Rapid Tooling by Using a Magnetic Powder System with Optimized Parameters

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Abstract. For shortening customized products of development cycle and reduce costs, rapid prototyping technology is one of the ways for the industry. In this paper, it will be combined of 3D printing forming technology and the magnetic field lines control of molding technology, to develop a set of parameters with the best control of the magnetic powder mold system. First, after molding to 3D printing technology printing desired model, and then generate the cavity via magnetic molding technology, in order to shorten the mold manufacturing time. In which, in the powder molding equipment related parameter setting, use Taguchi method to find the relevant parameters to produce the desired combination of hardness and precision, such as voltage, density, magnetization time. The results are shown the best parameters combination of stiffness and precision, in precision design the best combination of parameters S / N ratio improved by 56%, and the surface hardness to design the best combination of parameters S / N ratio is improved by 21%. Reuse fuzzy inference system inference mechanism to simulate various voltage, density and magnetizing time formed by a surface hardness, inferences parameters of various combinations of different conditions, the surface hardness of the formed, inference values and experimental values results are compared error is about 2.45%.

1. Introduction

The molding tool industry is rather important in our country industry, according to current output value, the world placings of our country molding tool industry are to come out in front, and the molding tool industry takes up above 25% of the manufacturing industry. In the manufacture process of molding tool, because the size of variety of models are different and shape also has the dissimilarity, they must manufacture a molding tool of a variety of different sizes, respond various different models. For example shoe insoles, the different shoe insoles sizes need the molding tool of matching with the dissimilarity, if the same style shoe insoles have many different sizes, needing to manufacture various molding tools, the cost is opposite to raise, and manufacture time more long, the procedure is more complicated, so need the manufacture methods of changing the tradition. Hsu [1] put forth to shorten product development time and decrease cost, promote the diversification product to the market quickly, combine a 3D printer to print out to model technique and magnetic force to control the magnetic powder system, development has the environmental protection to also repeat the rapid molding tool system of using, solve a traditional molding tool to the environment pollution and the cost problem. However, because of market at size accuracy need more and more fine, the methods of making use of the Taguchi methods can find out the quality characteristic of influence of each factor upon, reducing the time and manpower cost, finding out the best parameter to design to product and to promote the quality characteristic [2-3].

Chang [6] mentioned rapid prototyping (RP) is a technology directly from the part via the CAD design, the use of stacked laminated manufacturing technology. Lin [7] refers to rapid prototyping (RP) systems in the major advanced countries have gradually developed a wide variety of rapid prototyping systems. Generally it can be classified with a liquid processes, powder process, plastic extrusion process, paper lamination process, surface exposure process, 3D printing process. Guo [8] use of rapid prototyping (RP) combining computer-aided
manufacturing of the 3D stereoscopic graphic design generated by the production of molds and prototype the size of the error can be easily mastered. Yan [9] using the way of materials Precision accumulation, namely the point piled into the surface, 3D entity formed by the surface accumulation. KJ Suganth Kumar et al. [10] referred to the magnetic molding is an environmentally friendly and economical way to take advantage of keeping the ball in the field to make a mold for casting metal forming mold. JL Lin et al.[11] use Taguchi method combines fuzzy inference theory, and put forward a set of algorithm of multiple quality problems. Vijayalaksmi [12] proposed water supply system of the region desired by the user, a fuzzy inference system prediction. In the past this team [13] using the magnetic lines of force to control the magnetic stereotypes method combined with rapid tooling technology to produce a new type of shaping powder mold system, this team [14] also use the Taguchi method with the L18 orthogonal table magnetic control fast sole control of the magnetic powder of depression mechanical process parameter optimization.

This research existing 3D printer to model the rapid molding tool technique is foundation, developing a set of control the rapid molding tool system of magnetic powder by the 3D printing forming and the magnetic force. First, the 3D printer prints a prototype, making use of the electromagnet produce electricity magnetic field, the line of magnetic force controls the magnetic powder cladding molding tool of hard mode (Taiwan patent number: I319705), removing prototype molding tool. Finally, turning off electricity of electromagnet, stopping a function of electromagnetism field, will make the magnetic powder return to not-hard mode of plasticity molding tool [4-5]. This method can reduce development cost and time of molding tool of different sizes, promote the molding tool manufacture efficiency. In the system design, find out each parameter that the surface degree of hardness to the system mold and size accuracy influences and design the best surface degree of hardness and parameter combination of accuracy. The related data the parameter under a variety of conditions use fuzzy inference establish a database, reducing caused by human factors measurement error experiment in the future. Improve the magnetic powder to sticky to the problems of finished products, and through dissimilarity of flow a design to inquire into the results of finished product then raising the finished product rate of finished product.

