3D laser forming strategies for sheet metal by geometrical information

S. J. Na[1], J.T.Kim[2]

[1] *Department of Mechanical Engineering, KAIST, Daejeon, Korea*
http://alpa.kaist.ac.kr *e-mail: sjna@kaist.ac.kr*

[2]*Park Systems Corp., Suweon, Korea*
http://www.parkafm.com *e-mail: jitae@parkafm.co.kr*

ABSTRACT: Forming sheet metal by laser-induced thermal stress (laser forming) is considered to offer great potential for rapid prototyping and other flexible manufacturing. In order to apply the laser forming process to real 3D products, a method that encompasses the whole process planning, including the laser irradiation patterns, laser power, and travel speed, when the target shape is given. In this work a method for 3D laser forming of sheet metal is proposed by using a geometrical information rather than a complicated stress-strain analysis. Using this method the total calculation time is reduced considerably while affording strong potential for enhanced accuracy.

Key words: Laser forming, 3D surface, automatic path planning

1 INTRODUCTION

One of the final goals of laser forming application is to make a target shape from a flat sheet metal automatically. Thus, with the input information of the target shape, an algorithm should guide process planning such as the initial specimen size, laser irradiation pattern, and laser parameters. In order to realize this procedure, the inverse problem should be solved first.

3D laser forming studies have recently been undertaken. Edwardson et. al. [1] conducted experiments on laser forming of a saddle shape with various irradiation patterns and analyzed each method. A more detailed study with the concept of constant gradient vectors was published in 2004 [2] and good results for a pillow shape were presented. Hutterer et. al. [3] applied laser forming to flattening non-circular dents with a pulsed laser and Bartkowiak et. al [4] conducted experiments on the effect of an elliptical arc scan strategy and presented a laser formed hybrid cylinder part. Liu and Yao [5] made considerable progress on 3D laser forming area. They obtained a principal strain field by the optimal development algorithm and with the help of a FEM database they successfully determined laser scanning paths and process parameters.

This study presents a 3D laser forming strategy that utilizes a geometrical information.

2 SOLUTION OF INVERSE PROBLEM

The overall procedure of the 3D laser forming process is shown in figure 1. First, small plane patches are made from the given free surface. Then, the amount of shrinkage and the bending angle are calculated by the planar development procedure. Finally, process parameters are chosen from a FEM database map.

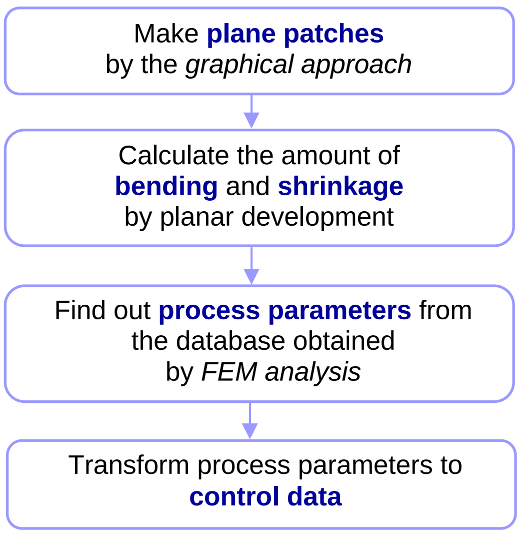


Fig. 1. Overall procedure of 3D laser forming

2.1 Making plane patches from a given surface

When making a target surface from a flat sheet metal, it is necessary to first determine the initial shape of the flat sheet metal, and then decide where to irradiate the laser. In order to achieve this, a method of decomposing a free surface into a group of flat plane patches, which is an expansion of Kim and Na [6]'s geometrical approach, is proposed. They proposed two different methods; one is using maximum distance criteria and the other is using offset angle criteria. The first method, distance-based method uses the maximum distance between the given sheet metal and the target shape as a criterion for a new forming point. If the maximum distance is larger than the offset distance, the point at the maximum distance is adopted as a new forming point. The procedure of the distance-based criterion algorithm, which is shown in figure 2, is as follows:

1. Set offset distance, h_{offset}.
2. Set both end points and the contact point as control points, P_i.
3. Start from $P_i(x_i,z_i)$, then calculate h_j.
4. Find a point that has the maximum distance between the target surface and the line from Pi to Pi_{+1}.
5. If the maximum distance is larger than the offset distance h_{offset}, adopt the maximum distance point as a new forming point.
6. Repeat 3 and 4 until all the maximum distances are smaller than the offset distance.
7. Find d_i, the distance between the forming points and the forming angle θ_i.

