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Use of Resin Tooling with Sheet Metal Hydroforming for the Manufacture of Aluminum Alloy Cases

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Products are continuously undergoing evolution according to changes in trends, and the need for a high surface quality, complicated shapes, and special materials make this kind of product more and more difficult to fabricate. A product of complex geometry with detailed features is not suitable for production by a conventional forming process, but the Sheet Metal Hydroforming (SHF) process can be employed to produce very detailed features. In this study, we integrated the SHF process with a resin tooling method for the rapid manufacture of products of minimal variety in low quantities, resulting in the reduction of both cost and time. We manufactured a freeform house with a small radius fillet using SHF with resin tooling in a unique and novel process. The process involved the forming of twenty pieces using Al 5052 and SUS 304 sheet plates, and the number of items fabricated, dimensional accuracy, and endurance to wear and tear of the tools was then used to evaluate the applicability of the method in a real manufacturing process. No defects were apparent on the tooling surface after production of a small quantity of products, and the average distance difference between points and curves of tooling was 0.0638~0.0946 mm. The results of analysis of the resin tooling process show that this is an acceptable method for use in the trial stage of product development. For the product cases manufactured, the average distance difference of the Al 5052 product was 0.097 mm, while that of the SUS304 product was 0.165 mm. Integration of SHF and resin tooling shortens the cycle time, reduces the total cost of the process, and results in a product with a good surface. It can be applied to form molds, plastic molds and waxing ejection molds, with a high potential for use in the motor parts, digital products and aeronautical parts markets.

Keywords: *rapid tooling, Sheet Metal Hydroforming (SHF), rapid prototyping, cases, complicated shapes.*

1. Introduction

A durable metal mold is usually used in the sheet metal forming process, which is normally performed in several complex and time-consuming steps: preliminary material preparation, rough machining, stress relief after preliminary machining, wire-cutting, electrical discharge machining, grinding, surface polishing, and an endurable coating process. This renders the product development process lengthy and high in cost. In order to avoid the shortcomings of the traditional steel mold, a simple mold (also referred to as a temporary mold or rapid tooling) such as one fabricated from a metal of low melting point, a Zn alloy mold, an electrically-formed mold, a ductile casting mold, or a metal spraying mold, can be employed in the development process to replace the steel mold in order to reduce the development time [1]. The rapid tooling process can potentially be employed to produce various kinds of products in low quantities, reducing both the cost and the trial time, and would be particularly useful in the product development stage [2,3].

A hydroforming process can be used to form a product of the tube or plate kind by employing a mold of a specifically-designed shape linked to a liquid pressure system [4]. Two categories of hydroforming are used in the forming industry, Tube Hydroforming (THF) and Sheet Metal

Hydroforming (SHF). SHF is typically used to fabricate a product from sheet metal and is designed with an inlet in the lower mold (die). A constant pressure flow into this inlet, which is on the bottom face of the die, generates a pressure in the direction opposite to the forming direction, and assists in forming the sheet plate into the product of the correct shape as the upper mold (punch) strikes down on the die [5]. Pressure-assisted forming results in more detailed forming and a deeper-drawn product, which increases profit and reduces the number of defects in comparison with conventional forming. Figure 1 shows the specification of the SHF process which requires only one punch and die, as the pressure assists in forming the metal sheet to the surface of the mold. In practice, SHF results in a high-quality product with a smoother, less-wrinkled surface and reduces the number of forming steps required. In addition, many materials can be used as the sheet metal in the SHF process, such as low-carbon steel and high-performance stainless steel, high-strength steel and titanium alloys), as the use of pressure enables controlled forming. SHF is a suitable method for the production of high-quality, detailed geometric and complex surfaces of small fillet radius with detailed features, and is particularly applicable in the formation of motor products, aeronautical products, electrical appliances, orbital vehicles and illumination appliances [6,7].

However, the cycle time of SHF is longer than that of the conventional forming process as the application of pressure lengthens the process, and this method also cannot be used for mass production. For small quantities of various products, though, the process integrating SHF and rapid tooling is potentially of great advantage.

