An Implementation Study of Patternless Casting Manufacturing for Ship 3D Modeling

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Abstract:-FRP ship is high technology fine art. It has a huge amount of technology and complicated high-value production. However, FRP ship form design, manufacture to navigation, takes a long time. Take a forty meter ship for example, this takes an average eight to twelve months to manufacture in Taiwan, and only takes three to six months in SuehZan China. Even though the quality level exceeds that of its Chinese counterpart, the production time is a lot different, and it's also a reason why ship owners from other countries hesitate to give countermands. In order to improve our ship-making efficiency, the main task for us is to investigate and strive to shorten our production times. The strength in making our ships is high technology specialized designing, choosing exacting material and precise processes, belonging to a typically unitary small amount of production. The crucial production of this industry is developing large ship patterns, if we can use five axes, NC control and the manufacture facilities, we can obtain optimum ship design by making 3D models through the CAE directly. Using CAD/CAM software can turn the curve surfaces of the NC machine program to accomplish producing a ship pattern. The design production system of 'Patternless Casting Manufacturing 'PCM', is exactly turning the production of ship pattern designs into a digitized form, departing from the traditional way of diagnosing ship shapes and carpentry. Not only can this control the precise shape and flow line of the design but it can also save over 60% of the time used in developing patterns.

Key-Words: - Patternless Casting Manufacturing, the best design of the ship, NC machine.

1 Introduction

In Patternless Ship Casting, with recyclable media or resin sand as a casting material, we can apply the principles of dispersed/accumulated forming in the Rapid Prototyping technique, working on computerized slicing on 3D hull models and layered processes to speed up the ship moulding. In this research we integrated Rapid Prototyping, Rapid Tooling, precise numerical controls, and applied them to the design of the ship surfaces with complicated geometric forms.

The Rapid Prototyping creates the moulds of prototypes with complicated geometric forms and curvature, made by Rapid Tooling without traditional NC processes or clamping fixtures involved. The technique of precise numerical control applies precise stack moulding with recyclable or resin sand as casting materials, through layered manufacturing processes to mould complicated, thin surfaces with great precision. This reduces the manufacturing duration and costs for ships and large-scale moulds. Therefore Patternless Ship Casting not only features accessible materials, short periods, low costs, great quantity as well as quality of moulds and rapidly nimble manufacture, but also opens up a new field in large-scale mould manufacturing.

2 Theoretical analysis of Patternless Casting Manufacturing

Patternless Casting Manufacturing (PCM) is the integration of Rapid Prototyping, Computer 3D digital design, numerical control programs and Materials Science, which rapidly and precisely turns design concepts into functional prototypes or mould parts. Hereby, we are able to make fast evaluations and alterations on products, thus shortening the time of development. With high rapidity and flexibility, it can be used widely in ship or big-scale mould fields.

2.1 Theory of Rapid Prototype Technology

The industrial machining is as good as an additional intelligence. It avoids faults or clamping fixtures changing in actual machining, by detecting any procedural or tool problem before the procedure starts, which reduces the costs of faulty designs. Also it greatly shortens the product development period and allows quick confirmation of the machining attributes because of the simultaneity of rapid manufacture and rapid machining. There is no need for concern about cutter-feeding paths and fixture or mould fabrication that is not necessary for prototyping. It not only decreases the cost, but also significantly improves the economic efficiency in the cases that require smaller quantities. In initial development, after the CAD files of required patterns are configured, the fundamental models produced before the actual manufacture, which are made for design confirmation, product alteration, function testing and mould fabrication are what we call prototypes. The rapid prototyping system is capable of prototyping every complicated or detailed construction without the limitations of blank moulding, but also manages to overcome model distortion problems. This is a definitely a major breakthrough in the machining industry.

The principles of rapid prototyping are based on concepts of layered machining. The machining process of rapid prototyping is shown in Figure 1. While a 3 dimensional object is sliced along one of the axes into thin layers, these layers could be regarded as 2 dimensional objects. Contrarily, while 2 dimensional objects are piled up together they turn into 3 dimensional objects. After a 3 dimensional model is constructed on a computer and converted into an STL file, it would go through slicing, with the STL file turned into 2 dimensional layers of the profile, each of these layers would be processed and piled up in the numerical controlling system. Finally the 3 dimensional object is produced[1]. The theory and process of rapid prototyping is shown in Figure 1.

