DEVELOPMENT AND REPAIR OF LAMINATE TOOLS BY JOINING PROCESS

by Suk-Hwan Yoon[1*] and Suck-Joo Na[1]

[1]Department of Mechanical Engineering, KAIST,

Kusong-dong 373-1, Yusong-gu, Daejon, 305-701, Korea, jugend@kaist.ac.kr

ABSTRACT

Laminate tooling process is a fast and simple method to make metal tools directly for various molding processes such as injection molding in rapid prototyping field. Metal sheets are usually cut, stacked, aligned and joined with brazing or soldering. Through the joining process, all of the metal sheet layers should be rigidly joined. When joining process parameters are not appropriate, there would be defects in the layers. Among various types of defects, non-bonded gaps of the tool surface are of great importance, because they directly affect the surface quality and dimensional accuracy of the final products. If a laminate tool with defects has to be abandoned, it could lead to great loss of time and cost. Therefore a repair method for non-bonded gaps of the surface is essential and has important meaning for rapid prototyping.

In this study, a rapid laminate tooling system composed of a CO_2 laser, a furnace, and a milling machine was developed. Metal sheets were joined by furnace brazing, dip soldering and adhesive bonding. Joined laminate tools were machined by a high-speed milling machine to improve surface quality. Also, repair brazing and soldering methods of the laminates using the CO_2 laser system have been investigated. In laser repair process, the beam duration, beam power and beam profile were of great importance, and their effects were simulated by finite element methods. The simulation results were compared with the experimental ones, and optimal parameters for laser repair process were investigated.

KEYWORDS

Rapid prototyping, Laminate tooling, Brazing, Soldering, Adhesive bonding

1. Introduction

Rapid prototyping is a method of making prototypes from the modeling data of products. The method usually consists of three-dimensional modeling, slicing, stacking and final machining, if necessary. Nowadays, rapid prototyping has been continuously modified to reduce building costs and time, thus enabling rapid manufacturing. Rapid manufacturing is a process of making real products with various shape-building techniques. Among various rapid manufacturing techniques, rapid laminate tooling is a fast and effective technique of making metal tools for various molding processes. That is, with the metallic tools developed by rapid laminate tooling process, large number of prototypes or even real products can be produced by suitable molding processes. According to the metals used in rapid tooling, various materials such as polymers and metals can be used in molding process. Hence, rapid laminate tooling is capable of producing both metallic and nonmetallic products [1-6].

In this study the dip soldering process was selected for a new joining method of steel laminates in addition to furnace brazing process. Steel laminated tools by furnace brazing have relatively high strength both at low and high temperature ranges; thus, they can be utilized at high temperatures and in high pressure molding processes like injection molding. Laminated tools by dip soldering have lower strength and working temperature range, and hence they are not suitable for high temperature and high pressure molding processes. Instead, they are appropriate for low temperature molding processes like reaction injection molding (RIM). Also, dip soldering has advantages in that it is a simple, fast and cost effective process. Therefore brazing and soldering were performed simultaneously for their own applications.

Also, repair methods of steel laminates by laser brazing and laser soldering were developed. When joining of steel laminates by furnace brazing or dip soldering, defects like voids can be generated under unstable environments. Voids exposed in the die surface causes several problems; they deteriorate surface roughness, dimensional accuracy and cause mold ejecting problems. In this study, a laser system and filler metals that have lower melting points were used to eliminate the surface voids by filling them with molten metals.

2. System Development

The sequence of the laminated tooling using steel sheets is as follows. Steel sheets of 1mm thickness are cut by the laser cutting process. The cut steel plates are stacked, aligned and joined using brazing or soldering. Finally, the surface of laminates is machined using a high-speed milling machine.

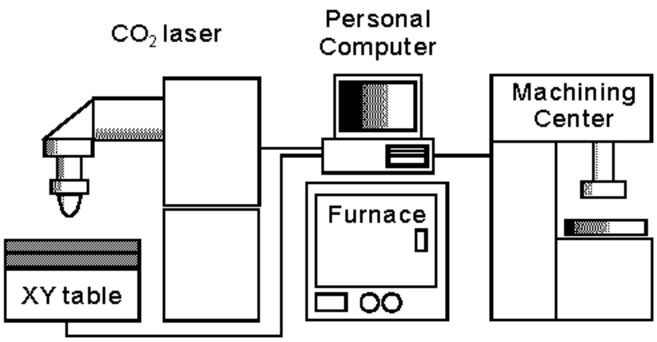
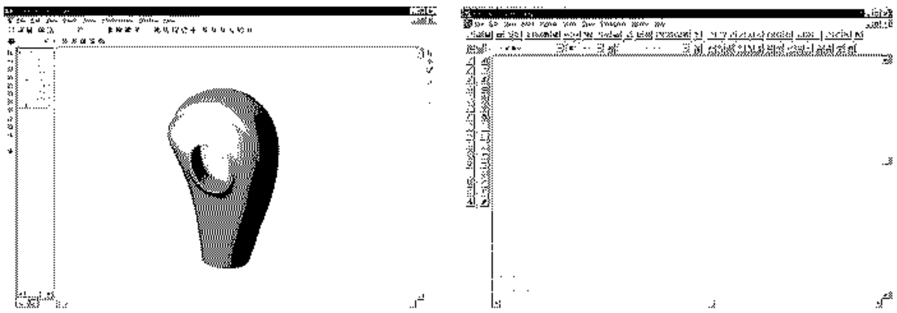