2. Design and experimental methods

This paper will develop a rapid tooling system device of magnetic controlling equipment development process shown in Fig.1. There are included two parts: 1. To use Taguchi method to design the best combination of accuracy and precision parameter and 2. Fuzzy inference theory is to establish different parameter combinations of hardness repository. In this paper, developed the magnetic powder rapid tooling system to control its operation principle for the use of 3D molding equipment for printing a list of the required prototype device, the purpose of the magnetic charge and magnetic devices combine to achieve magnetic control electromagnet magnetic molding of Fig.2. Users can via adjust parameters of the charge magnetic device and the mold of quickly and accurately obtain production.

![Figure 1. Flow chart of development process of the magnetic rapid tooling.](image-url)
Figure 2. Electromagnet and magnetization control system equipment.

Taguchi quality method to design the best combination of parameters desired hardness and precision, such as voltage, density, magnetization time, and then use the fuzzy inference system inference mechanism to simulate the surfaces of various voltage, density, magnetization time formed the die face hardness, achieving simple, fast and low-cost production of magnetic rapid tooling system. Taguchi quality method used in this paper is made in order to find the best combination of parameters, Taguchi quality method is a systematic quality and highly efficient way to import numerical experiments. Surface hardness and precision molding is appropriate, it will directly affect the magnetic changes produced by the different parameters of the finished product will not be good deformed or damaged, the flow chart shown in Fig.3.

Figure 3. Taguchi experimental method flow chart.

Taguchi experimental method selected control factors used in the paper. They are: A. Voltage strength (80V, 120V, 160V and 200V), B. The particle size (40 ~ 70 um, 0.5mm, 1mm and 3mm), C. Density (1.8 kg / m³, 1.9 kg / m³, 2.0 kg / m³ and 2.1 kg / m³), D. Magnetizing time (0.3s, 0.5s, 0.7 s and 1.0s), E. Box Type (quasi-metal box and plastic box (ABS material)), where the parameter A ~ D are set to four levels, the parameter E there are two standards. In the Taguchi method orthogonal array experiments we choose the orthogonal table shown in Table 1. The surface hardness test be made by 16 sets in Taguchi method, measuring the surface hardness of the five points shown in Fig.4.
Table 1. Orthogonal table 16 sets in Taguchi method.

| Exp. | A   | B   | C   | D   | E   |
|------|-----|-----|-----|-----|-----|
| 1    | 1   | 1   | 1   | 1   | 1   |
| 2    | 1   | 2   | 2   | 2   | 1   |
| 3    | 1   | 3   | 3   | 3   | 2   |
| 4    | 1   | 4   | 4   | 4   | 2   |
| 5    | 2   | 1   | 2   | 3   | 2   |
| 6    | 2   | 2   | 1   | 4   | 2   |
| 7    | 2   | 3   | 4   | 1   | 1   |
| 8    | 2   | 4   | 3   | 2   | 1   |
| 9    | 3   | 1   | 3   | 4   | 1   |
| 10   | 3   | 2   | 4   | 3   | 1   |
| 11   | 3   | 3   | 1   | 2   | 2   |
| 12   | 3   | 4   | 2   | 1   | 2   |
| 13   | 4   | 1   | 4   | 2   | 2   |
| 14   | 4   | 2   | 3   | 1   | 2   |
| 15   | 4   | 3   | 2   | 4   | 1   |
| 16   | 4   | 4   | 1   | 3   | 1   |

Figure 4. Magnetic mold surface measurement partition map.

Fuzzy systems under different conditions of voltage, density and magnetizing time, the use of guidelines inference mechanism of fuzzy inference system inference hardness output, and then establish a database, learning under different parameter combinations in the surface hardness. In this experiment, there are the voltage, density and magnetizing time as the three quality characteristics of the input variables, with surface hardness as output variables, shown in Fig.5. In the fuzzy interface, the present paper using the triangular function attributable to segmentation of fuzzy inputs and a total of four levels is defined, as shown in Fig.6. In the output section is nine output levels, as shown in Fig.6.

Figure 5. Fuzzy inference system interface.
3. Results and Discussion

3.1. S/N ratio and quality characteristics

In the process of Taguchi Methods to determine the objective function and quality is the key characteristic of an analysis. The paper uses of large characteristics of the surface hardness and the experiment of Taguchi method S/N ratio analysis shown in Fig. 7. Quality characteristics are continuous and the bigger is the better. The quality characteristics of the ideal value is treated as infinity, the experiments Taguchi method quality characteristics analysis shown in Fig. 8.

