

Rapid Prototyping and Tooling Technology in Jewelry CAD

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ABSTRACT

This paper presents the investigation of computer-aided design and rapid prototyping technologies in jewelry design and manufacturing. Computer-aided design (CAD) and Rapid prototyping (RP) technologies play important roles in many industries including the jewelry industry. In this paper, CAD and RP technology is applied to design and build jewelry prototypes, and Rapid Tooling to build molds. The main aim of this paper is to describe the implementation of CAD and RP processes in the jewelry design and manufacturing. The applicability and effectiveness of RP, using Stereolithography Apparatus (SLA), is investigated in the field of jewelry model and mold making, moreover, the methodology is compared to conventional methods in term of time requiring, quality and manufacturing factors.

Keywords: Computer-aided design (CAD), Rapid prototyping (RP), Rapid Tooling, Stereolithography Apparatus (SLA), Jewelry Design, Jewelry Making.

1. INTRODUCTION

The jewelry industry has traditionally been regarded heavily craft-based, with automation generally restricted to machines in the various individual stages of jewelry manufacture. Jewelry design and model making are time-consuming tasks, which require skills in drawing and hand-made manufacturing. CAD and RP technology in jewelry design and manufacture offers a significant breakthrough [1]. Both allow designers to simplify the iterative design or to easily change or adjust details of the sketches, to facilitate sketching of jewelry products in any sizes, and to shorten the time require to make models.

Rapid prototyping technologies are additive processes that fabricate parts layer-by-layer called Layer Manufacturing (LM). They are capable of creating parts with small internal cavities and complex geometries. The process for rapid prototyping and manufacturing (RP&M) basically consist of three step: form the cross sections of the object to be manufactured, lay the cross sections layer by layer, and combine the layers [3].

Therefore, RP&M processes require only cross-sectional data to generate a physical object, and they eliminate the problems often encountered with other manufacturing processes and conventional methods. Moreover, RP&M processes also generate physical objects directly from geometric data without special tools.

StereoLithography Apparatus is a type of RP, which based on the use of a light-sensitive polymer fluid and a

computer-driven laser scanning system [1], [4]. SLA process is illustrated in Fig.1.

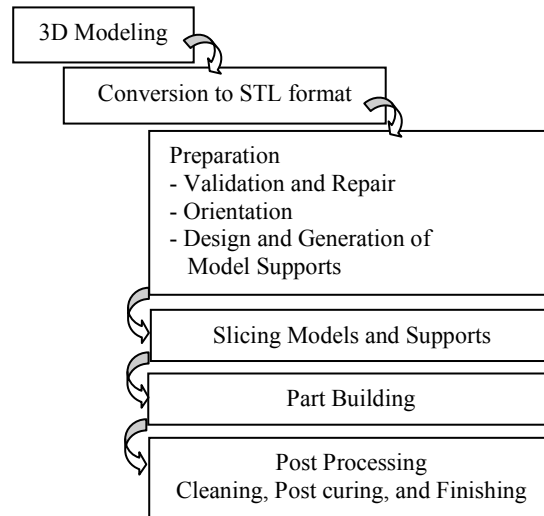


Fig.1. Stereolithography SLA Process.

2. JEWELRY DESIGN PROCESS

Jewelry design process generally begins at the concepts of design, which have been derived from the customers or the company. Jewelry design process is illustrated in

Fig.2. More details of jewelry design process are described in [7].

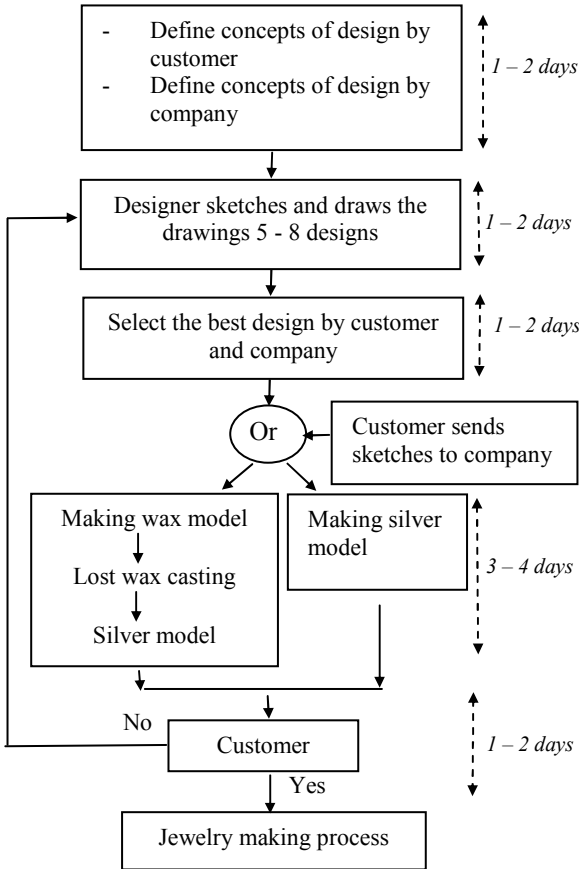


Fig.2. Jewelry design process.