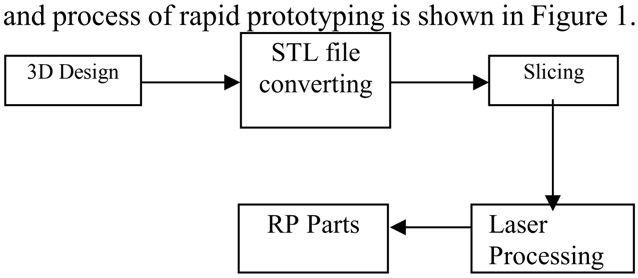

Figure 1. Theory and process of rapid prototyping

2.2 Variety of rapid prototyping

Moulding technique applies principles of rapid prototyping machining and becomes a particular process featuring high efficiency. According to moulding manner, it can be categorized into two types: direct moulding process and indirect moulding process. In direct moulding process, moulds are produced directly without any mould insert involved, followed by post processing. In indirect moulding process, a mould insert of required form is needed, then the mould is formed after casting procedure. Following is the list of some common moulding methods[2][3].

The first part is direct type molding process, include:(a)DTM: Rapid Tool, (b)EOS, DMLS(Direct Metalpowder Laser Sintering), (c)EOS, DCP(Direct Croning Process), (d)3D systems, AIM(ACES Injection Moulding), (e)Soligen Company, DSPC(Direct Shell Production Casting), (f)Helisys Company, LOM(Laminated Object Manufacturing), (g)Massachusetts Institute of Technology, 3D Printing, (h)Extrude Hone Company, ProMetal, (i)Stanford University, SDM(Shape Deposition Manufacturing), (j)Case Western Reserve University, CAM-LEM (Computer Aided Manufacturing of Laminated Engineering Materials), (k)Stanford University, LENS(The Laser Engineered Net Shaping), (l)New York State Centre for Advanced Technology, FPM(Freeform Powder Modeling), (m)3D System, SLA(Stereo Lithography Appatrtus) system, (n)CEMT, Japan, SOUP system, (o)Strastasy, FDM(Fused Deposition Modeling) system, (p)3D System and DTM, United States, SLS(Selective Laser Sintering) series, (q)Cubital, SGC(Solid Ground Curing), (r)Helisys and LOM(Laminated Object Manufacturing) system. The second part is indirect type molding process, include:(a)Silicon rubber mould, (b)Epoxy-aluminum mould, (c)3D System, 3D Keltool, (d)Metal spraying, (e)CEMCOM, NCC Tooling(Nickel Ceramic Composite), (f)Mitsubishi, MRM(Mitsubishi Chemical Rapid) and (g)Carnegie Mellon University, Spray Metal Faced Tooling.

2.3 Rapid Prototyping property and attributes

To summarize all the kinds of Rapid Tooling techniques above; because of the influences of property, process and equipment, the scale moulds are mostly limited to 0.125 cubic meters[4]. Besides, although the method from each company has its own character, these moulding systems share the same sort of concept or basic design theory . Thus, usually according to the form of materials in the process[5][6], the rapid moulding system is categorized into 4 types: liquid, semi-liquid, powder, and solid. Each type refers to a different principle, attribute, and property. Direct moulding process has an especially high efficiency in large-scale mould developing. all types are explained as below:

2.3.1 Theory and characteristics of liquid method

This method has been the first system commercialized with the highest occupancy rate. The theory is making liquid photosensitive polymer, hardened and polymerized, into a thin layer by laser lights such as

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He-Cd, Argon or UV. Then the operating lift is lowered to cover the machining area with a layer of resin, the liquid surface is levelled with a scraper, the level surface is scanned with laser light to make it closely bound to the upper layer and the liquid resin is heated to solidify and form it. The process will repeat until the 3 dimensional object is produced. The most distinguished feature of the liquid process is the high accuracy, the deviation is eliminated down to 0.1 mm to 0.025 mm. *(3.)* Also the low distortion rate, easy for retouching prototypes, is great for surface painting effects and so on.take, for instance, the SLA system from 3D System and SOUP system from CEMT, Japan[7].

2.3.2 Theory and characteristics of semi-liquid method

The theory uses a thermal head to melt the thermoplastic material by heating it up to **1** ℃[6] above the melting point, squeezing the melted material to the proper position layer by layer until object is in the required form. The machining head is controlled by the machine arm moving along X-Y axes, and the material supplier moves along with two rollers. Also, because the final object is constructed on top of another spongy-like object, it is very easy to detach. For instance, the FDM system from Stratasys, applying the hot melting method, melts the solid ABS or another particular wax material with two sprayers, and then sprays that to form each layer. When one of the sprayers is used for spraying ABS prototyping from semi-liquid material, the other one is in charge of spraying flexible or water-soluble material. The most distinguished feature of this method is that ABS prototypes can be produced directly with the material strength, for which both are almost exactly identical, as with the ABS parts from mass injecting production. This method is ideal for fast development for parts that need to be tested. Also it has an accuracy as little as around 0.178-0.25 mm [8] which is ideal for parts that require detailed characteristics or accurate surfaces.