In addition to, the paper uses Taguchi method in precision measurement (size error) using smaller characteristics, the Taguchi method in the experimental of dimensional accuracy S/N ratio analysis shown in Fig. 9, when the quality characteristic is continuous and the smaller is the better. Quality characteristics of the ideal value are treated as zero, the experimental method of dimensional accuracy of Taguchi quality characteristics analysis diagram shown in Fig. 10.

Figure 6. Fuzzy inference in the home function of the input (a) voltage, (b) density, (c) magnetizing time and (d) output hardness.

Figure 7. Surface hardness of S/N ratio analysis.
The best combination of parameters design and verification experiment via Taguchi method for each factor analysis, surface hardness will be in the original design value A4, B2, C2, D2, E1 (voltage of 200V, particle size of 0.5mm, density of 1.9 kg / m³, magnetizing time is 0.5s and metal box) to modify the parameter combination of A3, B1, C4, D4, E1 (voltage of 160V, a particle size of 40 ~ 70 um, a density of 2.1 kg / m³, and magnetizing time is metal box) for the best combination of surface hardness level parameters.

In terms of accuracy, parameter combinations modify A3, B1, C4, D4, E2 (voltage 160V, particle size of 40 ~ 70 um, density of 2.1 kg / m³, the magnetizing time is 1s and plastic boxes) for the best accuracy parameter level portfolio, through the results of experimental verification of the optimum combination of parameters, as shown in Table 2. Table 2 shows the optimum parameters after improving design accuracy by S / N ratio of 6dB (about upping 56 per cent ),and the hardness on the surface also improves 7.9dB(about upping 21%). In the results, can know the best parameters surface hardness and precision of different types of combination in that the box, it will do two boxes hardness test. First, the box is divided into A, B and C three parts and A, C in the case of the two sides, B is a point in the center of the box, At a voltage of 110V experimental conditions, the results shown in Fig.11 and Fig.12, after the figure can understand through magnetic, metal box will form with the direction of magnetic lines of magnetic force inconsistent, easy to make the model deformed shape, and in the use of plastic box can make uniform magnetic field lines down, improve the direction of the magnetic field lines do not mean to get a higher modulus surface accuracy.
Table 2. Experimental validation results.

|                                | The original design portfolio | Best design portfolio (verification) | Improve |
|--------------------------------|--------------------------------|---------------------------------------|---------|
| Reference standards            | A=B=C+D+E1                    | A=B+C+D+E1                             | -       |
| Surface hardness               | 10.7                           | 16.7                                  | -6dB (rise 50%) |
| (S/N Proportion)              |                                |                                       |         |
| Surface accuracy               | 37.4                           | 45.5                                  | +7.9dB (rise 21%) |
| (S/N Proportion)              |                                |                                       |         |

Figure 11. 110V Magnetic hardness experiment chart (metal box).

Figure 12. 110V Magnetic hardness experiment chart (Plastic box).
3.2. Fuzzy inference system

This study considers voltage, density and magnetizing time three parameters, the characteristics same degree of importance, and thus develop a fuzzy rule table, a total of 64 rules. Fuzzy inference result, the present experiment using Matlab software for fuzzy inference, the inference results shown in Fig.13 and Fig.14. The figure shows the relationship between voltages, density and magnetizing time three parameters, when the voltage and density parameters fixed, the surface hardness will increase with the magnetizing time enhanced surface hardness. While fixed parameters between the voltage and magnetizing the surface hardness of the magnetic density increases and enhanced. When the density and magnetizing time parameters fixed, as the voltage rises, the surface hardness increases, because when the electromagnet magnetic intensity reached saturation time, and then increase the voltage, the magnetic effect of increasing strength will become smaller and smaller, it was found from the experiment, electromagnet of this study, conditions will arrive at 160V magnetic saturation. 12 group via random sampling experiments verify the results in Table 3, the experiments found that the simulation results and fuzzy inference error is about 2.45 percent, therefore it is proven by fuzzy inference the surface hardness data generated by various parameter combinations of inferred and thereby establish a database.

