Journal for Technology of Plasticity, Vol. 28 (2003), Number 1-2

NEW DEVELOPMENTS IN METAL LAMINATED TOOING

Thomas Himmer, Anja Techel*, Steffen Nowotny*, Eckhard Beyer*,***

**Fraunhofer IWS, Dresden, Germany*
***University of Technology at Dresden, Germany*

ABSTRACT

Time reduction and quick geometrical changes of complex components and tools are currently the most important demands in product development. The manufacturing process presented in this paper is based on multiple additive and subtractive technologies such as laser cutting, laser welding, direct laser metal deposition and CNC milling. The process chain is similar to layer-based Rapid Prototyping Techniques. In the first step, the 3D CAD geometry is sliced into layers by a specially developed software. These slices are cut by high speed laser cutting and then joined together. In this way laminated tools or parts are built. To improve surface quality and to increase wear resistance a CNC machining center is used. The system consists of a CNC milling machine, in which a 3 kW Nd:YAG laser, a coaxial powder nozzle and a digitizing system are integrated.

***Key words**: Rapid Tooling, Laminated Tooling, Laser Cutting, Laser Build-Up Welding, Laser Cladding*

1. INTRODUCTION

Research and development in the field of metal sheet lamination technology has been done since the early 80's by Professor Nakagawa [1]. As a result of the accumulated know-how, it was decided to use a metal sheet lamination technology for Rapid Tooling of large car body parts [2]. For this purpose the Toyota group has launched a project to develop an automated process for the manufacturing of forming tools [3], [4]. The main objective is time- and thus cost reduction because the actual manufacturing of forming tools is a time consuming process [5].
Development and improvement of new process chains for manufacturing of large tools, is the purpose of the research at the Fraunhofer Institute for Material and Beam Technology (Fraunhofer IWS). Different technologies for cutting, assembling and joining of metal sheets by the LOM principle are used with regard to reduce the manufacturing time of large tools. This article describes the manufacturing of forming tools using the so called MELATO (Metal Laminated Tooling) -process chains.

Firstly, three-dimensional CAD data is modified, sliced and distributed across a sheet panel. The cross-sections are cut out by laser beam and are, subsequently, joined by form-closed and force-closed assembly. Strength and life of tools may be additionally improved, for example, by the finishing of critical edges by laser deposition welding. The use of various laser-based methods, such as cutting, welding and deposition welding, will ensure high flexibility of the manufacturing process and convenient geometric modifiability of tools.

2. DATA PREPARATION

2.1. CAD MODIFICATIONS

Three dimensional CAD data of the tool to be manufactured are read into the CAD system, using usual interface formats (VDA, IGES, STL), figure 1.

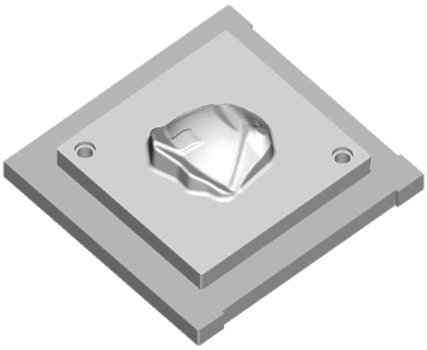

Figure 1: 3D CAD design of a punch

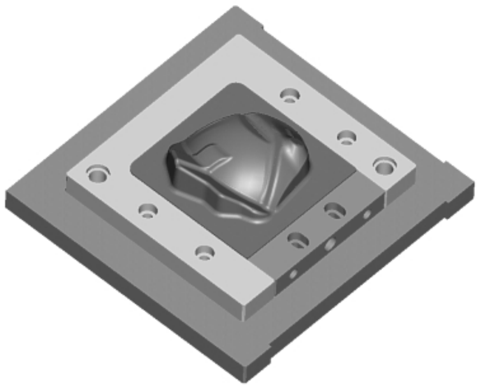

Figure 2: 3D CAD modifications

For the special MELATO-application, the tool is modified in the following way. It can be seen on figure 2, the contour geometry (middle part) is separated from the tool frame. This tool insert will be manufactured by metal sheet lamination. All other sections are conventionally made. These tool elements contain no complex shaped surfaces, thus they are easy to manufacture and they can be used as universal tool frame.