2.3.3 Theory and characteristics of powder method

The theory of powder method is based on prototyping from a combination of plastic or metal powder with either laser sintering or glue bonding mode. The laser sintering mode is especially distinguished for directly producing both Nylon prototypes with high strength, and the injection mould used for mass production. There are some common powder methods such as the SLS system from 3D (United States) and DTM, or the Z402 system from Z Corporaton, which both belong to the powder method in Rapid Prototyping.

In SLS Rapid Prototyping system, a medium-high power laser is used for scanning the plastic powder, wax or metal layer by layer, to heat up the scanned part to sintering temperature, then it melts, binds, and then forms into the prototype or mould. Its accuracy is about 0.25 mm. In industrial applications, one of the features of SLS is that the single system is capable of choosing the proper powder material for different purposes such as plastic parts, metal parts, or moulds. The direct sintering of Nylon powder produces Nylon parts with high strength, which are ideally used in the fields such as motor or machine industry that require high strength and function testing when developing plastic parts. As for systems like Z402 from Z Corporation, the theory is based on spraying the binder through a spray head to bind the powder of ceramic or mixed material, to form the prototypy with an accuracy of around 0.25-0.3 mm. Because of the rapidity, multiple colour combination, cheap price, and because the costs of materials required are far cheaper then other RP systems, this method is ideal for product shape design confirmation.

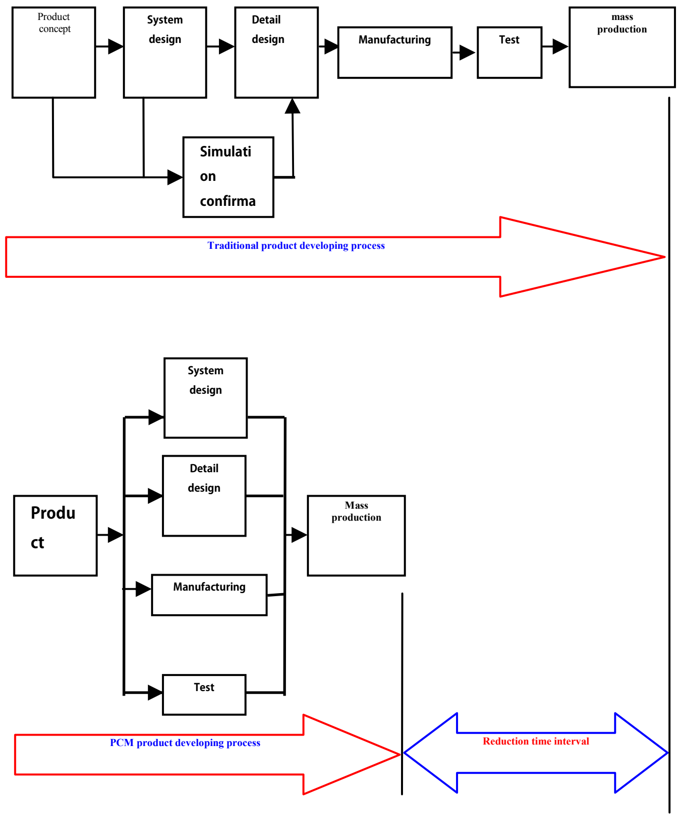

Figure 3. The difference between traditional product developing process and PCM

2.3.4 Theory and characteristics of solid method

The theory of the solid method in Rapid Prototyping is cutting some thin layered materials (normally paper) covered in adhesive into the shape, as these layers are the slices of 2D profiles of the target 3D object , and

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finish the 3D moulding process by hotpress uniting. The most common systems include the LOM series from Helisys, United States and SAHP Rapid Prototyping system from Kira, Japan. These prototypes have not only the accuracy about 0.25 mm but also have quite good strength and hardness, which makes them suitable for producing prototypes of function testing parts and wax squirt mold.