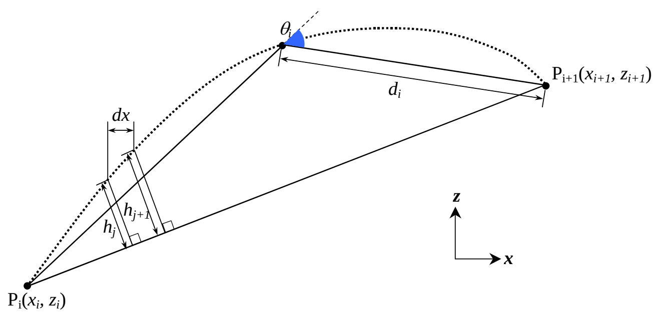


Fig.2. Procedure of distance-based criterion algorithm

For the case of a 3D free surface, it was found that the same situation happens at the edges of the surface (figure 3). The edge of the surface can be considered a free curve of 2D laser forming so that appropriate forming points can be achieved. Subsequently, a combination of flat patches is made by connecting those forming points across the surface.

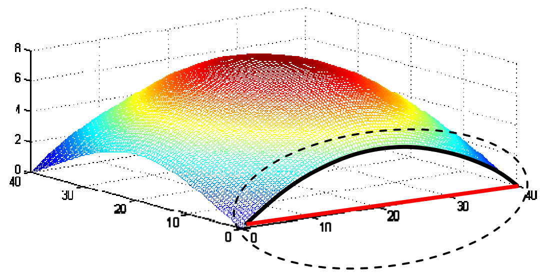
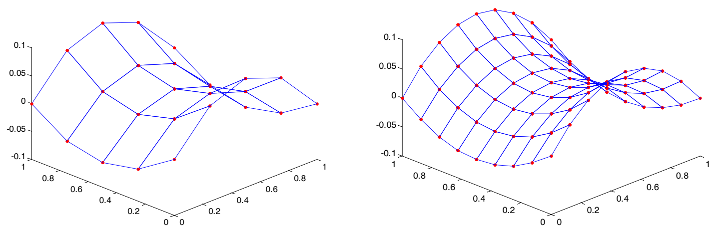


Fig.3. Applying geometrical approaches to 3D laser forming

Figure 4 shows the results of making plane patches with a saddle shape. As the number of plane patches increases, the overall shapes of the plane patches approach the original target shapes. Ideally, the shape error can be reduced to a desired level if the plane patch making procedure is repeatedly applied to the surface.



(a) (b)

Fig.4. Results of making plane patches with a saddle shape
(a) 16 patches (b) 64 patches

2.2 Planar development with plane patches

In this study, a method with imaginary springs was used for planar development. For the initial state of the plane patches for the planar development procedure, each patch is not overlapped with each other and the relative position to be maintained during planar development procedure is defined at the initial state. And for the next step, as seen in figure 5, every corner of each plane patch is connected by imaginary springs with neighbour corner points. These imaginary springs have zero initial length and no damping characteristic. The resultant force and torque are then calculated at one plane patch. If the patch is allowed to make a slight rigid body motion with other patches fixed, the position of the patch will be similar to the right one of figure 5. These steps can be applied to every patch iteratively, and the final optimized minimum energy state can be achieved with sufficient iterations. As long as the patches are not overlapped and their relative positions don’t change, the changes in initial position of each plane patch doesn’t bring a different outcome from the procedure. If some patch is located farther from neighbour patches, then the spring force of the patch is greater and, therefore, the patch moves faster to the neighbour patches.

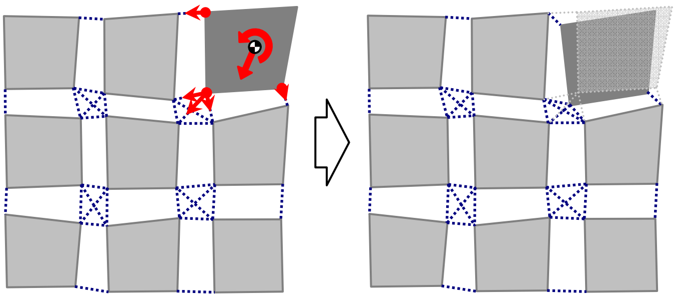


Fig.5. Iterative movement of plane patches by an imaginary spring model

2.3 FEM database map

The lines for laser irradiation are achieved at the step of making plane patches. The forming data such as the initial specimen shape, and the bending and shrinkage data along the forming lines can be obtained after the step of planar development. Thus, where to irradiate the laser and the amount of bending and shrinkage at every point of irradiation can be determined, as shown in figure 6. The third step is to match the process parameters to the bending and shrinkage data. The most important controllable parameters in laser forming process are the laser power and the travel speed. Thus, FEM is used to obtain the data map.

3. Experiments

The experiments were conducted using a 100W CW Ytterbium fibre laser on mild steel with carbon coating. The size of the specimen was 30mm×30mm×0.8mm. The laser beam diameter was 2mm and the workpiece was moved by a 3-axis Cartesian motion system with 10μm resolution.

