Chapter 3

New Casting Method of Bionic Non-Smooth Surface on the Complex Casts

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Additional information is available at the end of the chapter

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1. Introduction

Many studies have shown that the surfaces of most creatures contain non-smooth structures, such as dimple concaves on the Cybister bengalensis and riblets on the shark skin, as shown in Figure 1. Non-smooth structures are formed in special non-smooth surfaces which have specific biological consequences, such as "shark skin effect" see in [1], “lotus leaf effect” see in [2] and “non-smooth surface effect” in references [3-4], all of which are closely related to certain functions. In accordance with the above-mentioned effects, the functions are drag reduction in [1], self cleaning in [2] and anti-adhesion, respectively in [3-4]. For shark skin, Singh, Yoon and Jackson in [5] found the riblets are directed almost parallel to the longitudinal body axis and this effectively reduces drag by 5%–10%.Ren et al [6] also demonstrated that both riblet and dimple concave non-smooth surfaces could be applied in pumps to increase efficiency. Other studies have shown that these non-smooth surfaces (called bionic non-smooth surface) have some certain functions in the fields such as aviation see in [7], pipeline in [8] and antifouling see in [9-10]. As for the riblet on shark skin and dimple concave on cybister bengalensis, when applied in the engineering, they are simplified as the shape of groove and dimple concave, as shown in Figure 2.

The traditional process method of such non-smooth surface includes Electro Discharge Erosion (EDE), Metal Engraving method (ME) and machining, all of which have disadvantages such as high processing cost and low processing efficiency. For example, ME processes rib-like non-smooth surfaces whose cross-section is a triangle on the complex surface casts directly, as shown in Figure 3. There are several disadvantages as follows: first, because of the limitations of tool radius, it is impossible to process sharp angles on the surface, the eventual angles of the cross-section are round on the surface, which is different from the original design ideas; second, the surface of rib-like non-smooth structures is rough and it needs other post-reprocessing like polishing, which increases the processing cost; third, residual stress on the surface are produced, which affects the quality of the casts. Most important of all, when the casts have complex surface such as impeller flow of centrifugal pump, it is difficult to form continuous rib-like non-smooth surfaces from flow channel entrance to the exit due to the complex flow of impeller. However, this is different from the design idea that the bionic non-smooth surfaces should be arranged in the entire flow channel.