2.4 Comparing traditional and Patternless Casting Manufacturing

In Patternless Casting Manufacturing, the prototype of the product is constructed in a computer 3D design system, and then the slicing will be processed. The method is to approach the prototype with a triangular mesh to produce sliced layers, in the case with less triangular mesh there will be a smaller sized file but lower accuracy. On the contrary, with more triangular mesh, there will be a larger files and higher accuracy. Besides that, the thickness of each layer also primarily effects the finesse of the objects, because the thicker the layers are, the edges will be less smooth, especially on non-vertical or horizontal levels. The prototypes for the slicing are mostly processed in the form of STL file. After the 3D model is constructed, in the PCM prototyping system, the paths defined for each layer will be executed by the program to construct the mould prototype layer by layer. The 3D model and layered construction method are shown in Figure 2.

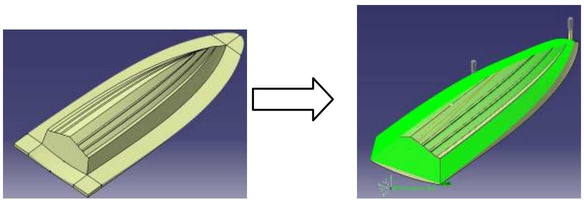

Figure 2. 3D model and layered construction method

Traditional ship or product developing always includes the whole sequential process of concept design, system design, detail design, producing and testing before the stage of mass production. However what PCM excels at is the best traditional product development for the the system design, detail design, producing and testing, all these are accomplished in the computer PCM system, with efficiency and accuracy. In Diagram 3. is the analysis of the difference between traditional product development and PCM. Besides, PCM also includes the feature detailed below(Figure 3):

(a)The materials used in PCM are recyclable medias or resin sand, which lowers the costs.

(b)The PCM model is constructed in a computer 3D modeling system, which makes it easier to revise without requiring to remake the wooden or PU mould. This greatly decreases the cost of manufacturing large scale and complicated products.

(c)After the ship 3D model has been constructed, the mould and numerical controlling program is then designed, which saves a lot of production time.

(d)In PCM there is no limit to any geometric form, and it is possible to carry out surfaces with any degree of complexity. Also, the parting surface is not necessarily set as the biggest section of the casting, which eliminates the limits inherent in product design and process analysis.

(e)It produces prototypes with recyclable media or resin sand in a short time, which after being processed properly, could take the place of wooden moulds as the basis of Rapid Tooling, leading to fast manufacturing and mass production of moulds.

Figure 3. The difference between traditional product developing process and PCM

3 Analysis of PCM

3.1 Theory of PCM

FRP ship moulding or large scale casting are often in forms of completely hand-shaped wood, CNC computer cut wood trimmed by hand, or CNC computer cut PU. Completely hand-shaped wood method could result in different accuracy because the staffs have different levels of skills, or because it is difficult to completely control the accuracy by hand. In the method of CNC computer cut then trimmed by hand, the radian of 3D mould surfaces is not really controllable. The method of CNC computer cut PU is the only one which is more accurate. However the large CNC computer numerical contolling equipment often costs tens of millions NT dollars. Also PU is expensive but not environment friendly. It is a heavy burden both economically and environmentally.

In this research a new casting technique is adopted, which uses casting sand or PLA as casting material, with the principle of dispersed/accumulated forming in Rapid Prototyping, then process the slicing on 3D model to obtain the closed curves from sections of different height. Then use the techniques such as section scanning, squeeze shaping, reasin catalyzing, injecting solidifying, to complete the mould casting. PCM in this research excels in recyclable, cheap and accessible materials, short casting time, and high accuracy for large-scale casting. It actually opens up a new field in ship or large scale mould casting. PCM (Patternless Casting Manufacturing) process is also the division or stacking according to RP technology, and it is a new shaping method different from traditional ones. PCM process is discribed in Figure 4.

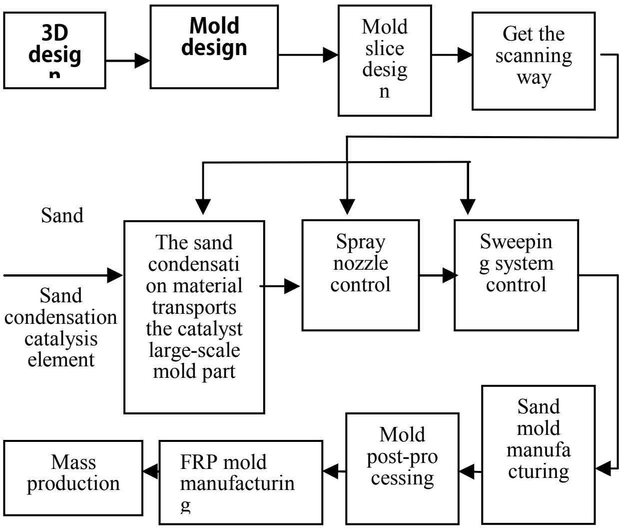

Figure 4. PCM process

In the process, the primary spray nozzle lays the resin along a particular path, followed by other nozzles laying the solidifying media, such as the catalyst, along the same path. The resin and the catalyst must be combined with the sand quickly during the moulding. It is also very important to meet the requirements of strength, heat transfer rate, and hardening time.

