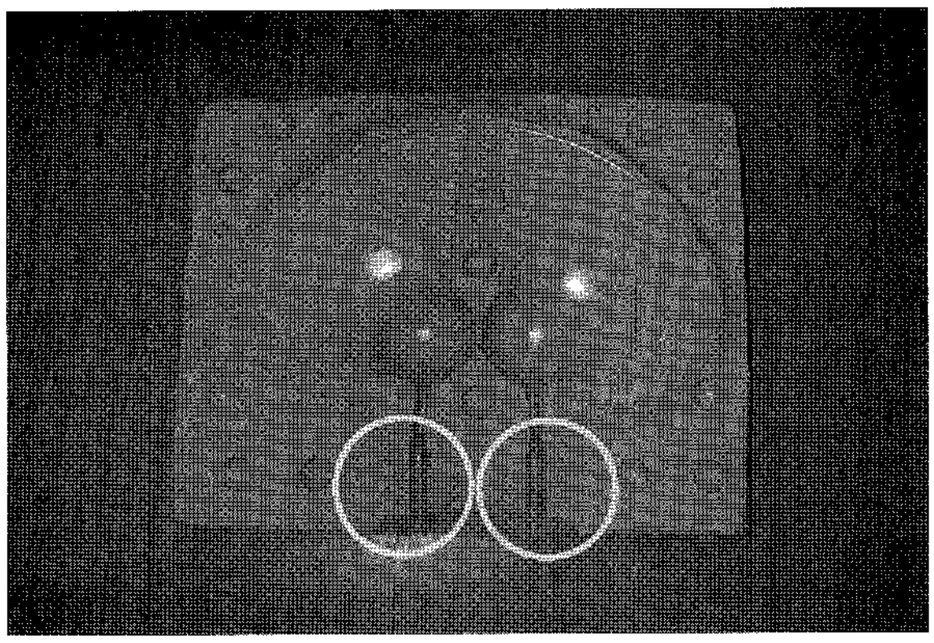

Fig 9. Installed Two Gates on Silicon Mold

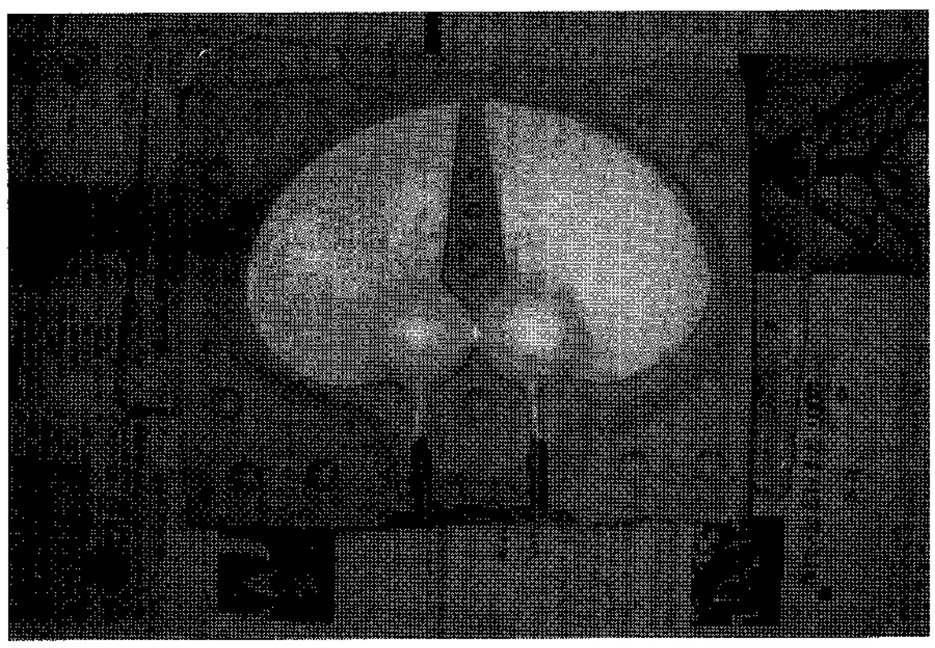

Fig. 10. The Replica

But we needed numerical accuracy. We scanned it with Vivid910 and arranged the scanned data with RapidForm 2006 of INUS Co. which is a three dimensional data modeling software. And we compared the result model with the master model as Fig. 11. The average difference is 0.072mm. If we represent it as ratio, difference rate is 0.214%. We concluded the replica is very similar to the master model.