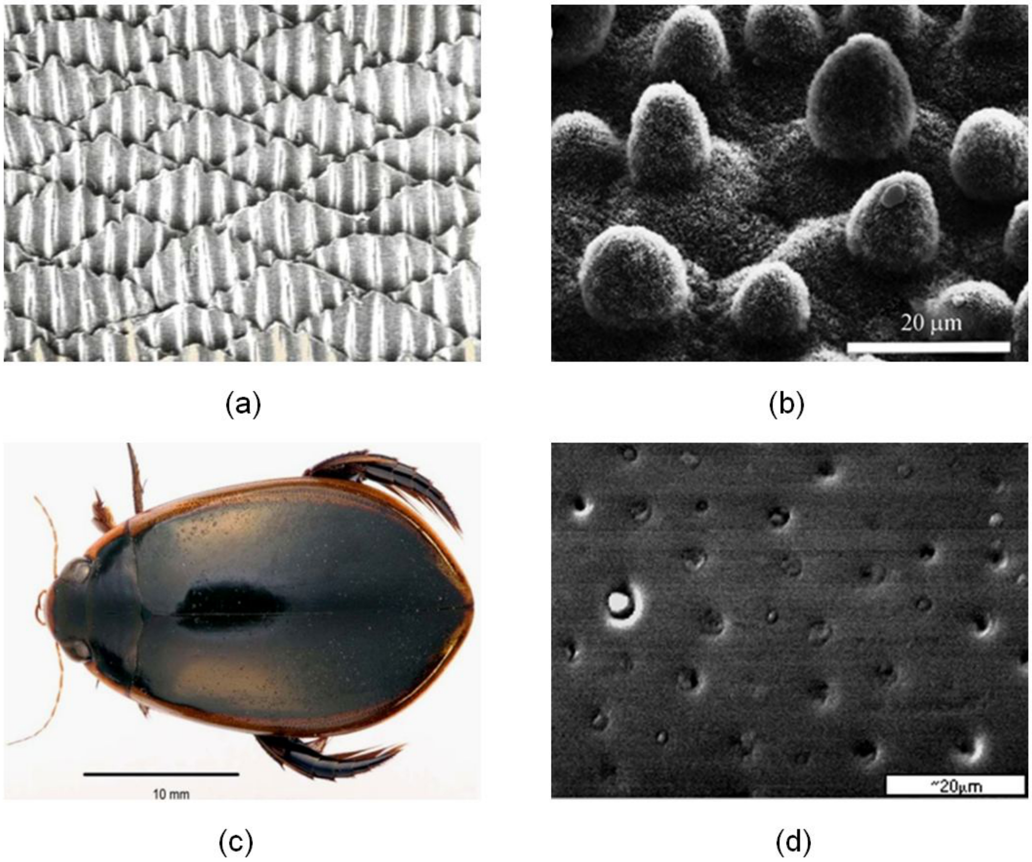

Figure 1. Non-smooth structures of some typical living creatures' skin. (a) riblets and grooves found on the shark skin [1]. (b) mastoid and micro-nano composite structure of lotus-leaf [2]. (c) Cybister bengalensis. (d) Dimple concave non-smooth structures on the back of Cybister bengalensis [3].

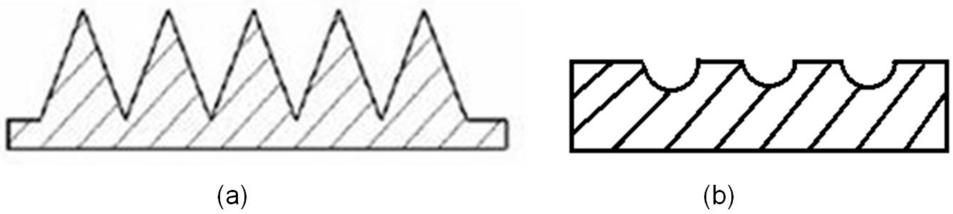

Figure 2. Simplified non-smooth structures. (a) Groove mimic from the shark skin. (b) Dimple concave mimic from the Cybister bengalensis skin.

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Figure 3. Engraving rib-like non-smooth structures on the complex surface.

In addition to traditional processing method, biology constrain forming technology based on the mechanism of bionic manufacturing see in [11-13] is used to produce a kind of biomimetic skin, but it is suitable for the polymer materials rather than for metal surface process. In light of this, this chapter investigates a new casting method to process non-smooth structures on the complex cast surface.

2. Method and Mechanism

2.1. Disadvantages of traditional casting method of rib-like bionic non-smooth surface

Traditional casting method to form such rib-like non-smooth surface has following disadvantages.

1) It is difficult to form small narrow rib-like structures continuously, as shown in Figure 4(a). Because the cross-section of Structure 6 is equilateral triangle with very small and sharp angels on Casting Mold 5, as shown in Figure 4(c). As Convex Section 4 in Figure 5 is formed by sand sculpturing on Casting Mold 3, it is difficult to depart the molds smoothly in the process of demolding. As a result, the part or the whole of Convex Section 4 collapses and the narrow rib-like non-smooth structures will not be formed or formed incompletely.

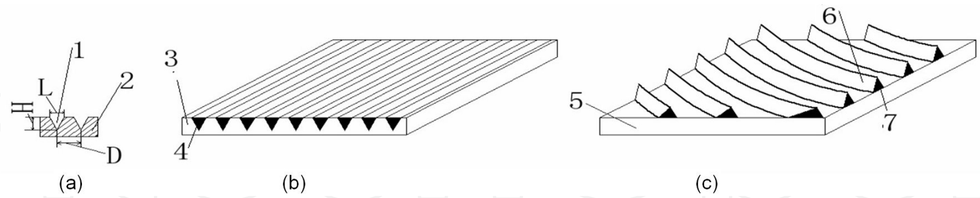

Figure 4. The casting mechanical diagram of rib-like non-smooth structures. (a) the cross-section of rib-like structures. (b) rib-like structures on the rubber plank. (c) paste non-smooth structures to form bionic non-smooth surface on the sand core.

In figure 4(a) L and H are the length and height of rib-like structures respectively, and D is the distance between them. 1 refers to the cross-section of rib-like non-smooth structure which is a triangle; 2 refers to the casting surface; 3 is the rubber plank; 4 is rubber rib-like structures cut from the plank; 5 is the sand core; 6 is the insulation coating materials painted on the rubber rib-like structure; 7 is rib-like non-smooth structures arranged on the sand core to form bionic non-smooth surface.