Subsequently, the tool insert is sliced into single cross sections, which is demonstrated in figure 3. The software allows to choose any slice direction. In addition, the layer thickness which must be determined before is set, considering metal sheet tolerances or shrinkage of adhesives.

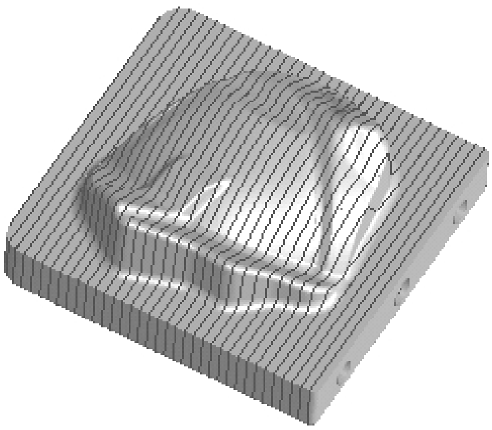

Figure 3: Sliced tool insert

After slicing, the single cross sections are arranged on a metal sheet panel. The CAM software was improved with respect to MELATO-purposes:
The size of the panel can be set and the distance of the sections to each other, offset functions for laser cutting, marking/numbering of layers and special tools for avoiding distortions, which may be arisen by laser welding.

2.2. ADAPTIVE SLICING

For the manufacturing of the die, represented in figure 4, several improvements have been done. Adaptive slicing and different joining techniques were introduced.
Figure 4 depicts, that the entire tool or other construction units can be divided into single modules according to the surface topology. The topology determines then the most favorable slice-direction, which can be seen on figure 5.

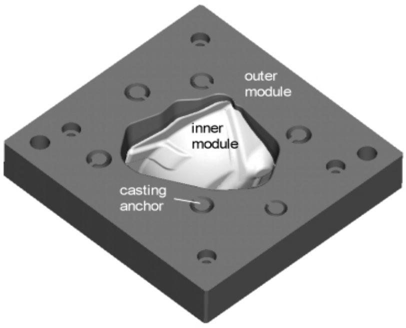

Figure 4: Modular design of the die

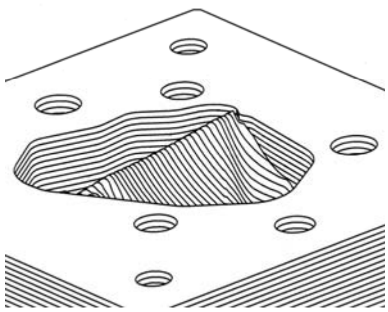

Figure 5: Die sliced in 2 dire-ctions

The metal sheets can be connected by screws or by so- called casting anchors. A conic shape of the anchors prevents delamination. Low melting alloys or casting resins are thinkable materials.
Advantages of this approach are:
The finish expenditure is minimized or even completely avoided, if combined with 3D-laser cutting or 5 axes-milling [6]. The processing conditions for a possible milling rework improve particularly for the lamination technology.
The build-up of the tools can take place in steps. Thus surfaces can be finished by milling after some developed layers, in order to eliminate for example the stair structure or increase the accuracy. A short cantilever length is possible, which reduces tool vibrations. This leads to higher accuracy.
Rough machining is avoided because of the adapted slicing direction and the contour can be directly finished by High Speed Cutting (HSC).
By the use of screws or remeltalbe anchors elements (low melting alloys) the components can be completely or partially detached and assembled again. If the sheets are bolted or connected with cold or low melting casting materials, no heat is applied to the part. Thus stress and distortions are avoided.
Geometry changes in the product development process can be quickly realized by the replacement of the appropriate layers. Completely new creating of the tool is not necessary, which means the tools are easily modifiable. Adding volume is possible without additional procedures. In addition,

screw connections are easily to design and inexpensive. However, the spectrum of use for this joining technology is limited.