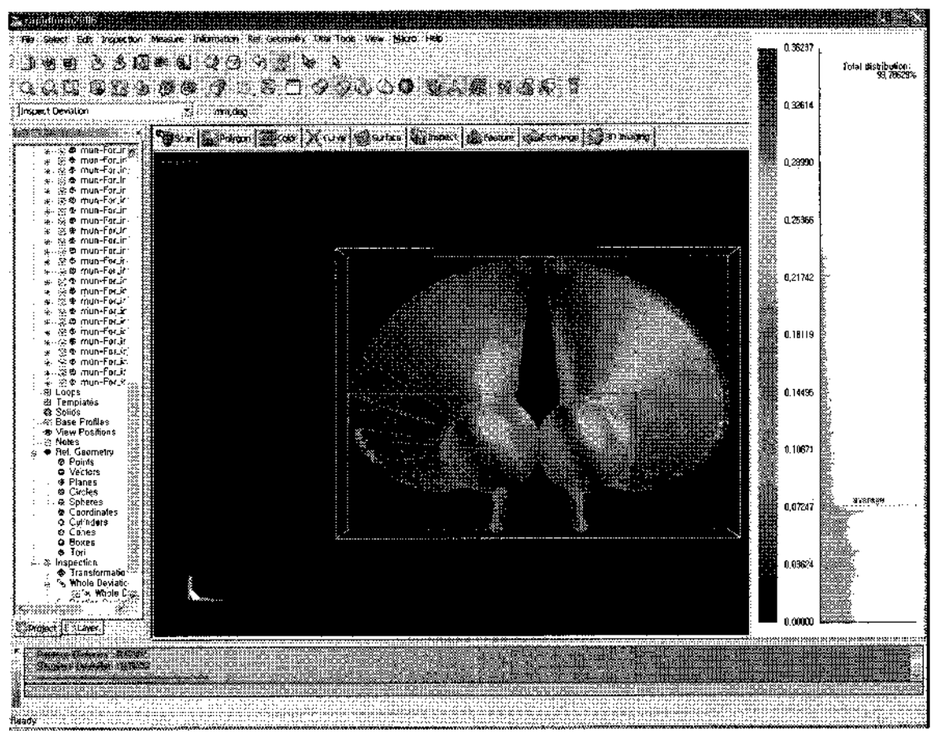

Fig. 11. Comparative Analysis between the Master and the Replica

In conclusion we knew that if a replica is made according to the result from forming analysis, even an unskilled one could work as experts by the experiments. Fig. 12 shows the finished good.

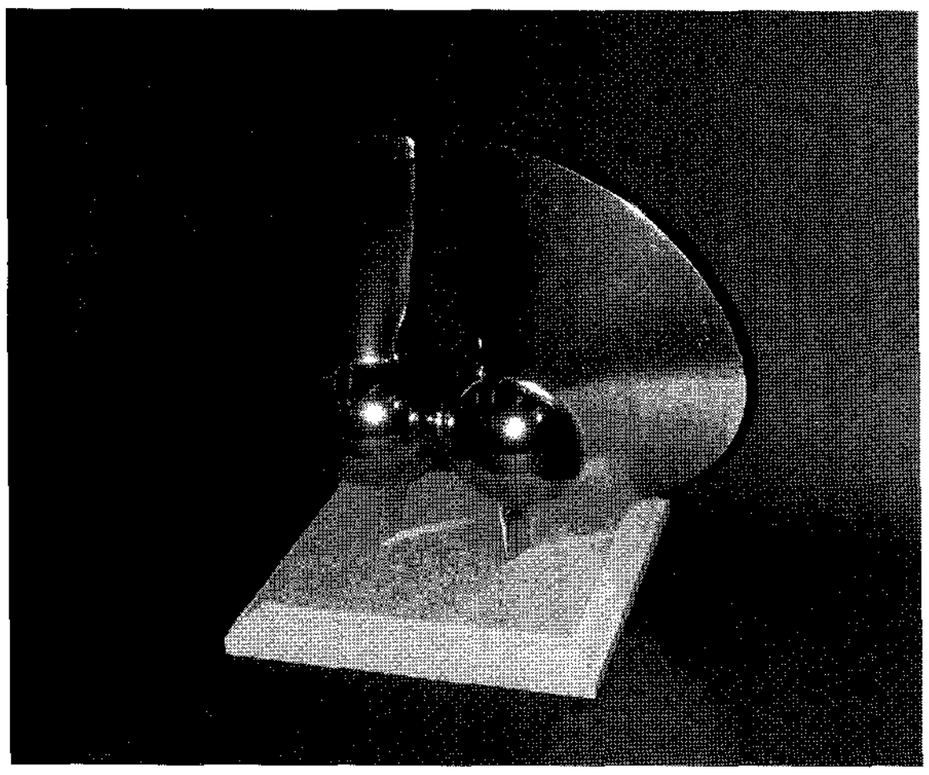

Fig. 12. The Finished Miniature of the Concord

5. Conclusion

The purpose of this research is to judge whether a forming analysis software for iron can be applied to silicon molding. If it is possible, unskilled workers can supplement their poor know-how in making replica by using its results, so that they can work as an expert.

According to the experimental result, the accuracy was 99.786% and we could make very good replica. In conclusion, we could say that a forming analysis software for iron can applied to silicon molding. If so, defectives of silicon molds and replicas will be reduced

In this research, shape of the target object to duplicate was not complicate. So we could select the best alternative easily. We will try to test our methodology to complicate shaped objects.

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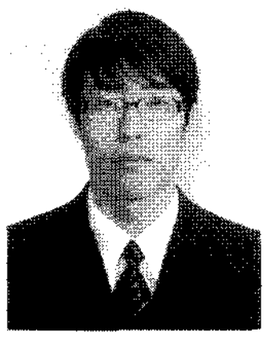

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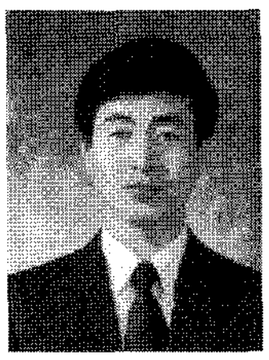

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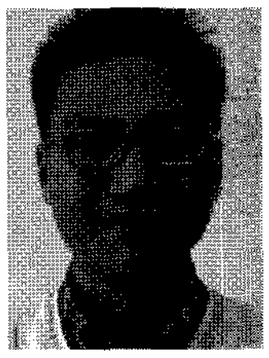

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