The jewelry company typically creates approximately 50-80 styles of jewelry products per week. Styles or fashion of jewelry products generally are defined referring to trends of new-fashioned clothes, colors, and social value judgment, and from ideas and concepts of the international and famous designers. In any interval, some jewelry styles are very popular and have good sales, then these styles will be imitated and modified in some details for market needs.

3. JEWELRY MAKING PROCESS

The jewelry making process begins with the creation of an original model or prototype. Normally original models for casting can be made of both metal and wax depending on the skill and the intent of the model-maker. Metal models generally are made for duplicating castings of wax models from the rubber molds. Wax models typically are made for one-of-a-kind jewelry pieces or as the original model for casting a metal

model. Jewelry making process is described in details in [8] and illustrated in Fig.3.

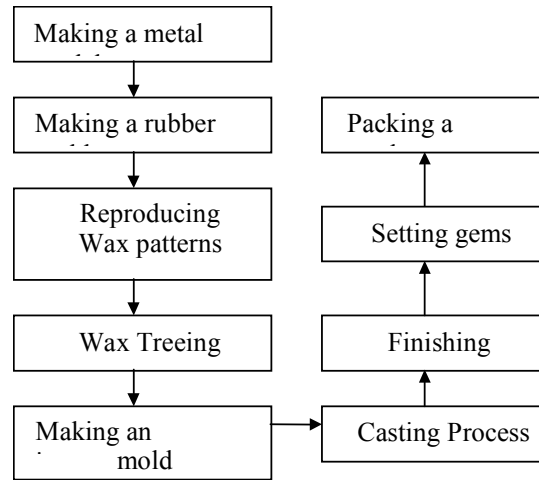


Fig.3. Jewelry making process.

4. CAD AND RP TECHNOLOGIES IN JEWELRY INDUSTRY

To build the jewelry prototypes and molds using RP, .STL files of those prototypes and molds are required, thus it starts with part modeling by CAD. Then .STL file are generated and verified before sending to the SLA system to build the prototypes and molds. The overall procedure for building jewelry prototypes and molds by RP is illustrated in Fig. 4.

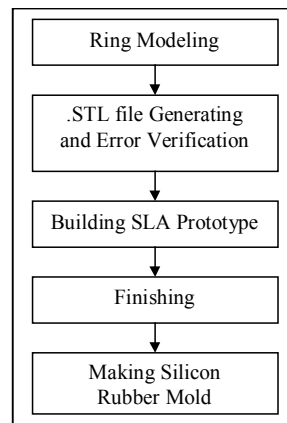


Fig. 4. The overall procedure for building jewelry prototypes and molds by RP.

4.1 Part Modeling: Ring Models and Molds

In the world of CAD, there are many approaches for 3D modeling including surface modeling and solid modeling. By using surface modeling, the adjacent

surfaces may be not perfectly joined; this impacts on inaccuracies in output .STL files. Sewing those surfaces to enclose the volume that holds the mass of the part can solve this problem, while the same problem will not occur when using solid modeling.

In this study, part modeling can be divided into 2 groups: (1) ring models, and (2) ring molds.

Those models are created using Unigraphics [9], ArtCAM [10], and JewelCAD software [11]. Some models are created using at least two software.

4.2 STL files Generating and Error Verification

This step is referred as preprocessing. Once the solid or surface model of the ring was created, this model is next converted into STL file format. The STL file format approximates the surfaces of the ring using tiny triangles. Some .STL files generated from CAD software still contain some errors. Therefore, the .STL files are verified to be error-free by using MAGIC software.

4.3 Examples of Ring Models and Molds

The first example of ring model is simple. The ring is fixed with the sprue rod and the sprue former, shown in Fig.5. This model is created and the .STL file is generated using Unigraphics software. Secondly, MAGIC software [12] is used to verify any error in STL file. For this model, no error is generated in STL format.



Fig.5. Modeling Ring fixed on sprue rod and former

The second and third examples of ring models are created using JewelCAD and Unigraphics.



Fig.6. The second and the third examples of ring models created using JewelCAD and Unigraphics.