2) The sharp angle in design will not be formed. Many experiments have shown that, compared with other non-smooth rib-like structures whose cross-section is a triangle, those with a sharp angle have the best drag reduction. However, traditional casting method will not form a sharp angle directly in the demolding process.

2.2. The casting mechanism of one-time casting molding (OTCM) rib-like bionic non-smooth surface

In light of the disadvantages of the above-mentioned traditional casting method, a new casting method is investigated which is called one-time casting molding method (OTCM). During the casting process, two intermediate media are used, namely, hard rubber and high temperature insulation coating material (HTICM). The former is used to form the shape of rib-like non-smooth structures and the latter paints on the surface of rubber non-smooth structures in order to prevent the melted iron from contacting the rubber directly and keeps the rubber from melting within 1 or 2 seconds, so non-smooth structures would be formed as expected. It is especially helpful for the formation of a sharp angle of rib-like structures. After the metal liquids cool with a rapid decline of temperature, the rib-like non-smooth surface is formed. The mechanism of this method is shown in Figure 5. In order to form a triangular cross-section of rib-like non-smooth structure (indicated by 2) on the cast (indicated by 1), the same shape of the convex section (indicated by 4) should be formed on the sand core (indicated by 3), as shown in Figure 5(a) and 5(b).

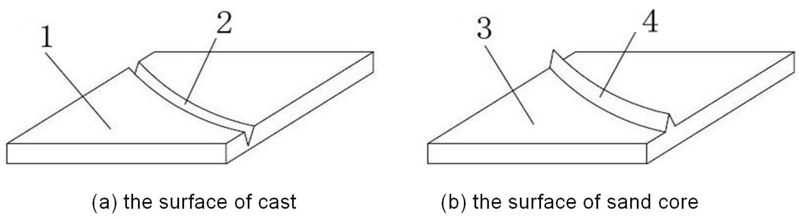

Figure 5. Schematic diagram of OTCM. 1 refers to cast; 2 is the triangle cross-section of the rib-like non-smooth structure; 3 is sand core; 4 is the rubber triangular convex section.

The steps of casting are as follows: ◎cutting many rib-like structures on the rubber plank, whose shape is the same as the final target cast; ◎brushing insulation materials evenly on the non-smooth structures, and only brushing two sides of the rib-like structures; ◎pasting those rib-like structures on the sand core according to the designed direction, location and curvature to form rib-like bionic non-smooth surface; ◎air-drying and trimming the non-smooth structures; ◎installing the sand core with non-smooth surface to the cast mold; ◎casting and demolding. In the casting period, both the hard rubber and HTICM are used as shape media. In the continual high temperature of metal liquids, HTICM become powder and triangular rubber convex melt and disappear, so the narrow triangular rib-like non-smooth surface is formed desirably. By using this method, rib-like non-smooth surface can be achieved even in complex casts. In order to describe the method of OTCM in detail, the impeller of centrifugal pump is selected to show the procedure of casting. The flow of impeller is an irregular complex surface; it is difficult to process such non-smooth surface desirably by using traditional casting or machining method. Non-smooth structure is designed as shown in Figure 4a. The cross-section form of it is triangle, the width of triangle is L, and L=0.5~3.0mm, the height H= (1~1.5) L, the distance between two rib-like structure is D, and D= (1~3) L. The method of OTCM process should be followed in the flow chart, as shown in Figure 6.

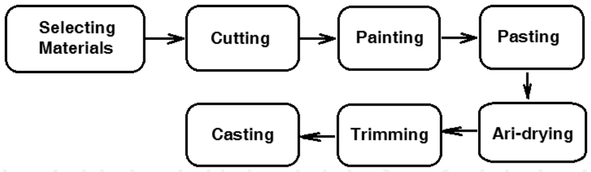

Figure 6. The flow chart of casting process.

2.3. Process

1) Selecting Materials

Two intermediate media, namely, hard rubber and HTICM, should be selected. They are the key factors to obtaining non-smooth surface.

a) Hard rubber

The thickness of hard rubber should more than the height of non-smooth structures. Since the height of this designed non-smooth structure is H=(1~1.5)L, and L=0.5~3.0mm; that means the maximum height is 4.5mm, so the thickness of hard rubber plank should be the 5mm. The hardness of rubber should be moderate; that means, on one hand, it should be convenient to machining, and on the other hand, the deformation should not be large at a high temperature in order to ensure the designed size of triangle. Considering this, the hard rubbers which had hardness values HD is 30 are selected, as shown in Figure 7(a). They are hard black materials at the room temperature; they have good chemical stability, excellent resistance to chemical corrosion and organic solvent resistance, low water absorption, high tensile strength and excellent electrical insulation; most important of all, they should have good machinability performance.