Fig.1 Overall system architecture

The overall system for laminated tooling is shown in Figure 1. The system is composed of a CO_2 laser, a furnace, and a high-speed machining center. The CO_2 laser is for laser cutting and has a continuous beam mode and circular polarized beam of 700W maximum power. An XY table and a personal computer were installed in the laser cutting system to enable numerical control of the laser cutting. An electric furnace was used for furnace brazing and the dip soldering process. For dip soldering in the furnace, a soldering pot was made from stainless steel and was placed in the furnace. For machining of steel laminates, a 5-axis machining center was used.

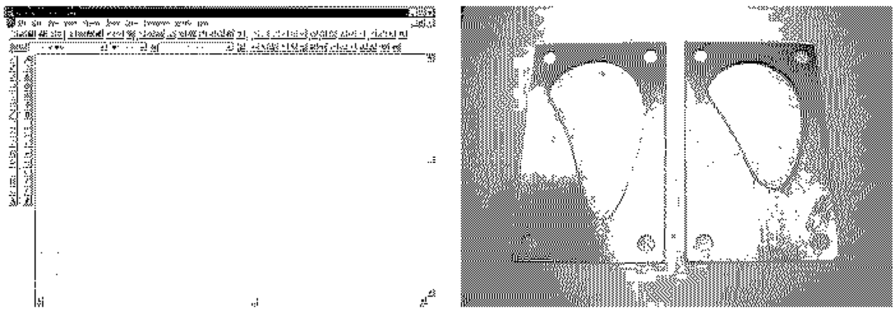
3. Building of Laminates

The process begins with the information of a desired product. From the information, the product's three-dimensional shape is modeled by computer using CAD software. Stacking direction and layer thickness are then selected and the slicing process is conducted according to these selections. A slicing process is a process in which a three-dimensional model is sliced into many two-dimensional contours. Each contour defines the shape of each layer, so laser cutting should be done according to the contour. To automate this process, a program was developed to convert two-dimensional contours into NC input files for laser cutting. With the input files, steel sheets are cut by the CO_2 laser, and the cut sheets are stacked and joined by brazing or soldering. Finally, the surfaces of the steel laminates are machined to achieve better accuracy and surface roughness. Inspection is also required after the joining and machining processes.



(a) 3D Model (b) Sliced contour

Fig.2 3D modeling and slicing process



(a) Modified contour (b) Laser cut steel sheets

Fig.3 Modification of 2D contours and laser cut sheet metals

Figure 2 shows a three-dimensional model of an automatic shift gear knob part and its slicing and cutting results. A three-dimensional model of the part is shown in Figure 2(a), and one of the two-dimensional contours achieved by slicing is shown in Figure 2(b). The desired object to build is not the part itself, but rather a tool to produce the part. Therefore, to build a tool from the slicing data of the part, some modifications are inevitable. Figure 3(a) shows a modified contour to build a tool. The original contour forms an inner cavity curve, and a rectangular contour is added to define the outer shape of the tool. Four circular contours are also added to define holes for alignment of the steel sheets when stacking.

From the modified slicing results, NC input files for laser cutting are generated. For a reduction of the total building time, this process was assisted by a computer program. The program was written in C language, and was designed to get process parameters such as cutting speed, laser power and flow rate of oxygen gas from the operator, and to generate NC input files from the two-dimensional CAD files. With these NC input files steel sheets are cut by the CO_2 laser system. Steel sheets cut by the laser are shown in Figure 3(b).