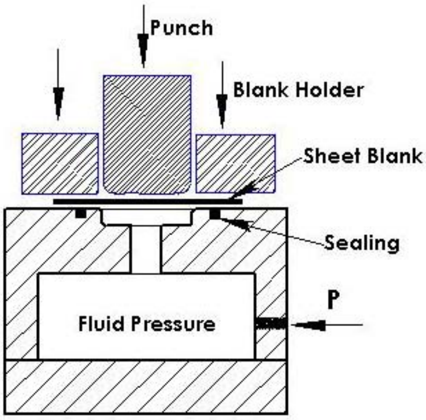

Fig. 1. The SHF process.

Fig. 2. 130-ton sheet SHF machine.

In addition, the simplicity of the process, good surface quality, ease of modification, fast machining and low scrape of this process renders it superior to the traditional method, and combining THF with resin tooling has the potential for application in the development of new products and the creation of new processes.

2. Experimental Procedure

2.1 Sheet hydroforming press

We used a hydroforming machine (Amino, Japan) to manufacture casings and investigated the forming ability achieved using SHF with resin tooling, as shown in Fig. 2. The main specifications of the forming machine were as follows:

Pressure total : 130 Ton.
Inner pressure : 80 Ton.
Outer pressure: 50 Ton.
Working table: 400mm x 500mm.
Maximum liquid pressure: 700 bar.

We used an ATOS II non-contact 3D scanner (GOM mbH, Germany) to capture the point clouds of the surfaces of mold and product, and employed the comparison software Rapidform XOV (INUS Technology, Korea) to analyze the distance difference.

2.2 Forming test

The details of the test were as follows:

(1) Test products:

Target: metal housing of a cell phone.

Product materials: Al alloy 5052 and SUS304 stainless steel.

Plate thickness: 0.5 mm.

Detailed characteristic fillet radius: 1.5 mm.

Mechanical properties:

Al alloy 5052–yield strength 180 Mpa.

SUS304–yield strength 300 Mpa.

(2) Test tooling:

Machining block resin into the mold and die helped to minimize the cost and decreased the length of time required for fabrication.

(3) Measurement:

After forming twenty individual products out of Al-alloy and SUS 304, we measured the surface distance error arising through the resin tooling process. Three main analyses of measurements were made, as follows:

- Point comparison of the total surface to evaluate whole-surface deformation.
- Point comparison of a cross-section of the mold to evaluate the deformation and wear and tear at the critical point of the section.
- Comparison of the cross-section of the mold and the characteristic curve in order to assess the error in the complex curve in the critical section.

(4) Evaluation:

The point cloud of the scan data was compared with that of the 3D CAD of the mold. In the evaluation process, we calculated the distance error by comparing the measurements of the 3D CAD model with the scan data of the products manufactured by SHF resin tooling, as described in the previous section (Measurement).

3. Results

3.1 CAD model and physical product

The 3D CAD model of the housing product with a small radius, which was designed using the software Solidwork, is shown in Fig. 3, and the 3D CAD model of the tooling is shown in Fig. 4. After machining, the resin tooling shown in Fig. 5 was obtained. Figure 6 shows the Al alloy 5052 forming product and Fig. 7 the stainless steel SUS 304 product.

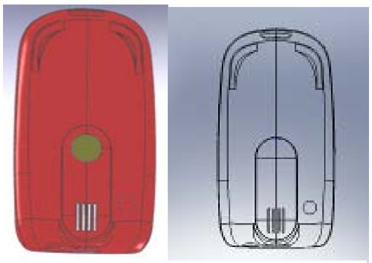

Fig. 3. 3D model of the digital product.

Fig. 4. 3D model of the mold.

Fig. 5. Machined resin tooling.

Fig. 6. Al-alloy 5052 forming product.

Fig. 7. Stainless steel SUS304 forming product.

3.2 Resin tooling

A point cloud of the scan data obtained using a 3D scanner is shown in Fig. 8a. First, the measurements of the point clouds of the holes in the physical die (Fig. 8a) obtained using a 3D scanner were compared with those of the holes in the 3D cad model (Fig. 8b) using the best fit alignment function of Rapidform XOV software. Then, the holes in the scan data were aligned with the reference holes in the nominal 3D CAD model using Rapidform XOV, and Fig. 9 show the results of merging of the 3D CAD model and the scan data using the best fit function.