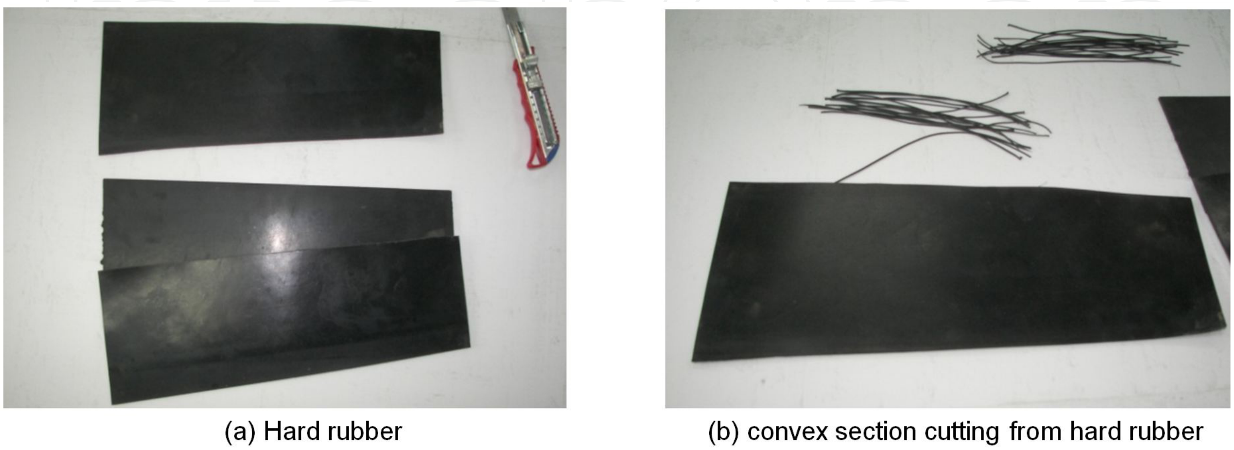

Figure 7. Hard rubbers.

b) High temperature insulation coating material (HTICM)

HTICM is a kind of coating, which can protect the surface at a special high temperature for a long time. It has excellent heat resistance compared with ordinary paint. The silicon element or inorganic high temperature insulation paint are used widely. In this chapter, the later insulation paint is selected, and in a certain condition, it still has protective function even at the temperature of 1700°.

2) Cutting

Triangular convex rib-like non-smooth structures which are in agreement with the designed ones should be cut on the selected hard rubber, as shown in Figure 7b. This process is very important, since it is related to the final quality of non-smooth surface on the casts. The non-smooth convex section structures can be machined by the special designed tools, and can also be cut by hand. Considering that some factors will affect the width of rib-like non-smooth structure, such as the thermal expansion and deformation of rib-like triangle in the process of casting and a layer of HTICM painted on the both sides of rib-like triangular convex section, as shown in Figure 8 the size of rib-like convex section should be smaller than that of the designed one, and the difference between them are called reserved size (refer to s, is shown in Figure 8) the size of it depend on the thickness of the coating layer and cross-section of non-smooth structure, and it can be expressed as following formula.$s = l / \cos\alpha$ The relationship between reserved size and thickness of coating layer is shown as Figure 8. Here l is the thickness of the HITCM layer, $\alpha$is the angle between l and s, which is related to the shape of rib-like non-smooth structure. For example, in this chapter, the cross-section of rib-like non-smooth structure is an equilateral triangle, and the reserved size$S = 2l / \sqrt{3}$. So, in order to produce the designed width of rib-like non-smooth structures, the width of rubber convex section L can be expressed asL=D-2S.

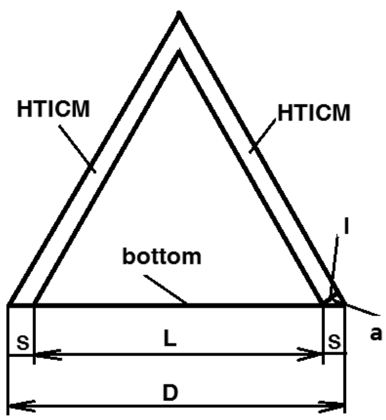

Figure 8. The schematic diagram of HTICM on the rubber convex section. Here, l is the thickness of the layer of HITCM, S refers to reserved size, L is the length of rubber convex section and D is the designed size of rib-like non-smooth structure.