From basic joining experiments, appropriate joining parameters were selected. Figure 4 shows the stacked, joined and machined steel laminates. Figure 4(a) shows a pair of steel laminates after dip soldering and machining. The soldering temperature was 270°C and soldering time was 60 seconds. Figure 4(b) shows a pair of steel laminates after furnace brazing and machining. The brazing temperature was 800°C and brazing time was 40 minutes. Figure 4(c) shows steel laminates after adhesive bonding and machining. Epoxy film was used for bonding, and the bonding temperature was 150°C.

(a) Dip soldered (b) Furnace brazed (c) Adhesive bonded

Fig.4 Joined and machined die tools

4. Repair of Laminates

The laser repair joining method of steel laminated tools is schematically shown in Figure 5. After furnace brazing or dip soldering of laminates, inspection is conducted for voids exposed in the surface. The void is prepared and cleaned in appropriate ways such as mechanical grinding, acid pickling and rinsing with water. A laser beam is irradiated into the void, thus enabling temperature to increase in that area. When the void is heated sufficiently, filler metal wire and flux is automatically fed into the void under laser irradiation. The flux fed into the heated area immediately melts and becomes activated due to the high temperature. By the action of molten flux, oxide films on the base metal surface are removed.

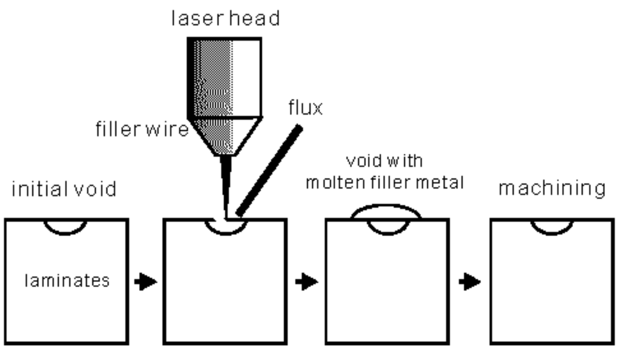
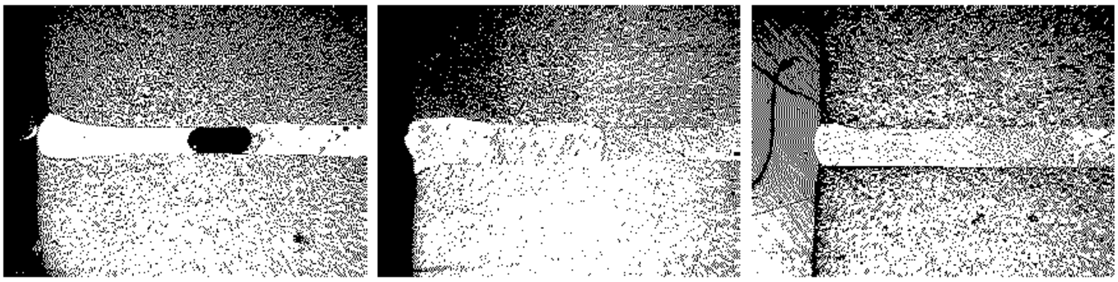


Fig.5 Method of die-repair joining with laser beam and filler metal wires

Filler metal wire is fed into the void, and heated over the melting temperature by laser irradiation. This molten filler metal completely fills the void by gravity force and capillary force. Suitable filler metals were chosen to minimize thermal effects and to prevent remelting of previously joined laminates.

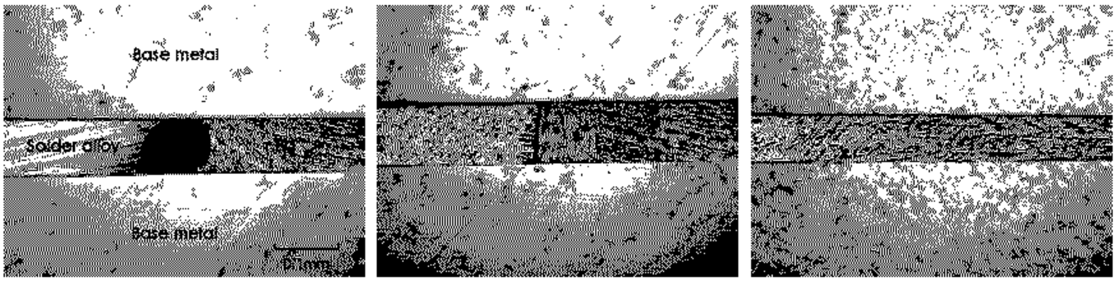
To perform the repair experiments, a pair of low carbon steel sheets were lapped together and brazing/soldering filler metal were applied between the gap. The size of base metal was 20×20×1mm. A small void was intentionally created in the gap at one side by applying flux-stopoffs before furnace brazing or dip soldering at that area. A half-circular void with about 3mm radius was created.

