



RAPID PROTOTYPING OF 3D COMPOSITE STRUCTURES USING LAYER BY LAYER METHOD

Dragan Cvetković¹, Duško Radaković², Zora Kostić¹, Dragan Marković¹

¹Singidunum University, Serbia

²College of Professional Studies – Belgrade Polytechnics, Serbia

Abstract:

Current methods for rapid prototyping of composite products, applied by a computer during manufacturing, allow for materializing even the most complex 3D objects created in a CAD application in a very short time and without any subsequent processing. After determining the validity of a designed prototype, it can be physically implemented using standard methods or tools for plastic injection molding. This paper presents application of commercial CAD programming packages in modelling 3D objects for rapid implementation of composite prototypes using layer-by-layer method. This specific method, in which the shape of the product is built by adding, instead of separation or deformation of materials, offers a number of advantages over other similar methods. Amongst the most prominent ones are producing parts directly from a file, reduced processing and operation planning time, process implementation without the use of tools, reduced production cost, increased product quality, improved design, faster audit and product review. This method slowly gives way to the process of 3D printing, which, according to some indicators, being current job in the next 20 years.

Key words:

rapid prototyping,
CAD,
CAD/CAM,
3D printing.

INTRODUCTION

State of the art methods for rapid prototyping of composite products that utilize computers in manufacturing enable fast materialization of complex 3D objects, created in various CAD packages, without the need for post-processing. After validating the resulting prototype, it is possible to yield casting or molding tools for plastics processing by using standard methods. Features of methods in which the shape of a product is obtained by adding, and not by subtracting or deformation of materials, are as follows:

- ◆ The need for drawings is reduced, i.e. the part is made directly from 3d model file, from computer;
- ◆ Processing and operations planning time is reduced to minimum;
- ◆ No need for assembling, positioning and clamping of tools;
- ◆ Process is performed without tools;
- ◆ No need for making molds;
- ◆ Manufacturing costs are reduced;
- ◆ Product quality is increased;
- ◆ Product revision and inspection is faster;
- ◆ Improves designing; etc.

WHY AUTOCAD?

Makers of AutoCAD have organized work in this package in order to satisfy needs of most users. This organization of work required more effort from users to undergo training for using such a package. This disadvantage was solved by the fact that AutoCAD can be adapted to user needs. This has enabled development of modules necessary for adapting the package to customer needs.

Certain advantages are achieved by elaborating the system of automatic drawing production. Most important are:

- ◆ Work time reduction;
- ◆ Designer overload reduction;
- ◆ Work comfort is enhanced;
- ◆ Document quality is improved;
- ◆ Segment designing costs are reduced;
- ◆ Complete system design costs are reduced;
- ◆ Costs for complete work unification in a single project are reduced.

Prepared in this way, the quality of a unique project is surely at a higher level than if it were prepared “manually”.



PRODUCING THE MODEL

One of the methods for rapid prototyping is based on section profiles of a certain thickness. These profiles are obtained by cross sectioning the 3D model within the CAD package and consolidating them into a three-dimensional prototype.

As a bridge between computer-aided design (CAD) and manufacturing by machines operated by computers, CAM systems have emerged. The input into a CAM system is the prototype. The output is a program that is entered into the control unit of certain machines, based on which the machine produces the corresponding part. Further integration of CAD / CAM systems with various knowledge bases, expert systems and information systems, leads to Computer Integrated Manufacturing - CIM.

This is the general story, but still, in most cases composite prototypes are layered manually. No matter what kind of composite prototype is produced, in general, this is still manual work. It should be noted that this is about creating composite prototypes using the "dry" method. This means the composite fabrics that are used already have resin on them and are heat activated within the curing oven.