3. BUILDING PROCESS

3.1. LASER CUTTING

The next process step is the generation of the cross sections by high speed laser cutting. To ensure high accuracy in the slicing direction, the cut must be free of burs.
For laser beam cutting, a focused laser beam (CO_2) is moved over the work piece, evaporating or melting all material in the focal point due to the high local energy density. A coaxial to the laser beam-fed, cutting gas beam drives out the molten material or vapor, resulting in a bur-free and rectangular cutting groove [7].

3.2. JOINING

The key technology for MELATO is the joining method. Several technologies might be considered, however the usage of the tool determines the bonding type. Injection molding and pressure die casting require the strong bonding of the entire cross section surface, since the mechanical and thermal load during injection is very high.
Figure 6 shows the die connected by screws and casting anchors. Furthermore, the gaps between inner and outer module is filled with a low melting alloy. If this alloy expands during solidification, the connection will be much stronger. On the other hand, shrinkage behavior of the anchor casting material will pull the layers together.

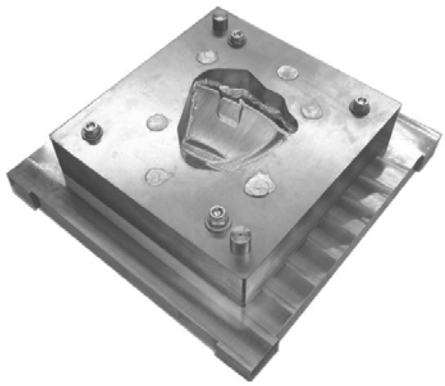

Figure 6: Joining using cast anchors and screws

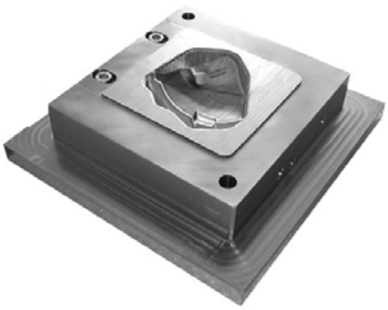

Figure 7: Assembled die

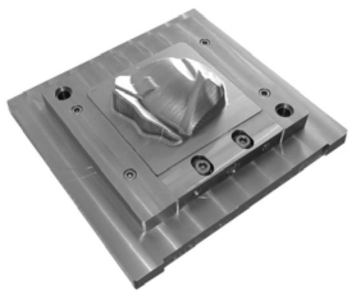

Figure 8: Assembled punch

Bonding by adhesives should also be taken into account. However, the slice thickness tolerance introduced by the glue must be compensated and all sheets must be carefully cleaned to enable high strength [8]. Post treatment such as hardening or tool repair by laser cladding is not possible.

According to the manufacturing concept described in chapter 2, figure 7 and figure 8 show the laminated inserts assembled and clamped in the tool frame by a pressure plate and threaded bolts. Additionally, the lamellae were bonded by adhesive.

4. POST PROCESS

4.1. LASER BUILD-UP WELDING

For reinforcement of heavily loaded sections, e.g. draw edges of forming tools, laser build-up welding is applied. This welding technique is also considered for the connection of lamellae. Initial experiments have shown promising results, given with figure 9.

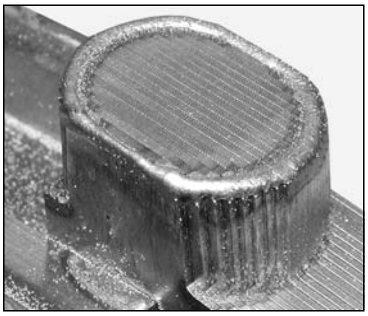

Figure 9: Reinforcement by laser build-up welding

For build-up welding the beam of a 3 kW Nd:YAG laser is integrated into the milling center. The focusing optic, combined with the coaxial cladding unit, is mounted at the Z-axis of the machine, figure. 10. The coaxial nozzle is an advanced version with reduced size and variable nozzle tips for a better adaptation to the given application and for easier maintenance. The system will be improved further with respect to 5-Axes applications and free form surfaces, which means a reduced size for better access of narrow sections.