The fourth example of ring model is created using ArtCAM software. The main purpose creating this model using ArtCAM is to compare .STL file from this software with others.



Fig.7. The fourth ring model created using ArtCAM.

Furthermore, CAD software can be used to create ring molds as illustrated in Fig.8.



Fig.8. Ring molds created using Unigraphics (Left) and MAGIC (Right).

The following are the STL models of ring models created in the study.

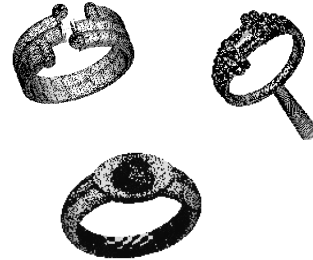


Fig.9. The example of .STL models of ring model.

The next example shows the errors in the STL file of the ring model.

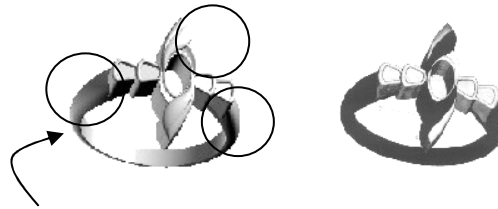


Fig.10. Ring models created by JewelCAD (left), and after fixed errors it still shows flipped triangles in black color (right).

The last example illustrated in Fig. 11 is the .STL model of the ring mold in this study.

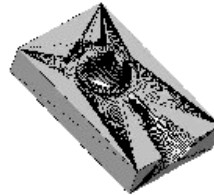


Fig.11. STL Model of the ring mold.

4.4 Building Ring Prototypes and Ring Molds by SLA

After the .STL files are error-free and complete. They are loaded to the workstation software of the SLA system. The SLA machine then builds the ring models and molds from the STL files.

After following the overall SLA process, the ring prototypes are built. The followings are the further steps undertaken in sequence.

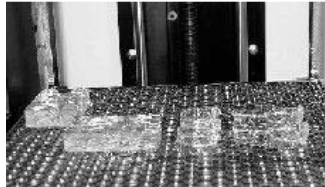


Fig.12. The ring prototypes and molds in SLA machine.

- Removing the prototypes from the platform,
- Cleaning the prototypes by alcohol,
- Removing support structures,
- Post curing prototypes done in the UV oven,
- Surface finishing.

After completing the overall process described above, the SLA prototypes and molds now are ready to use as the master for building the silicone rubber mold. The ring mold is ready to inject the molten wax for reproducing the wax patterns, which are described in the next section.

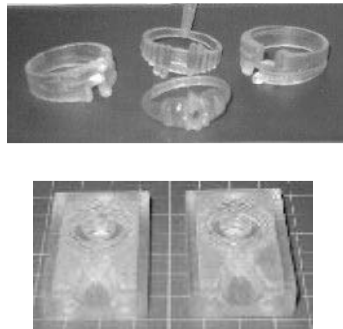


Fig.13. SLA ring prototypes (top) and molds (below).

4.5 Building Silicone Rubber Mold : Rapid Soft Tooling

In jewelry making process, the mold is mostly made from materials such as uncured rubber and silicone rubber. Rubber has the important advantage of flexing and releasing from undercuts. However, a significant disadvantage of a rubber mold is the extended cycle time due to the low thermal conductivity of rubber, and the resulting inability to rapidly extract heat from the molten wax [6].

In this study, the rapid tooling is made by the silicone rubber mold, which uses the RP prototype to be model. The RP model is fixed in the small box, silicone rubber then is poured around the model. Once the silicone rubber has solidified, it becomes a silicone rubber bar with RP model inside. Next, the bar is cut in the parting line with a scalpel that separates the bar into two parts. The RP prototype is taken out from the silicone rubber bar to create a cavity. Thus the silicone rubber bar now becomes a silicone rubber mold or rapid soft tooling in this study. After finishing the surface in the mold, the mold now is ready to cast the wax pattern. Wax pattern is cast by injecting wax into the cavity inside the mold that can reproduce a number of wax patterns. The rapid tooling is illustrated as in Fig.14.

In this study, the silicone rubber molds are made from

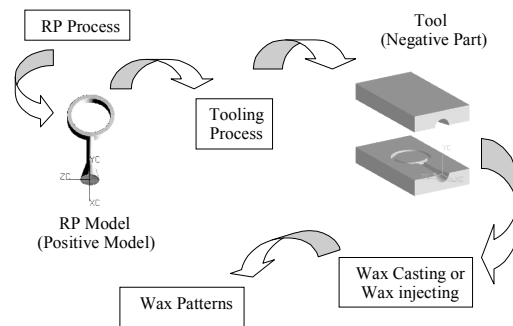


Fig.14. Rapid Tooling by using RP Positive Model.

the white silicone and the translucent silicone to compare the surface quality and building time.