The rapid prototyping process assumes:

- ♦ Designing for rapid prototyping begins by modeling the 3D object using AutoCAD software package. In addition, we used Mechanical Desktop to solve issues that AutoCAD did not address adequately.
- ♦ Composite fabrics must be properly placed inside the cutting machine. Also, the cutting direction for every layer has to be accounted for. Orientation of fabrics depends on prototype model height, i.e. number of layers. Certain accuracy has to be achieved in order to prevent slippage of layers.
- ♦ A layer-by-layer production requires cutting fabrics along contours that are defined within AutoCAD. Within AutoCAD, the 3D model is cross-sectioned at increments according to fabric thickness after oven curing. Obviously, lots of testing and analyses were performed in order to obtain best relation of cross-section increments and fabric thickness. Cutting tool paths, generated individually for every layer, have a significant impact on product accuracy and prototype build time.
- ♦ An adequate connection has to be established between AutoCAD and the cutting machine. This was possible by using AutoLISP to make an additional module that delivered coordinates to the cutter, following a defined cross-section contour. Also, the cutter speed had to be adjusted as to prevent heating and activating the resin on the fabric.
- ♦ Authors from Autodesk managed to create a corresponding module that provided optimized cutting. This was a material saving issue and a matter of how to cut adjacent fabrics in order to achieve proper joining at suitable angles, as well as. Adjacent fabrics have their weaving overlapping at an

angle of 45 degrees. All this was considered and the module operates with satisfaction, although, still there are some efforts to eliminate minor flaws that arose during operation.

PROTOTYPE BUILD USING PROPOSED METHOD

This paper presents a method how to take advantage of solid modeling abilities and programming capabilities within AutoCAD. Other software packages were used to prevail smaller flaws in AutoCAD. This step was taken because these two packages are products of the same company – Autodesk; hence, they are fully compatible and enable a two-way relationship. As a result, the prototype is split into layers corresponding to composite fabric thickness, and a set of six cross-section profiles is obtained. Each layer has its contour defined in a cross-section plane and by further processing the cutting path is defined by the cutting machine. This is possible by the above-mentioned module. There were other ways to build the composite prototype, but the layer-by-layer method proved best. The proposed method defines every layout by cutting the fabric with resin along the corresponding contour. This is similar to the way a plotter draws. Instead of using a pen (isograph technical drawing pen), a knife was used. Figures 1 and 2 present the example prototype made by this layer-by-layer method. Figure 3 shows the example prototype with a quarter cutout showing thickness.



Fig. 1. The example 3D model, visualized with 3D Studio MAX



Fig. 2. The 3D model view from below

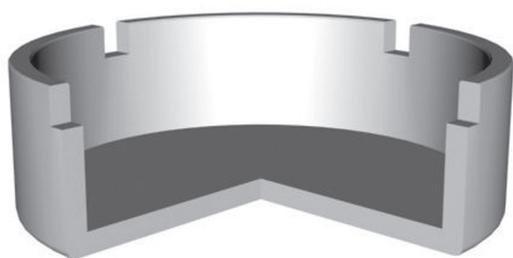


Fig. 3. A quarter cutout showing model thickness

The part being made has to be defined as a solid, and with the help of programs written in AutoLISP performs its cross-sectioning with horizontal planes at the proper increments. In this way, the intersection of planes and the prototype provides a contour along which the cutting machine defines the cutting path of the knife. There is also the option to add a mesh to the contour in order to overcome the point of origin problem for the knife movement over the fabric. In this way, the program allows the knife to start from an arbitrary position, allowing significant material savings during contour cutting, because the user can control the knife to cut contours wherever he wants. Also, important to mention is that the knife may cut contours at arbitrary angles in order to satisfy the requirement that the weaving of adjacent fabrics layup at an angle of 45 degrees.

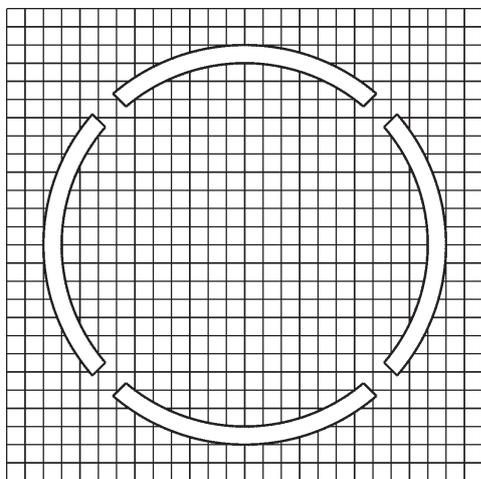


Fig. 4. Cross-section contour and the corresponding mesh

Figure 4 presents a contour and mesh in the intersecting plane. This figure also represents the cross-section obtained by positioning the intersection plane at notches' half height at the rim of the model.