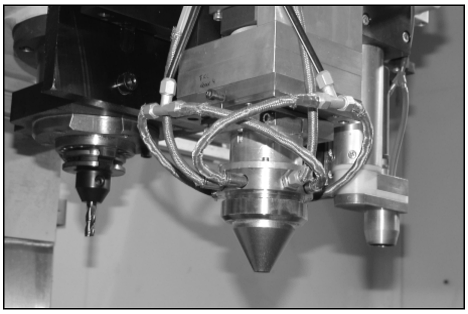

Figure 10: Laser integrated CNC milling center; left: cutter, middle: cladding head, right: plasma welding head

The diameter of the powder focus lies between 1 and 2 mm, depending on the powder type and the powder feed rate. The powder efficiency amounts at least 60 % if the melt bath diameter is not less than 1.5 mm. Powder feed rates from 1 to 50 g/min are possible (e.g. Ni base alloys). The new nozzle type is designed for a minimum focal length of 70 mm, this is especially interesting for diode laser cladding applications.

In addition, 3D structures of Ni and Co base alloys as well as steel can be produced with this equipment. Using a sealed inert gas chamber, also Ti, Al, and Cu alloys are possible. The generated structures are completely dense and flawless, even without intermediate machining. The accuracy depends on the powder and the process parameters. Typically it lies in the range of 0.3 to 0.6 mm.

4.2. GEOMETRY MODIFICATIONS AND TOOL REPAIR

Common laser techniques of repair include the process steps, 1. import of 3D data or digitizing the damaged area, 2. data processing, 3. CNC programming, 4. material build-up and 5. finish machining. Usually, these manufacturing sections are sequentially carried out on different machines. The consequence is an increased effort of transportation and adjustment of the workpiece as well as of CNC programming. Especially for the remanufacturing of parts, time and costs of programming and adjustment often exceed the effort of the actual material replacement. Thus, the economy of the whole process is affected and some potential laser applications in this field cannot be realized because of financial reasons [9]. To solve this problem, all necessary hard- and software were integrated into a CNC milling center. Specially developed software connects laser, machine tool, and additional components, so that the whole machining process takes consequently place in one machine and in one clamping of the workpiece.

5.3 CNC-Milling

The basis of the integrated solution is a 3 axes CNC milling center. The maximum spindle speed is 10,000 rpm. To assemble all process steps and to connect all components, the CNC controller has got interfaces to two lasers (Nd:YAG and diode), 2 powder feeding lines, and to the CAM system. Additionally the machine is equipped with an interface to a plasma build-up welding system (PTA). This can be used for a laser/plasma combination to increase efficiency and productivity when larger volumes should be build up.

At the beginning of this year, a 5 axes CNC machining center has been installed at the IWS. Each laser technology mentioned above will be integrated in the 5 axes machine. This system will allow to machine complex surfaces. The tools, which could be milling cutters or powder nozzles are moved in X,Y, and Z direction. The work piece is rotated in A- and C-axis, which is very important for a reliable process.

Advanced 5 axes programming software includes several functions for an efficient NC data preparation, for example collision control for tool and adapter, machine simulation, strategies for cutting and building, post processor editor and tool editor in order to define, modify and select several tools, such as cutting tools or powder nozzles. Regarding to such issues, several software systems have been tested.

5. SUMMARY

The investigation on laminated tooling has shown that this technology has a high potential for time and cost reduction in the product development. With an efficient process chain, laminated tools can be fabricated and modified in a time a cost effective manner. The savings will grow with the part size. Although the manufactured tool has the size of 430 mm x 430 mm, the obtained results can be applied for large tools as well. Further investigation are focused on the bonding technology, the accuracy, the introduction of new materials and improvements concerning manufacturing time and costs.

Additional information can be found for

Metal Laminated Tooling: www.iws.fhg.de/~melato/

Laser Build-Up Welding: www.iws.fhg.de/projekte/051/e_pro051.html

6. ACKNOWLEDGEMENTS

This research and development project is founded by the German Federal Ministry of Education and Research (BMBF) within the framework concept "research for the production of tomorrow" and cared by the agency “Production and Production Technologies” (PFT) at the Forschungszentrum Karlsruhe.