3.2 Parameter planning of PCM

In the PCM process, there are lots of factors that need to work in co-ordination, including the scanning speed, liquid flow, mold sand scale and thickness of slices. They do not only respond to one another, but there are also chain reactions among them. Many of these factors could possibly effect the moulding process. For instance, the choice of physical or chemical properties of moulding sand media is related to the amount of resin and catalyst, the distance between the spray heads and moulding sand, flow of injection, scanning speed, and pressure of spray heads, etc.

To some extent, the environmental temperature and humidity could also effect the PCM process. The first major problem in this research relates to the media injection technique. The second is the liquid diffusion rate of moulding the sand cohesion material and the third is the choice of the properties of moulding sand cohesion material. The study from now on will focus on these last three aspects, in order to improve the PCM production efficiency. The forming method of PCM prototype is discribed in Figure 5.

3.3 Key technique and method of PCM

3.3.1 Development of PCM

PCM casting system is an innovative design of resin injector and casting theory, which has to overcome the pressure and temperature of injectors and allocate the equipment properly. Thus, well designed hot runners and controlling interface of runner system are necessary.

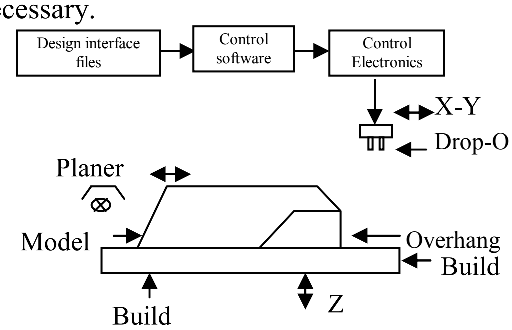

Figure 5 The forming method of PCM prototype

3.3.2 Intergration of CNC numerical control machine and PCM system

The CNC numerical control machine is a highly automatic technology with a computer interface. Apart from the accurate construction of 3D models, the computer integrated process design and program design are the key techniques which should be dealt within this project as well. Especially, the planning for integration of the CNC numerical control machine and PCM system requires both theoretical knowledge and practical experience in numerical control and injection moulding, to solve all the difficulties.

3.3.3 Chose for moulding materials

The development and innovative use of PCM materials is another key point of this research, because there were no precedents. Therefore, it is quite a challenge choose the proper moulding materials in an innovative way. In this project we search for the properties with the best application values to both experiment and verify, through both theoretical analysis and bibliography. We look for the best moulding proposals through a mixture of cross-comparison of ingredient structure, prescription, and strength of materials.

3.3.4 Adjustment of materials and system parameters

The adjustment of materials and system parameters is definitely a point to deal with in this research. When the PCM system is used in large moulds, the requirements include being environmently friendly, cheap, accessible, and maintaining a proper degree of strength and accuracy. In this project we analyze the experiments by an optimized system, to obtain the setting of the parameters in the PCM process, such as the pressure of the casting system, stage temperature of the injectors, forming temperature of resins, moving speed of casting, and thickness of slices, etc.

4 The future development of PCM

In this project a specially designed operating lift is used with the large 3D CNC numerical control machine to complete the PCM of a large scale ship. The injection moulding theory of PCM, integrated with the CNC program control system, squeezes out layers in the form of X-Y axes and 2D closed curves, using the automatic operating lift moving along the Z axis, to construct the 3D mould. The PCM system and structure is explained in the Diagram below. In order to improve the forming method of PCM prototype is discribed in Figure 5, the PCM concept for pleasure yacht is discribed in Figure 6, the process of PCM slicing for pleasure yacht is discribed in Figure 8, the objective placement of PCM is discribed in Figure 7.