Since the devices are very much alike, and it's all about a plotter and a cutter, the HP-GL format was used to create the control code for the cutter to cut along the outline. This provided a good driver and control code for cutting along contours.

The prototype was finished by forming (cutting) the last layup. Layups should then be arranged and prevented from sliding. This is achieved by appropriate clamping so the fabrics won't move when curing in the oven. It is impor-

tant to note that there is a procedure for polymerizing any each type of composite material, and the designer should take that into account when choosing materials. The curing oven should have capability of both, temperature and pressure control along the extent of the prototype.

THE CURING OVEN

The final stage of making a composite prototype is polymerization inside the oven. Due to specific requirements of composite materials, it is necessary to provide computer control over the curing process. This means that the computer, via the corresponding module, performs constant control of oven temperature and the pressure distribution. As to control temperature, the computer module turns on and off heaters and thus meets the requirements of polymerization of various composite materials. A chart representation of the connection of computers with the curing oven is shown in Figure 5.

A BRIEF ON 3D PRINTERS WORKING IN A SIMILAR FASHION

Laminated object manufacturing (LOM) is a method of 3D printing. Initially, the California-based Helisys Inc. (now Cubic Technologies) developed this rapid prototyping system. During the LOM process, layers of plastic or paper are fused — or laminated — together using heat and pressure, and then cut into the desired shape with a computer-controlled laser or knife. With this method, after printing the objects, additional modification is done by machining or drilling. Typical layer resolution for this process is defined by the material feedstock and usually ranges in thickness from one to a few sheets of copy paper.

While LOM is not the most popular method of 3D printing used today, it is still one of the fastest and most affordable ways to create 3D prototypes.

Like all 3D-printed objects, models made with an LOM system start out as CAD files. Before a model is printed, its CAD file must be converted to a format that a 3D printer can understand — usually STL or 3DS.

An LOM apparatus uses a continuous sheet of material — plastic, paper or (less commonly) metal — which is drawn across a build platform by a system of feed rollers. Plastic and paper build materials are often coated with an adhesive. To form an object, a heated roller is passed over the sheet of material on the build platform, melting its adhesive and pressing it onto the platform. A computer-controlled laser or blade then cuts the material into the desired pattern. The laser also slices up any excess material in a crosshatch pattern, making it easier to remove once the object is fully printed.

After one layer of the object is formed, the build platform is lowered by about one-sixteenth of an inch — the typical thickness of one layer. New material is then pulled across the platform and the heated roller again passes over the material, binding the new layer to the one beneath it. This process is repeated until the entire object has been formed.