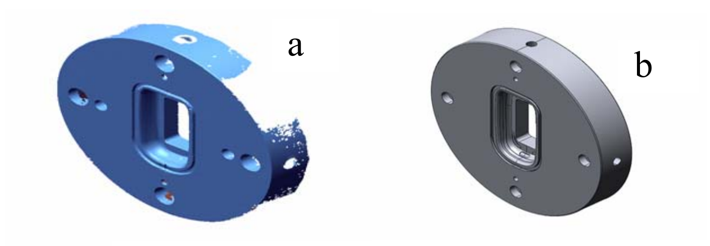

Fig. 8. Scan data (a) and nominal 3D CAD model (b).

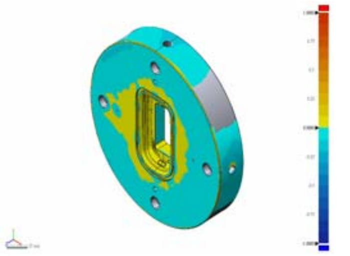

Fig. 9. Best fit alignment of the 3D CAD model and the scan data.

The average distance difference of the whole model was 0.0638 mm, as shown in Table 1. Point cloud data of the cross-section were selected using a selection function in order to find the average distance error between the scan data and the 3D CAD model, as shown in Fig. 10. Table 2 shows that the average difference between cross-section points was limited to under 0.0946 mm, and comparison of the critical curve of the cross-section showed that the results were within an error range of 0.15 mm, as shown in Fig. 11.

Table 1. Average distance error of whole surface.

Function	Min.	Max.	Avg.	RMS
Best Fit Alignment	0.1586	-0.1584	-0.0083	0.0638

RMS: root mean square.

Table 2. Average error of cross-section points.

Function	Min.	Max.	Avg.	RMS
Best Fit Alignment	-0.4779	0.3564	-0.0092	0.0946

RMS: root mean square.

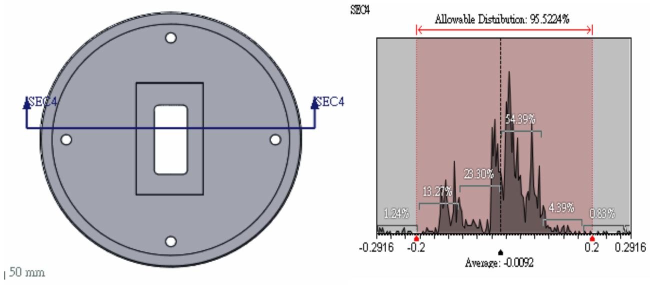

Fig. 10. Cross-section comparison.

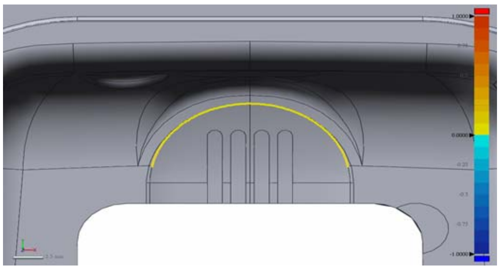

Fig. 11. Cross-section significant curve comparison.

3.3 Housing products

The average distance difference error between the CAD nominal data and the scan data was 0.097mm for the Al-alloy 5052 product and 0.165mm for the stainless steel forming product, as shown in Figs 12 and 13.

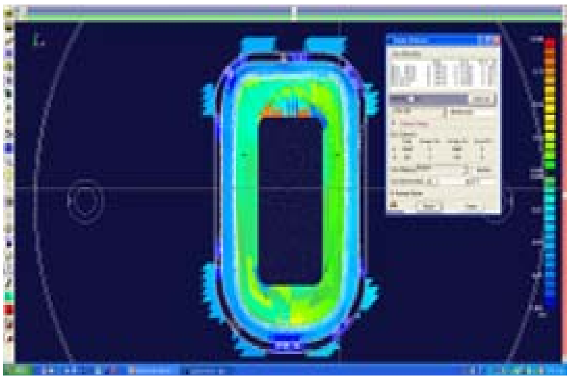

Fig. 12. Distance difference between the 3D CAD model and the Al alloy 5052 product.