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3) Painting

A small brush is used to paint a layer of HITCM evenly on both sides of rib-like rubber convex section, as shown in Figure 8. The thickness of the layer of HITCM is about 0.1mm. This process should be quick to avoid paint drop on the surface of convex section due to the solidification of HITCM.

4) Pasting

A layer of emulsion is painted on the bottom of rib-like non-smooth convex section and then paste them on the two sides of sand core according to the designed direction, location and curvature to form rib-like bionic non-smooth surface, as shown in Figure 9. It is very important to paste the convex section along the flow of impeller, since it is the key steps related to the quality of the final casts.

(a) positive side (b) negative side

Figure 9. Pasting non-smooth structure on the two side of sand core.

5) Air-drying

Air-drying the sand core at the room temperature. Since heating and drying method will make the rubber deformed, which will affect the size of non-smooth structures, the quality of non-smooth structure will not be guaranteed.

6) Trimming

Removing extra rubber with a knife. Check whether it has already met the designed requirements. Figure 10 shows the samples of sand core, which is formed after the above series of processes.

Figure 10. Examples of sand core which have rubber non-smooth structures pasted on their surface.

7) Casting

Assembling the above mentioned sand core on the cast molding and pour the metal liquids. HITCM keeps the rubber convex section from being gasified in 1 or 2 seconds, during which the temperature of metal liquids in other places decline rapidly. At the continual high temperature of metal liquids, the sand molding, HITCM, and rubber convex section melt and disappear, and the rib-like non-smooth surface will be formed desirably, the sample of rib-like non smooth surface impeller cast is shown as Figure 11. As the size of non-smooth structure is very small, it does not affect rigidity and life span of the pump impeller. At the temperature of 1000°, the rubber convex is gasified and volatilized completely. HITCMs are mainly silicon, and only a small quantity of them is painted on the surface of rubber convex. After casting, most of them become powder and remain on the surface of casting. And the mechanic properties of casting will not be affected.

Figure 11. The rib-like non-smooth surface impeller cast.

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2.4. processing dimple concave non-smooth surface on the impeller

By using the above mechanism of OTCM, the dimple concave non-smooth structures can also be processed on the complex surface of impeller. However, the process is slightly different from above process of rib-like non-smooth surface. Obtain dimple concave non-smooth surface needs a lot of convex domes pasted on the sand core. The process should be included as follows.

1) selecting the intermediate media

In this process, three intermediate media are needed to form convex domes, namely, Mastic 704, plexiglass, and HITCM. Mastic 704 is a kind of silicone with such characteristics as anti-aging, anti-acid and anti-alkali, high temperature resistance (up to 250°) and with capabilities of no corrosion, insulation and good curing performance, which is a very important feature to form convex domes. Plexiglass, with the chemical name of polymethylmethacrylate, is a kind of polymer polymerized by the methacrylate. Its characteristics are: (a) high transparency. It is currently the best transparent polymer material with light transmission rate reaching 92%, higher than that of glass; (b) high mechanical strength. It is a kind of long chain polymer, and molecular chains are soft, so its mechanical strength is very high with the tensile and impact resistance 7-18 times higher than that of the ordinary glass; (c) easy to process. It can be processed by machining. Above characteristics make plexiglass ideal materials which help form convex domes. In this chapter, the thickness of plexiglass plate is 3mm. The third material needed is HITCM, the same materials used to help cast rib-like non-smooth structures.

2) Drilling dimple concave on the plexiglass plate

Selecting the appropriate drill bit and drilling dimple concaves on the plexiglass plate with an electrical drill. It is very important to select a right drill bit, since it is conductive to controlling the shape and size of dimple concaves.

3) filling Mastic 704 into the dimple concaves on the plexiglass plate

In this process, the whole dimple concaves should be filled completely by Mastic 704 so that no small holes will appear when the mastic is solidified. Only in this way can the desired convex domes be produced.

4) solidifying and forming

Solidifying Mastic 704 fully as soon as possible at the room temperature to form the desired shape and size of convex domes, they are shown in Figure 12.

