PRECISION FORMING TECHNOLOGY AND APPLICATION IN HIGH RELIABILITY SUBMARINE MECHANICAL STRUCTURES

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Abstract: For the high reliability requirement of the submarine cable system, the dimensional accuracy of the underwater product structure is very high, and the metal structural parts are mostly manufactured by machining/CNC which cost long lead time. Precision forming technology is widely used in the materials industry, such as precision casting, precision forging, semi-solid precision forming, liquid precision forming, etc., and is often used in the Hi-Rel industries like aviation, aerospace, marine and automotive fields. In underwater products, those mechanical structures with less fating relationships and complex shapes are worth formed by such material processing, which not only saves machining time but also reduces raw material waste. This paper discusses the processing in submarine products and make trails by precision casting, mechanical tests on which show that it meets the design requirements of high reliability and products have been applied in contracts.

1. INTRODUCTION

The submarine communication systems have very strict requirements such as 25-year service life, extremely low failure rate, excellent corrosion resistance and strong strength to undergo continuous impact of sea water, which bring in the high reliability requirements in material selection, mechanical structure design and structure formation processing. Therefore, special valuable materials such as super stainless steel, copper beryllium alloy and titanium alloys are selected as the repeater housing materials which are used to manufacture aerospace products. With the increasing demands in fibre pairs, bandwidth and capacity, cost-effective and comparable system solutions become more and more significant and attractive. Precision casting (or called investment casting) is a net-shape and near-net-shape manufacturing processing, able to directly obtain components with complex shapes , make the design flexibility, and lead to less machining and lead time in the mass production, importantly, less costs. Precision casting has developed for several decades and plays an important role in the aerospace and submarine applications, for its dependence on the progress of material science, chemistry, vacuum metallurgy, high accuracy non-destructive inspection, and computer aided design and simulation. Compared with wrought alloys, the mechanical properties of castings have greatly improved. One case is titanium cast parts, properties associated with crack propagation and creep resistance are even superior to those of wrought products [1]. However, few attempts regarding precision casting were ever reported in the submarine communication parts. In this paper, precision casting procedure of titanium alloys was introduced and manufacture trials related to repeater bend limiter parts were made and good results were obtained as expected.

2. PROGRESS OF INVESTMENT CASTING

Casting procedure is normally classified into sand casting, graphite casting and lost wax casting by the difference of mold pattern materials. Sand and graphite are employed to cast large size parts which require neither precious size tolerance, fitting/cooperation with other parts, nor high mechanical properties. Sand mold is ever reported to manufacture Cu-Be repeater structure to reduce costs and have serviced for decades [2] that is encouraging to study further on titanium castings. However, titanium is too reactive for conventional sand-casting methods because of its high chemical active performance. Lost-wax process is now the principle technique in the high quality aerospace applications. The dimensional tolerance of titanium aviation castings with thin thickness 2.5mm, large outer diameter 920mm, have reached as high as IT5～7 by this method [3]. Progress in aerospace provides confidence for practice in submarine communication field. In the past few years, wrought titanium has been used successfully to manufacture repeaters and branching units. Since then more and more followers recognize titanium as valuable option in the design of new submarine products. Titanium investment casting processing are thus worthy studying and better understanding to explore its application.

3. TRIALS OF TITANIUM INVESTMENT CASTINGS

The critical parts of investment casting are wax pattern, shell materials selection, runner and gates design, and heat treatment. Shell materials are studied widely as the most important process. Runner and gates design is corresponding with the castings feature, usually is optimized by molding flow analysis software. Such analysis is helpful to understand potential defects and their distribution in different runners design, as well as to determine the competitive design.

In the meantime, software is also employed to simulate a multi-mold design in order to obtain the quality chart of each casting. Figure 1 shows how a software simulates an isolated casting process, what defects form and where be located, and what about the defects density. Simulation analysis plays a part in estimating the flaws and helps optimize the runner design, for example, to decrease quality risks, and now has been a standard part of casting process.

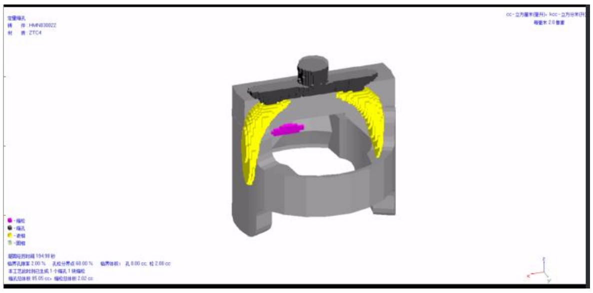
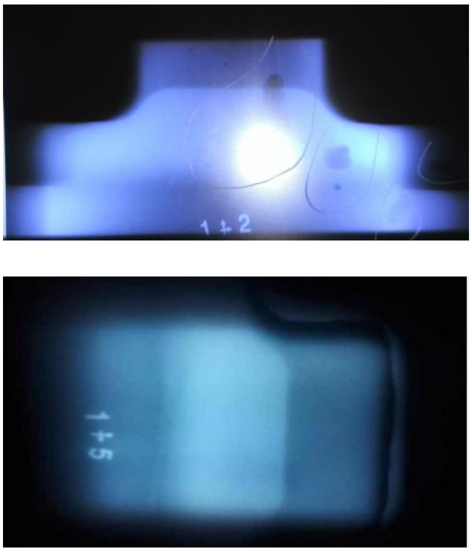