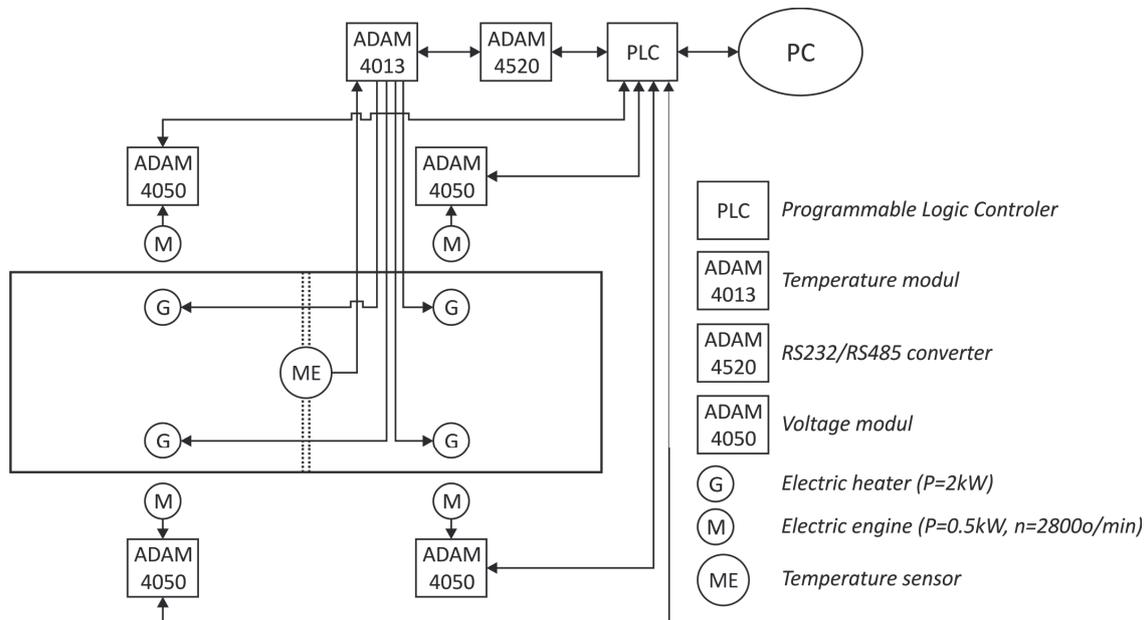


Fig. 5. Two-way connection between a computer and the curing oven

Once an object is done “printing,” it is removed from the build platform, and any excess material is cut away. Objects printed in paper take on wood-like properties, and can be sanded or finished accordingly. Paper objects are usually sealed with a paint or lacquer to keep out moisture.

Advantages:

- ♦ very cheap and affordable materials (paper and adhesive)
- ♦ small thickness
- ♦ Paper models have wood like characteristics, and may be worked and finished accordingly
- ♦ Relatively large parts may be made, because no chemical reaction is necessary
- ♦ Primary use for creating scaled models and conceptual prototypes that can be tested for form or design
- ♦ the most “green” technology of 3D printing

Disadvantages:

- ♦ limited choice of materials
- ♦ low strength of manufactured parts
- ♦ not ideal for creating objects with complex geometries
- ♦ can't create hollow objects
- ♦ low accuracy not ideal for functional prototypes

CONCLUSION

Despite the limitations, such using HP-GL format as an equivalent control code for the cutter, and some other trivialities, we have shown this method as a possible use to obtain parts with complex structures. This paper presents, in brief, a method of obtaining composite components, but it can be applied to other components, as well. Due to the various uses of the HP-GL format, it can also be used to create drivers for appropriate CNC machines.

Using the capabilities of AutoCAD and mentioned modules staff is trained quickly and easily, documenta-

tion is unified and completed, no matter who was working on it or on which computer. Thus, effective teamwork was possible within it one or more work units. The implementation of these modules and AutoCAD proved to be a powerful solution, confirmed many times within the Aviation Institute of the Faculty of Mechanical Engineering at Belgrade University.

The possibility of error occurrence in generating contours, and supporting documentation, is kept to a minimum. With introduction of automated generation of technical documentation, complete order was established in formulation of the overall project. All these parameters comply with current and effective standards.

Our future efforts are directed to further development of existing modules and eliminating minor imperfections. Also, there is a possibility of creating new modules to automate contour creation and related technical and technological documentation.

REFERENCES

- [1] Kruth, J. P.: *Material Incess Manufacturing by Rapid Prototyping Techniques*, CIRP, Keynote paper, 1991.
- [2] Wood, Lamont: *Rapid automated prototyping*, Industrial Press Inc., New York, 1993.
- [3] Kelly L. Murdock, *3ds Max 2012 Bible*, ISBN: 978-1-118-02220-7, John Wiley & Sons, Inc., 2012.
- [4] Grupa autora: *Pod lupom... AutoCAD 2000*, (prevod sa engleskog jezika), CET Computer Equipment and Trade, Beograd, 2000.
- [5] D. Cvetković: *AutoCAD 12 i 13 – Korak napred*, CET Computer Equipment and Trade, Beograd, 1995.
- [6] Grupa autora: *AutoLISP Release 12 – Programmer's Reference*, Autodesk, Inc., 1992.
- [7] Paul Richard, Jim Fitzgerald, *Introduction to AutoCAD 2013: A Modern Perspective*, Peachpit Press, 2012.
- [8] Robert. D. Smith, John C. Peterson, *Mathematics for Machine Technology*, Cengage Learning, 2008.