5) heating and removing

Heating the plexiglass at the temperature of 80° so that it will be softened and deformed. This characteristic of plexiglass helps the convex domes which are formed by Mastic 704 to be removed easily and completely.

Figure 12. Solidifying Mastic 704 on the plexiglass plate.

6) pasting convex domes on the sand core

Pasting these convex domes on the two side of sand core according to the designed direction, location and curvature to form non-smooth surface, as shown in Figure 13.

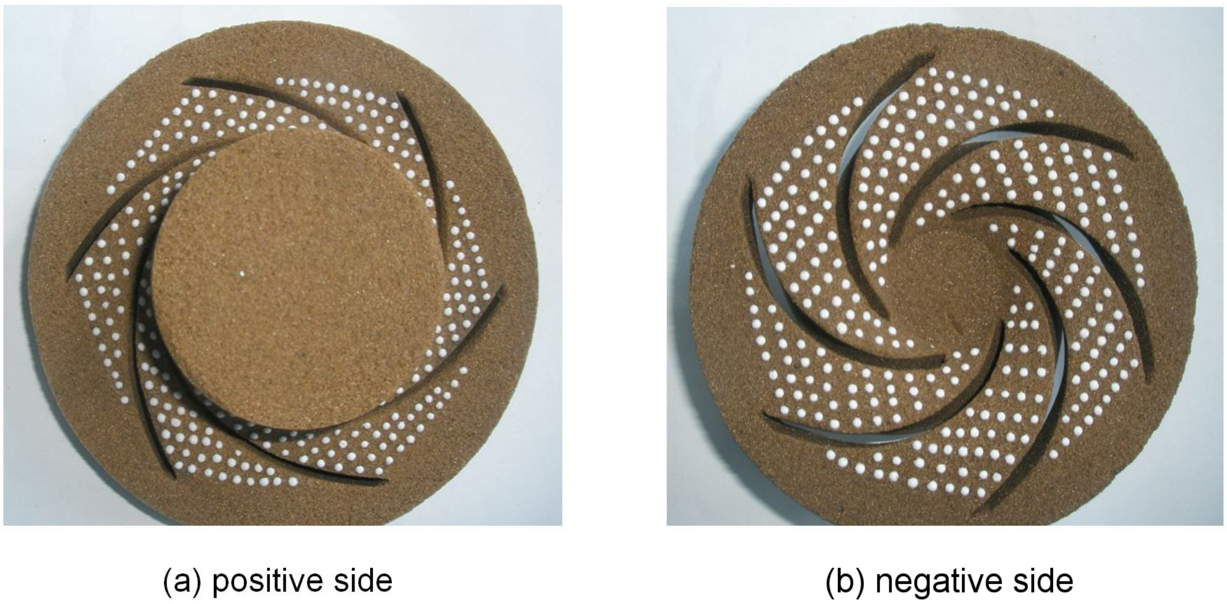

Figure 13. Pasting non-smooth structures on the two sides of the sand core.

7) painting

Painting HITCM on the convex domes and trying not to paint them on the sand core as much as possible.

8) Assembling and casting

Assembling the sand core with convex domes non-smooth surface to the cast mold, as shown in Figure 14 and then casting.