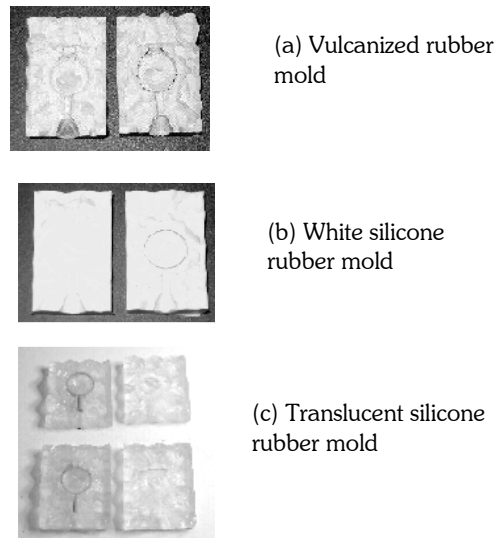


Fig.15. After-cut rubber molds.

5. ANALYSIS OF RESULTS

5.1 Analysis of Part modeling with CAD Software

Modeling jewelry products using JewelCAD is easiest, because it contains built-in library of several catalogues of settings, materials, stones, ring shape, and jewelry components. Some components could be loaded to change the shape and details to make a new design. However, a simple ring with little detail could be modeled using Unigraphics. Moreover, jewelry products designed and modeled using JewelCAD have been exported in IGES format, then they are imported into Unigraphics to add more components and create the mold, which is easier than model using JewelCAD. The ability of ArtCAM for modeling jewelry products is placed between JewelCAD and Unigraphics.

| CAD Packages Features | UG | JewelCAD | ArtCAM |
|--|------------------|------------------|----------------|
| Type of Modeling | Solid Modeling | Surface Modeling | Solid Modeling |
| Tool Options for Jewelry Design | No | Yes | Medium |
| Intricate Shape Modeling | Difficult | Easy | Medium |
| Modeling other components on Jewelry Product | Easy | Difficult | Medium |
| Modeling Mold of Jewelry Product | Easy | Difficult | Medium |
| Easy to Co-ordinate or Position the part | Easy | Difficult | Medium |
| Rendering Jewelry Products | Poor to Moderate | Superior | Moderate |
| Cost of Packages (U.S \$) (Approximated) | \$ 8,000 | \$ 5,300 | \$ 7,500 |

Tab. 1. Comparison of CAD packages for modeling jewelry products

5.2 Analysis of .STL files Generation

In the study of modeling the rings, and generating the STL files, several problems and errors have occurred and some techniques are invented during generation of .STL files. Those problems, errors and techniques are briefly concluded as follows.

1) The STL files generated using Unigraphics, mostly no error. When a model is created using Unigraphics, and the STL file generated by MAGICS, some errors are found, they typically are gaps or missing facets. The errors appear during transformation from MAGICS to IGES from Unigraphics to STL format, these are errors in CAD interface.

2) If a model is created using JewelCAD and exported into IGES file. MAGICS is used to translate IGES to STL format. Most of STL file errors are gaps or

missing facets, degenerate facets, non-manifold condition, and flipped triangles. The same errors occur if the model is created and generated STL file using JewelCAD. Because the tessellation algorithms used by JewelCAD is not robust and JewelCAD creates any model based on surface modeling.

3) If a model created using Unigraphics, and decorated some parts of the ring using JewelCAD. Next, STL file of the CAD model is generated using Unigraphics or MAGICS software. As a result, the output typically has no or less errors.

4) If a model created and generated STL file using ArtCAM, the output STL file mostly has no error. In ArtCAM, there is ArtSTL that can generate STL file with robust tessellation algorithms and also TriFIX, a tool designed to verify and repair of STL triangle files for rapid prototyping [14].

Furthermore, other factors affect generation of STL file such as triangulation tolerance. Some errors are corrected by setting smaller tolerance. If the smaller tolerance requires much computation time but the smaller triangles are smoother and better the surface of model. The designer must trade-off between time to build and quality of model.

| Error types of STL file | CAD Software | | |
|-------------------------|--------------|----------|----------|
| | UG | JewelCAD | ArtCAM |
| Gaps or missing facets | No | Yes | No |
| Degenerate Facets | No | Yes | No |
| Non-Manifold condition | No | Yes | No |
| Flipped Triangles | No | Yes | No |
| Generating STL File* | Good | Poor | Superior |
| No. of Triangles* | 23,975 | 28,120 | 55,492 |
| Size of STL file* | 373 KB | 5.76 MB | 2.45 MB |

Tab. 2. Comparison of STL file generated from different CAD software.