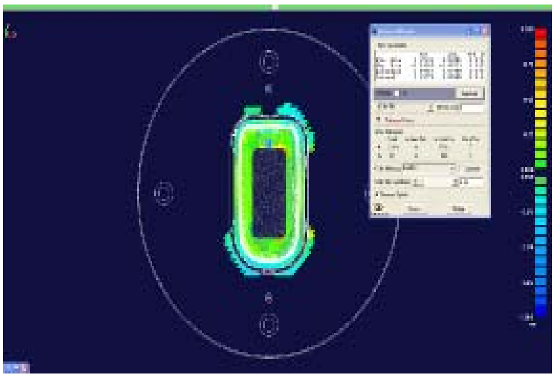

Fig. 13. Distance difference between the 3D CAD model and the stainless steel SUS304 product.

4. Discussion

Twenty products made from Al alloy 5052 and SUS 304 sheet plates were formed by SHF with resin tooling, and after manufacturing all parts, no scrapes were seen on the surface of the mold of the resin tool. However, some scrapes were apparent on the corner or complex part of the product when the process was operated at a high holding pressure, resulting in tooling damage. Therefore, it is apparent that finding the optimum process pressure is key to achieving a successful forming product, particularly when using high-stress material.

The liquid pressure is also a very important parameter in the SHF resin tooling process. In order to achieve a high-quality product, various different liquid pressures are used during the process, and liquid pressure control is crucial. A pressure of 150 kg/cm^2 was applied when using the Al-alloy, while a pressure of over 200 kg/cm^2 was applied when using the stainless steel SUS304 sheet in order to achieve formation of the required shape. A higher liquid pressure in the forming process results in better shape forming, but too high a pressure can cause tooling damage: in other words, a low liquid pressure cannot be used form a very detailed feature such as a small radius chamfer or products of complex geometry. To reduce the risk of product breakage in the SHF–resin tooling process, lubricator is spread on the plate before the product is carefully formed to the correct shape.

From the measurement and comparison of the product and resin tooling data, it was confirmed that not only was Al alloy 5052 suitable for application in the SHF–resin tooling process, but SUS

304 was also able to be formed using this method. After producing a small quantity of products, comparison of the scan data of the mold with the 3D CAD model showed the average distance difference between points of the whole surface to be 0.05~0.15mm. This distance error is acceptable at the trial stage of product development, and the resin tooling forming process is therefore a suitable method for use in the trial stage. The distance difference between the product scan data and the 3D CAD model was 0.097mm for Al alloy 5052 and 0.165mm for the SUS304 product: these errors are also acceptable for real applications at the trial stage, but use of the SUS 304 plate causes more wear and tear of the tooling.

Conventional steel mold manufacturing with a several processes *is used to mass-produce hundreds of thousands of pieces*, but SHF with resin tooling is a potentially suitable method for the manufacture of a small quantity of customized products of complex geometry.

5. Conclusion

Resin tooling has been used in real applications in Germany, Japan and American to develop personal customized products. In the trial stages of a new product development, resin tooling is suitable for functional testing or pre-production. In the manufacture of complex shape of product, the SHF process better enables the formation of characteristic features, resulting in a reduction in the number of forming process needed and lowering the cost. The employment of rapid tooling in the SHF process speeds up the production cycle, especially at the trial and test stages. In this study, we manufactured housing products of small radius using SHF with resin tooling in a single forming process. After fabricating twenty pieces, no scrapes were present on the surface of the mold, and the linear distance difference error was less than ±0.2%. This simple resin tooling process could be widely applied for the manufacture of various products using a number of materials, and the integration of SHF and resin tooling has the advantage of reducing the cycle time, lowering the cost, and resulting in products with a high-quality surface. Integration of SHF and resin tooling shortens the cycle time, reduces the total cost of the process, and results in a product with a good surface. This process can be applied to form molds, plastic molds and waxing ejection molds, with a high potential for use in the motor parts, digital products and aeronautical parts markets.

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