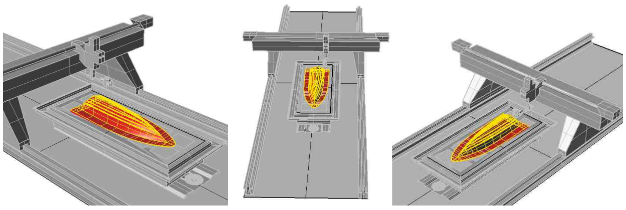

Figure 6. The PCM concept for Pleasure Yacht

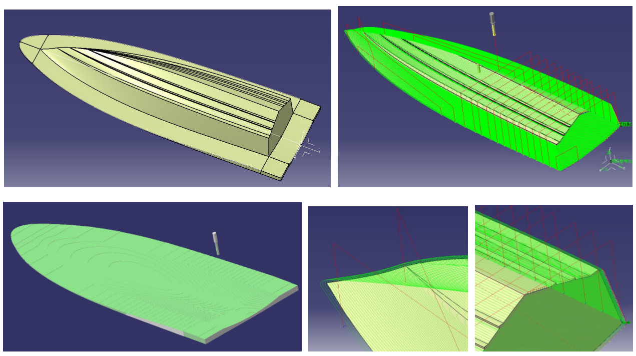

Figure 7. The process of PCM slicing for Pleasure Yacht

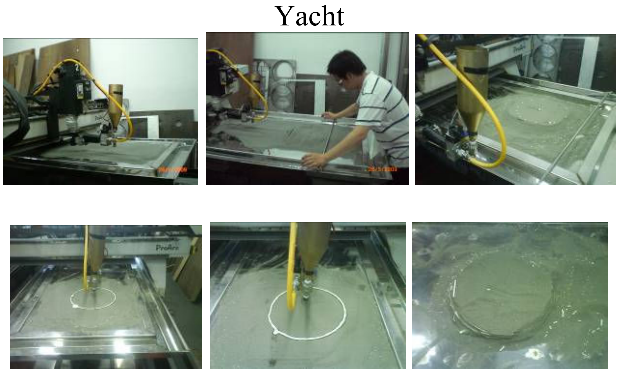

Figure 8. The objective placement of PCM

5 Conclusion

Revealed by the experimental results in this research, the PCM system not only greatly shortens the period of trial manufacturing and marketing of large scale products, but also decreases the cost of product prototype design. It also excels in rapid and nimble production and opens up a new field in ship and large scale mould production.

In the design, analysis and simulation of the PCM system in this research, it has been proven that the technique of computerized slicing of complex surfaces and RP/RT technology, is capable of constructing a pure PCM system result. The PCM system has the feature benefits, in the mould design industry, of shortening product developing time and exacting the sought after perfection of moulds, which is now a feasible and extremely economical reality.

REFERENCES:

[1] Xi Zhi-gang, Liu Jun, Liang Man-jie, Yang Ru-yu, Yu Yang, Based on fast patternless casting manufacture technique of the complex casting part, *Casting Technique*, **28(8)**, (2007), 1030-1033.(in Chinese)

[2] Mao Zuo-fei, Wu Cheng-mau, Liang ping-wei, Yang Liang-kui, The industrial application of R P, *Mechanical Monthly Publication*, **30(8)**, (2004), 58-67. (in Chinese)

[3] Guo Chi-chuan, Conformity fast prototype, fast mold, precision casting technology and metal fast manufacture practice research, *Mechanical Monthly Publication*, **27(12)**,(2001), 392-407. (in Chinese)

[4] Huang Chong-wen, Chen Jian-ren, Chai Zhao-fong, Chen Sheng- iung, Zheng Sheng-yuan , The fast foundry process application for pate mold technology in high pressure delinting oxidization of the mercury impeller development, *Mechanical Monthly Publication*,**28(6)**, (2002), 128-139. (in Chinese)

[5] Luo Ren-chuan, Zou Zhi-hua, Xie Zheng-eii, Zhou Xiu-hong, Development of present situation and future tendency on fast mold technology. *Mechanical Monthly Publication*, **28(2)**, (2002), 162-176.(in Chinese)

[6] Detlef. Kochan., Chua. Chee. Kai., Du Zhaohui., Rapid prototyping issues in the 21st century, *Computers in Industry*, **39**, (1999), 3-10.

[7] Prasad K.D.V, Feasibility studies on the production of electro-discharge machining electrodes with rapid prototyping and the electroforming process, *Journal of Materials Processing Technology*, **89**, (1999), 231-237.

[8] D.I. Wimpenny., G..J. Gibbons., Metal spray tooling for composite forming, *Journal of Materials Processing Technology*, **138**, (2003), 443-448.