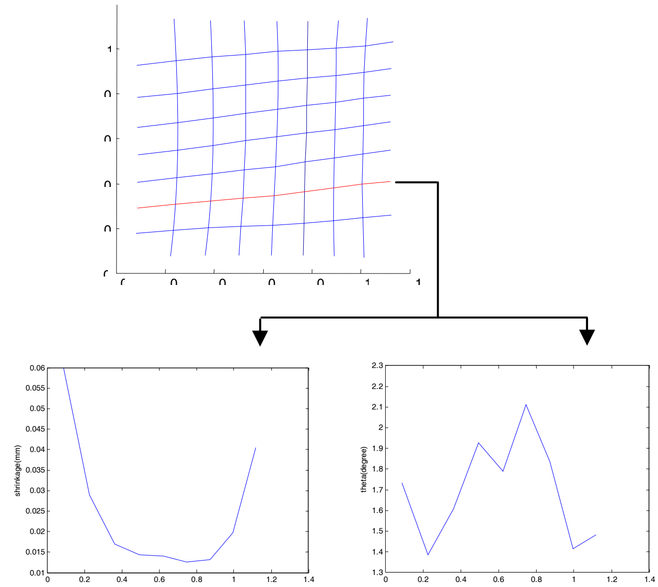
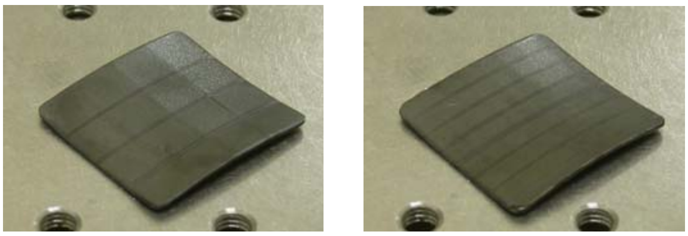
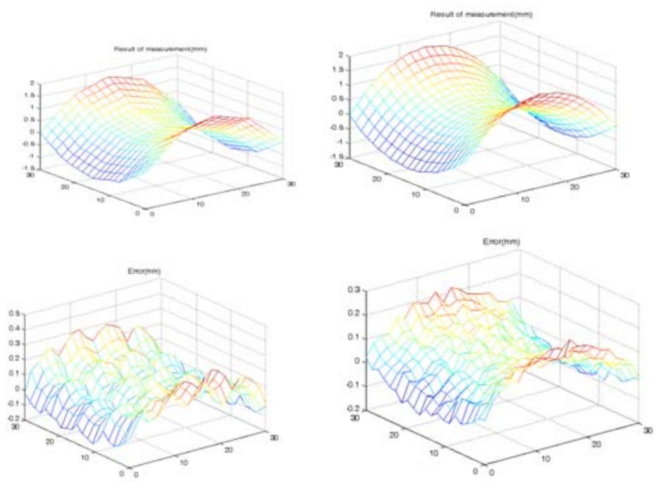


Fig.6. Bending and shrinkage data along a specific forming line



(a) (b)

Fig.7. Experimental result of saddle shape (a) 16 patches (b) 64 patches



(a) (b)

Fig.8. Result of measurement with saddle shape (a) 16 patches (b) 64 patches

Figure 7 shows the experimental results for the

saddle shape. The measurements were conducted by a coordinate measuring machine, figure 8.
The maximum errors of the laser formed saddle shape with 16 patches and 64 patches are 0.380mm and 0.223mm respectively. Although the overall shapes were very similar to the intended target shapes, shape errors are inevitable because of the fact that formed shapes are a combination of plane patches. However, the maximum error with 64 patches is almost half that obtained with 16 patches. Hence, with a sufficient number of patches, the error can be controlled to a desired level.

4. Conclusions

A new method for 3-dimensional laser forming was proposed. This method does not require a complex stress-strain analysis and uses only geometrical information. The free surface is first decomposed into a combination of plane patches and the forming data such as laser irradiation lines, bending angles, and shrinkage data along the forming lines are calculated. Process parameters are then matched to the forming data by using FEM data maps. With this method, the calculation time is reduced significantly compared to the stress-strain analysis method and it is very easy to control the error bound by changing the number of patches. In order to verify the algorithm, a saddle shape was formed with different patch numbers.

ACKNOWLEGEMENT

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REFERENCES

1. Edwardson SP, Watkins KG, Dearden G, Magee J. 3D laser forming of saddle shapes; Proceedings of Laser Assisted Net Shaping; 2001; 559-568
2. Edwardson SP, Moore AJ, Abed E, McBride R, French P, Hand DP, Dearden G, Jones JDC, Watkins KG. Iterative 3D laser forming of continuous surfaces. Proceedings of the 23rd ICALEO; 2004; 36-45
3. Hutterer A, Hagenah H. Correcting non circular dents by means of laser beam forming; Proceedings of Laser Assisted Net Shaping; 2004; 1071-1081
4. Bartkowiak K, Dearden G, Edwardson SP, Watins KG. Development of 2D and 3D laser forming strategies for thin section materials using scanning optics. Proceedings of the 23rd ICALEO; 2004; 68-77
5. Liu C, Yao YL. Optimal process planning for laser forming of doubly curved shapes. Journal of Manufacturing Science and Engineering; 2004; 126; 1-9
6. Kim JT, Na SJ. Development of irradiation strategies for free curve laser forming. Optics and Laser Technology; 2003; 35; 605-611