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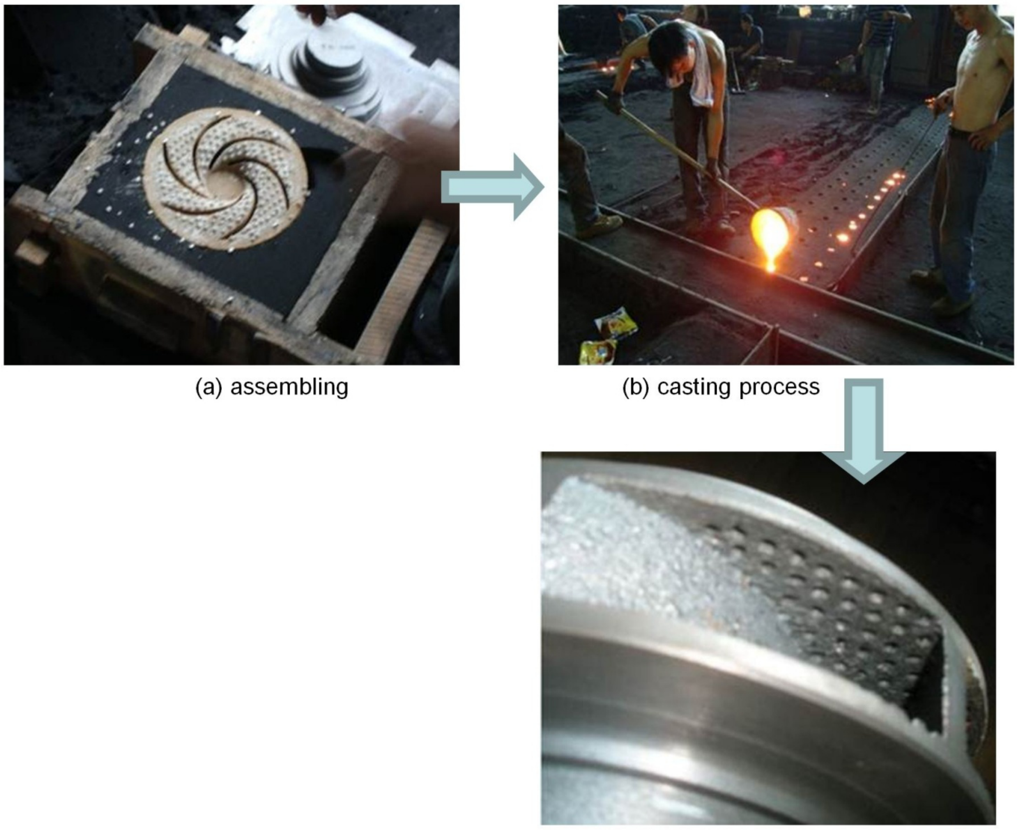

(a) assembling

(b) casting process

(c) sample of dimple concave impeller

Figure 14. Assembling and casting.

3. Results and error analysis of OTMC

According to this method, small rib-like bionic and dimple concave non-smooth surface can be formed on the complex cast, as shown in Figure 11 and 14c respectively. As for the rib-like non-smooth structures, its sharp corner can be formed desirably when the cross-section is a triangle. Compared with other processing methods, OTCM is advantageous in forming accurately and continuously, and most important of all, it will not produce residual stress on the casts.

Take the rib-like non-smooth structures as an example to conduct error analysis of OTMC. Here, the non-smooth structures are casted on the complex surface of water centrifugal pump impeller and their cross-section is an equilateral triangle. The designed size on the casts is as follows: the width of rib is 3 mm, the height of rib is 3 mm, and the distance between the two ribs is 6 mm. Measured by the calipers, the size of the final cast is: L=2.96 mm, H=3.03 mm and D=6.03 mm, as shown in Figure 15. This error is in the permissible designed range, and it can be accepted.

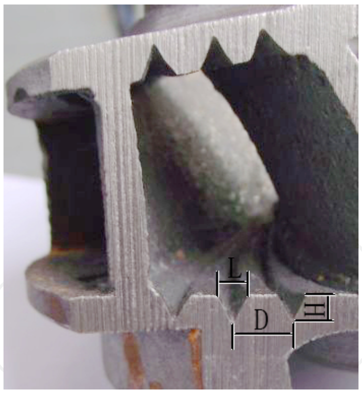

Figure 15. The size of the final cast. L is the width of rib, H is the height of the rib, and D is the distance between the two ribs.

4. Conclusion

It can be concluded from the above description and analysis that the process of OTMC should have a small adjustment according to the shape of non-smooth structures, although its mechanism is the same. The main process of OTMC should include: selecting material, forming non-smooth structures, painting HITCM, pasting non-smooth structures on the sand core to form non-smooth surface, drying, trimming and casting. The selection of intermediate media is very important, especially the selection of HITCM, because it is a key step to help form the desired non-smooth surface on the complex casts. In order to obtain desired non-smooth surface on the complex surface, several technical requirements should be met in the process of casting.

1. The surface of rubber convex section and the plexiglass plate should not be polluted by oil or other impurities which may affect the surface quality.
2. The highest resistant temperature of HITCM should not be lower than 1700°.
3. The shape and size of rubber convex section and convex domes should meet the designed requirements.
4. The non-smooth structures should be lined in accordance with the designed direction, location and curvature to form bionic non-smooth surface.
5. The process of casting should agree to the casting technical requirements set by different institutions.

By adopting this method, bionic rib-like non-smooth surface of impeller have been produced in large quantity and with a relatively low productive efficiency. However, production of dimple concave non-smooth surface on the complex casts in quantity still needs improving in the future.

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