From the experiment, considering in the same model, the volume of model: 718 mm³, surface area of model: 1278 mm², and triangle tolerance: 0.02 mm. JewelCAD has generated STL file at largest size of file, which it mostly contains some errors. The smallest size is done using Unigraphics. ArtCAM and MAGICS generate a more superior STL file at medium size. The recommended triangle tolerance is 0.02 mm that gives a surface roughness of 0.650 mm, and the size of STL file is about 2 - 3 MB containing 25,000 - 30,000 triangles for a ring with average complexity.

5.3 Analysis of Building Ring Prototypes

In this study, jewelry models are built by both the conventional method and the rapid prototyping process. In the conventional method, models are made from metal and wax. By rapid prototyping technology, the models are built with SLA process. Thus the models are categorized into 3 groups by methods and materials. They are compared and explained in Table 3.

| Types of Model | Polishing & Finishing | Surface Quality | Max. Working Temp. (°C) | Working in Vulcanized Temp. | Building Time |
|----------------|-----------------------|-----------------|-----------------------------|-----------------------------|---------------|
| Metal | E | E | 760 (Silver) 900 (Brass) | Yes | Highest |
| Wax | M | G | 109 | No | High |
| SLA | M | M | 125 | No | Moderate |

E = Excellent; G = Good; M = Moderate.

Tab. 3. Comparison of models building in different methods and materials.

Surface roughness of the metal model and wax model are better than the SLA model. The building time of SLA model is shortest comparing to the others. However, the price of SLA machine used in the study is approximately U.S \$ 70,000 that user should consider and trade-off between time, quality and cost of prototypes.

The other consideration is the shrinkage of the SLA models. Thus the tolerances in X and Y-axes are considered in the design and building process, and found by experimental statistic data.

5.4 Analysis of Building ring molds

Ring molds, in this study, are built in four different materials; vulcanized rubber, white silicone rubber, translucent silicone rubber, and Photo-polymer resin epoxy (by SLA process). The comparisons of four different molds are explained in Table 4.

| Types of Molds | Surface Quality | No. of Wax Pattern produced | Max. Service Temp. (°C) | Hardness Shore D |
|-----------------------------|-----------------|-----------------------------|-------------------------|------------------|
| Vulcanized Rubber | Excellent | 150 | 80 | 65 |
| White Silicone Rubber | Moderate | 30 | 205 | 41 |
| Translucent Silicone Rubber | Very Good | 50 | 230 | 85 |
| SLA | Good | > 150 | 130 | 86 |

Tab. 4. Comparison of molds building in different methods and materials.

Comparing to the other molds, the vulcanized rubber mold are lowest in the total mold cost and the total process time. The vulcanized rubber mold also can be reproduced wax pattern with excellent surface quality in high volume. This mold is strongly reasonable to use in making rubber mold in jewelry making process. However, in some case, the RP prototypes are easier to build comparing to conventional methods, thus the silicone rubber mold is required.

In the case of building the mold without the prototype, SLA mold is built directly by SLA machine. The main considerations of this case are part orientation and part shrinkage in SLA mold building.

6. CONCLUSIONS

CAD and RP allow designers to simplify the iterative design or to easily change or adjust details of the sketches, to facilitate sketching of jewelry products in any sizes, and to shorten the required time for making models. In the jewelry design stage, the ring models are created using CAD software; Unigraphics, ArtCAM, and JewelCAD. Some ring models are created using two CAD software. The ring models created by CAD software are verified and fixed the errors in the .STL file using MAGICS software. The comparison of CAD software to generate the ring models are explained in the paper.

Any ring model and mold created using CAD should bases on solid modeling to avoid errors (such as gaps, non-manifold solid, and flipped triangles) during generating STL files. Some techniques to avoid and fix the errors in STL file are described in the paper.

STL file is used in RP process to build the prototypes and molds. In this study, the ring prototypes and ring molds are built by Stereolithography Apparatus (SLA) process. It is found that the overall qualities of the SLA models are promising. Applications of some additional finishing processes to the SLA models and mold are necessary. As a result of the appropriate part orientation, not only shrinkage is reduced but also surface roughness is minimized by placing part in the suitable building direction.

Moreover, When CAD and RP are used collaboratively, it is capable of designing and making mold directly without any prototype, they thus can shorten the production time. CAD and RP technologies offer the great benefits to the jewelry industry from the design stage through manufacturing process.

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