Figure 1: Casting processing simulation analysis of an isolated mold

Casting defects like inclusions, shrinkage and gas voids, are often identified as potentially affecting the mechanical properties, and are investigated worldwide aimed to greatly reduce them. Inclusions consist mainly of shell inclusions, hard alpha inclusions in the microstructure [3]. Experience of foundry has shown that to carefully select sponge titanium particles is prone to eliminate hard alpha inclusions in the subsequence melting and solidification process, which is used to cast high quality components not only in castings but also in a number of wrought materials. The complicated ceramic shell design and valued ceramic material make it less reaction of face coat and molten titanium. That greatly decreases the formation of shell inclusions. Unlike other alloys, titanium casting process is controlled under vacuum, so oxidation inclusions are hardly formed on the surface and easily removed by grinding and machining. Voids and shrinkage are the lack of solid materials, which can be bonded by subsequent high-isostatic pressure processing (HIP) at elevated temperature and high inert gas pressure. It is ever briefly summarized that HIP is able to eliminate void size less than 10mm for castings with small volume and weight smaller than 11kg [4]. Figure 2 clearly shows the internal shrinkage and void completely disappeared after HIP processing on a complex feature.



Above: prior to HIP Below: post HIP
Figure 2: Non-destructive inspection pictures

After HIP, castings are inspected from the surface to the internal by surface immersion and non-destructive X-ray methods. Those oversize defects, generally formed in thick and complicated features, will be removed by welding repair, 3 times at most for each feature. However, welding repair is not always a pass but will be rejected for the structures to endure hydraulic pressure. Experiments show that strength of the welding area is nearly the same with parent metals but ductility becomes weaker, because microstructure is different due to the fast cooling rate of the welding process. That is the main reason why to control the welding repair and set application limitation. Unfortunately, it is ever reported [4] that inert gas protection tungsten arc welding used in repair process is one source of inclusions formation, where the tip of the tungsten electrode is incorrectly contacted with the molten titanium liquids, resulted in the melting and solidification of tungsten inclusions. Definitely, these inclusions can be greatly improved by proper casting workshop environment control and personnel training, and have less effect on the final performance.

Generally, all weld repaired castings are stress relief annealed to enhance the ductility and plasticity. Annealing treatment shall be different based on the thickness, size of a casting. Figure 3 compares the mechanical properties of a cast titanium part with thickness of 20 mm in different annealing processes. The mechanical strength is similar, but elongation decreases with the time prolonged due to micro grain size growth. Temperature is recognized as the most important factor of annealing process, and shall be treated and optimized in priority rather than holding time.

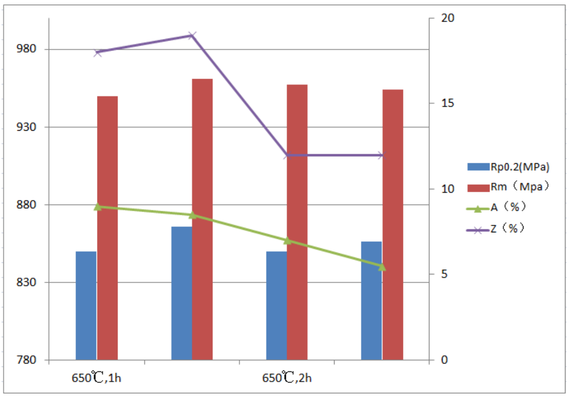


Figure 3: Effect of annealing treatment on mechanical properties of castings

The combination of strength, ductility, machinability, and dimensional stability of a casting reaches the best post annealing procedure. Mechanical testing shall be taken prior to qualification tests to understand what the weakness is. Figure 4 is a tension facility setup of titanium repeater bend limiter castings. The break tension load was only 460kN in the first trial where samples had no special requirements on the internal defects. The failure lesson requires more attention on the flaws and then process improvement was practiced to eliminate all defects in the stressconcentrated features. Finally, break tension qualification results demonstrate more than 100kN increasing, and meet the requirements. In the meanwhile, the same samples passed the round sheave testing and Fatigue test integrated with double armoured cable as well, as shown in Figures 5 and 6. The titanium investment castings have been successfully applied to one cable system in 2017 year.

Figure 4: Engineering tension facility setup for investment castings

Figure 5: Round the sheave testing on castings @ 200KN

Figure 6: Fatigue testing on castings

4. SUMMARY

Compared with wrought materials and machining process, investment casting has significant advantage in improving material utilization and decreasing machining lead time for parts with complexity features. Practice has approved that by proper processing, it is achievable to remove and finally eliminate the internal defects, enhance the combination of mechanical performance, meet the designs as required, and reduce the costs.

5. REFERENCES

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