The width of the gap was maintained at about 0.1mm by gap gauges. Furnace brazing was done in a brazing furnace with argon atmosphere to prevent oxydizing. After furnace brazing, laser repair brazing was conducted. The repair brazed specimen was cut, grinded and polished in order to observe the cross-section with a microscope. On the other hand, dip soldering was done in a soldering bath with molten lead. After dip soldering, laser repair soldering was conducted.



(a) 300W, 5 seconds (b) 340W, 5 seconds (c) 380W, 5 seconds

Fig.6 Results of laser repair brazing for various amounts of laser heat input



(a) 210W, 5 seconds (b) 230W, 5 seconds (c) 250W, 5 seconds

Fig.7 Results of laser repair soldering for various amounts of laser heat input

Figure 6 and Figure 7 show some laser repair brazed and soldered results respectively, with respect to laser beam power. As in the figures, the repair results were closely related to the amount of heat input.

In both brazing and soldering results, incomplete filling occurred under small heat input. It is thought that due to the relatively small amount of heat input, the depths of the gap did not reach a high enough temperature to make the filler metal flow on. Good filling results appeared under suitable heat input conditions. Too much heat input resulted in the melting of preceding filler metals, thus mixing of two filler metals occurred.

The developed laser repair joining system can be alternatively utilized in laminated tooling for removal of side-steps. Suitable amounts of molten filler metal can be deposited by laser brazing or laser soldering process. Figure 8 shows the deposited results with laser brazing. As in the results, various shapes could be acquired by controlling the amount of molten filler metal. With this feature, time and cost for machining process could be minimized.

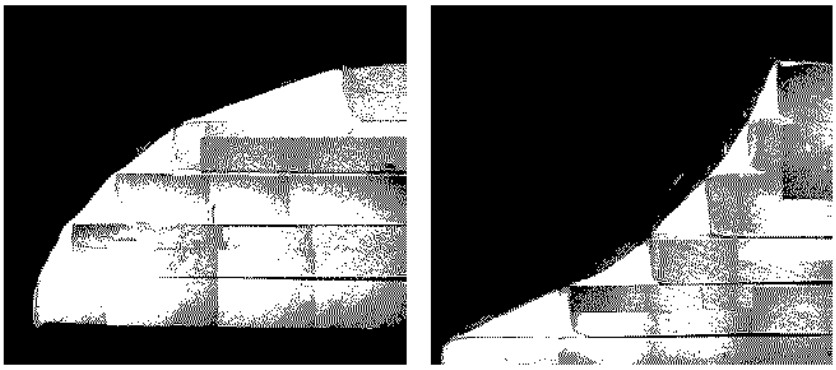


Fig.8 Various shapes acquired by deposition of molten filler metal with laser brazing

CONCLUSIONS

A rapid laminated tooling system with a CO_2 laser, a furnace, and a machining center was developed. As joining methods of steel laminates, the dip soldering and the adhesive bonding were selected for new joining methods in addition to furnace brazing process. Dip soldered or adhesive bonded steel laminates were appropriate for low temperature molding processes like reaction injection molding.

Also, repair methods of steel laminates by laser brazing or laser soldering were developed and investigated. By basic experiments, surface voids between steel plates were filled with molten filler metals by laser brazing or laser soldering process. The experimental results showed that the repair results were closely related to the amount of laser heat input

ACKNOWLEDGEMENTS

The authors would like to thank the Korea Institute of Science and Technology Evaluation and Planning, for the financial support by a grant from the Critical Technology 21 Project.

REFERENCES

[1]. Park J, Tari M J and Hahn H T 2000. Characterization of the laminated object manufacturing process, Rapid Prototyping Journal 6(1), 36-49.

[2]. Kulkarni P, Marsan A and Dutta D 2000. A review of process planning techniques in layered manufacturing, Rapid Prototyping Journal 6(1), 18-35.

[3]. Karapatis N P, Griethuysen, J-P S and Glardon R 1998. Direct rapid tooling: a review of current research, Rapid Prototyping Journal 4(2), 77-89.

[4]. Obikawa T, Yoshino M and Shinozuka J 1999. Steel sheet lamination for rapid manufacturing, Journal of Materials Processing Technology 89-90, 171-176.

[5]. Bryden B G and Pashby I R 1999. Sequential laminated tooling, joined by brazing, for injection moulding, Rapid Prototyping Journal 5(2), 89-93

[6]. Adams C, Bryden B G and Wimpenny D 1999. Rapid laminated tooling, Rapid Prototyping & Manufacturing'99 Conference Illinois 647-657