7. REFERENCES

[1] T. Nakagawa, K. Suzuki: "A low cost blanking tool with bainite steel sheet laminated", Proceedings of 21. International MTDR Conference, 1980

[2] T. Nakagawa, M. Kunieda: "Manufacturing of Laminated Deep Drawing Dies by Laser Beam Cutting", Advanced Technology of Plasticity, 1984, vol. 1

[3] T. Nakagawa: "Recent Developments in Auto Body Panel Forming Technology", Annals of the CIRP vol. 42/ 2/ 1993

[4] T. Himmer, T. Nakagawa, N. Mohri: "Rapid Die Manufacturing System", Proceedings of the 7th European Conference on Rapid Prototyping and Manufacturing, 1998

[5] P. Dickens, D. Simon, R. Sketch: "Laminated Tooling for Moulding Polyurethane Parts", Proceedings of the SME Conference - Rapid Prototyping and Manufacturing, 1996

[6] D.F. Walczyk, D.E. Hardt: "Recent Developments in Profiled-Edge Lamination Dies for Sheet Metal Forming", Proceedings of the Solid Freeform Fabrication Symposium, 1996

[7] L. Morgenthal, E. Pfeiffer, E. Beyer: "Laser contour cutting of transformer sheet segments", Laser Opto, vol. 31, April 1999

[8] J. Dietrich, T. Himmer, K. Krüger, J. Stiller: „Vergleichende Untersuchung zur schnellen Fertigung von Umformwerkzeugen für Prototypen (Rapid Die Making)", Tagungsband 6. Sächsische Fachtagung Umformtechnik, Dresden, 1999

[9] St. Nowotny, S. Scharek, T. Naumann, R. Gnann, Eckhard Beyer: "Integrated Laser Milling Center for Complete Machining", The International Congress on Applications of Lasers and Electro-Optics, 2001

NOVI REZULTATI U RAZVOJU LAMELIRANIH METALNIH ALATA

Thomas Himmer, Anja Techel, Steffen Nowotny, Eckhard Beyer

REZIME

Skraćenje vremena razvoja i izrade alata jedan je od osnovnih zadataka u okviru razvoja novog proizvoda. U ovom radu prikazani su procesi brze izrade alata na bazi višestrukog aditivnog i substraktivnog postupka, kao što su: lasersko sečenje, lasersko zagrevanje, direktna laserska depozicija i CNC glodanje.

Istraživanje i razvoj na planu lameliranih metalnih alata počeo je 80-tih godina (Nakagawa [1]). Jedna od prvih industrijskih primena ovog principa bila je izrada alata za otpresak karoserije automobila. Alat je bio izrađen metodom Rapid Tooling-a.

Na Franhofer Institutu u Drezdenu vrše se intenzivna istraživanja i razvoj na polju proizvodnih lanaca u izradi alata velikih dimenzija. U okviru ovog rada data je analiza procesa izrade alata za deformisanje metodom MELATO (Metal Laminated Tooling). Kao prvi korak u procesu, kreira se 3D CAD podaci a zatim se vrši podela takvog modela u horizontalne slojeve. Pomoću lasera se isecaju iz lima dati slojevi, koji se zatim na odgovarajući način spajaju, čineći alat za deformisanje.

U radu su detaljno opisani svi neophodni koraci za izradu lameliranih metalnih alata (modifikacija 3D CAD modela, adaptivni način delenja modela u tanke slojeve, sečenja konture sloja laserom, spajanje pojedinih isečenih limova u jednu celinu – alat).

Svaki od navedenih koraka direktno utiče na kvalitet izrađenog alata. Na bazi izloženog autori zaključuju da tehnologija izrade alata metodom lameliranja ima visok potencijal primene jer se njom znatno skraćuje vreme i snižavaju troškovi izrade. Ova metoda može biti veoma efikasno integrisana u procesni lanac proizvodnje novog proizvoda. Uštede rastu sa veličinom radnog komada. U radu je analiziran alat koji je izrađen na Franhofer Institutu (430 mm x 430 mm) ali i znatno veći alati mogu se na ovaj način izraditi.

Dalja istraživanja na ovom planu usmerena su na optimizaciju metode spajanja pojedinih lamela, tačnost, primenu novih materijala i još veće skraćenje vremena izrade alata primenom Rapid Tooling tehnologije.