![Figure 13. Fuzzy inference - magnetizing time and density graph.](image1)

![Figure 14. Fuzzy inference - voltage and density graph.](image2)
Table 3. Fuzzy inference experimental verification.

| Voltage (V) | Density (kg/m³) | Time (s) | Measured Value | Inference Value | Errors % |
|------------|-----------------|----------|----------------|-----------------|----------|
| 80         | 1.8             | 0.3      | 9.3            | 9.52            | 2.31     |
| 80         | 1.9             | 0.5      | 10.5           | 10.8            | 2.77     |
| 80         | 2               | 0.7      | 12.13          | 12              | 1.08     |
| 120        | 1.9             | 0.3      | 11             | 10.8            | 1.85     |
| 120        | 2               | 0.7      | 13.86          | 13.5            | 1.91     |
| 120        | 2               | 1        | 13.33          | 13.6            | 1.98     |
| 160        | 2               | 0.3      | 12.37          | 12.2            | 1.39     |
| 160        | 2               | 0.7      | 11.7           | 12              | 2.5      |
| 160        | 1.9             | 1        | 12.8           | 13.6            | 2.88     |
| 200        | 2               | 0.5      | 12.6           | 12.9            | 2.32     |
| 200        | 2               | 0.7      | 13.8           | 13.6            | 1.47     |
| 200        | 1.9             | 0.7      | 12.3           | 12.8            | 3.9      |

Average
=2.43%

Taguchi method and fuzzy inference results: In this study, the quality of the Taguchi method to find out the best design combination of surface hardness and dimensional accuracy, however, using a combination of parameters A3, B1, C4, D4, E1 (voltage 160V, particle size of 40 ~ 70 um, density of 2.1 kg / m3, magnetizing time is 1s and metal box) optimum surface hardness can be obtained, if the parameter combination of A3, B1, C4, D4, E2 (voltage 160V, particle size of 40 ~ 70 um, density of 2.1 kg / m3, the magnetizing time is 1s and plastic box) to obtain the best accuracy.

3.3. To improve the finished quality design

The use of the magnetic field lines control powder forming, because the molding surface is part of hard powder state, if perfusion silicone or resin material will generate magnetic sticking problems in the subsequent processing of finished products will increase the number of processing costs and high degree of difficulty, therefore, this study uses two methods to isolate powder and model surface, first using plastic wrap to cover up before molding surface materials needed reperfusion, isolating the magnetic and the material, after reperfusion make the finished molding material deformation, because the plastic wrap is part of an irregular shape, though the material can be effectively isolated from the powder, but could not immediately attached to the magnetic forming surface, it will have a greater size error. The second magnetic isolation mode, this study used a liquid rubber spray forming surface formed thereon is attached to isolated magnetic film as shown in Fig.15, the advantage is that at room temperature and normal humidity, normally hardened form elastomers, no special techniques and expensive equipment you can use. The temperature has little effect on the liquid rubber and can be used for vertical fill the gap seal, in the use of convenience, safety, material does not shrink, compression and tensile excellent elasticity, suitable for most of the material surface. From the experimental results, in addition to the use of spray liquid rubber powder can be effectively cut off from the outside with the material, size and surface finished to minimize the impact.
4. Conclusion

Purpose of the paper was to develop a magnetic powder control of rapid tooling systems and this system features are by fast magnetic mold to quickly produce the products needed for rapid tooling. In addition, through rapid prototyping methods to control the magnetic basis of magnetic force, also to avoid the problems of the conventional mold and rapid tooling cost cannot be reused. Magnetic control in magnetic technology developers is to work with Taguchi method and fuzzy inference theory. The required magnetic mold system is quickly and accurately in the quality and design.

Development of this system is expected to accomplish the objectives set by:

1. Optimal parameter design: the use of Taguchi method can design the best parameters combination mold surface precision of A3, B1, C4, D4, E2 (voltage 160V, particle size of 40 ~ 70 um, density of 2.1 kg / m3, magnetizing time as 1s and plastic box) precision design parameter combination S / N ratio improvement 6dB (about 56 per cent rise), and the surface hardness of the optimum parameters combination A3, B1, C4, D4, E1 (voltage 160V, 40 ~ 70um particle size and a density of 2.1 kg / m3, magnetizing time is 1s and metal box) surface hardness design parameter combinations S / N ratio is improved 7.9dB (about up 21%).

2. Fuzzy inference repository established: fuzzy inference theory in combinations of different parameters of the conditions of various, formed by the surface hardness, pushing with the experimental error of about 2.45%.

3. Surface coating isolated magnetic surface coating: the use of liquid rubber surface coating powder sticking to overcome the problem and a smaller effect on the dimensional accuracy of the finished product.

4. Gate design to get a good product: The three kinds of gate design, it is found as a double gate and gate design placed on edge than the other two models available gate design products with a higher rate.

5. References

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