Research on investment casting of TiAl alloy agitator treated by HIP and HT

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Abstract: Using TiAl alloy to substitute superalloy is a hot topic in aeroengine industry because of its low density, high elevated temperature strength, and anti-oxidization ability. In this research, Ti-47.5AL-2Cr-2Nb-0.2B alloy was used as the test material. By applying a combination process of ceramic shell mold and core making, vacuum arc melting and centrifugal pouring, and heat isostatic pressing (HIP) and heat treatment (HT) etc., the TiAl vortex agitator casting for aeroengine was successfully made. This paper introduced key techniques in making the TiAl vortex agitator with investment casting process, provided some experimental results including mechanical properties and machinability, and explained some concerns that could affect applications of TiAl castings.

Key words: TiAl; aeroengine; high temperature strength; heat isostatic pressing; heat treatment; investment casting

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Titanium is a very abundant structural metal element in the earth's crust. There is no other engineering metal that has so swiftly inclined to its pre-eminence in critical and demanding applications for aeronautical and aerospace industries since 1960s [1-4]. TiAl alloy is the most promising alternative lightweight high temperature structural material to conventional superalloy due to its specific modulus, specific high temperature strength, and anti-oxidization ability. The advantage in low density and high elevated temperature strength makes TiAl alloy an excellent candidate for some aeroengine combustion chamber components compared with conventional superalloy. Lighter weight components allow achieving improvements in either aeroengine performance or reduction of fuel consumption [5-12]. Many developed countries have done the research on TiAl alloy applications and obtained a lot of achievements [5-7]. In Japan Mitsubishi Motor Corporation manufactured TiAl automotive turbochargers by LEVICAST, a vacuum suction casting technology. In Korea TiAl automotive turbochargers were produced by VIM (Vacuum Induction Melting). In Germany ALD Vacuum Technology AG produced TiAl automobile valves by VIM. In USA GE produced TiAl aeroengine low pressure vanes. Comparatively more researches focus on applications of TiAl casting methods for automobile than for aeroengine because aeroengine requirements for the quality of TiAl castings are more and stricter than automobile [13-16].

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Therefore, in the present work, TiAl aeroengine vortex agitator was produced by VAM (Vacuum Arc Melting), and centrifugal investment casting methods on a laboratory scale. The issues involved in the study include preparation of ceramic mold and core, melting process, pouring system design and so on.

1 Experiment procedures

1.1 Preparation of TiAl alloy

Taking into account contamination and efficiency, water-cooled copper crucible substituted refractory crucible as TiAl alloy melting container. Ti-47.5Al-2Cr-2Nb-0.2B was selected as test material and was melted by VAM using a consumable electrode. In order to ensure ingot ingredient homogeneity, ingot was remelted. TiAl ingot chemical composition was shown in Table 1. The main chemical compositions were closely controlled to the nominal ones and the gas contents of N, H and O were also controlled to be as low as possible.

Table 1 Chemical composition of TiAl alloy, wt.%

	Al	Cr	Nb	N	H	O
Nominal	32.94	2.67	4.42			
Tested	33.56	2.71	4.77	0.014	0.0016	0.056

1.2 Preparation of ceramic shell mold and core

Because titanium is very active at high temperature and nearly reacts with most refractory materials, refractory ceramic shell is a key to titanium investment casting. Chinese researchers have mastered well several major titanium casting shell technologies such as graphite shell, metal surface layer ceramic shell, and oxide surface layer ceramic shell [3-4].

In this research oxide surface layer ceramic shell was used and yttrium and zirconium oxide materials were selected for surface coating materials. These oxide materials are very inactive to high temperature liquid TiAl alloy. The back layers were the same as those of steel and superalloy casting shells. This kind of oxide ceramic shell has high strength and low reactivity. It is suitable for gravity pouring and centrifugal pouring.

Because vortex agitator has very fine boss holes with 2 mm diameter, it is too difficult to be manufactured by machining. Technology of using ceramic cores to form these fine boss holes is a favorite way. The cores with 2 mm diameter were made by injection. Figure 1 shows the baked oxide ceramic shell.

Fig. 1 The baked oxide ceramic shell

1.3 Melting and pouring process of TiAl casting

Self consuming electrode vacuum arc skull furnace was used to melt and pour the TiAl vortex agitator castings. The ceramic shell was fixed on the centrifugal plate. When the vacuum level reached 3-5 Pa, the TiAl ingot was melted. As centrifugal plate rotates, the liquid metal was poured into the ceramic shell. The melting and pouring parameters were shown in Table 2. Figure 2 was the melting and centrifugal casting furnace.

Table 2 TiAl alloy melting and pouring parameters

Vacuum Pa	Melting current A	Melting voltage V	Rotate speed r/min
3-5	9 000-12 000	18-25	240

1.4 Heat isostatic pressing and heat treatment processes of TiAl alloys

During solidification, titanium alloy and TiAl alloy castings are easily to have shrinkage and gas holes. In order to eliminate the casting defects and to increase their compacted density, reliability and mechanical properties, the castings and their specimens were

Fig.2 The melting and centrifugal casting furnace

HIP processed. The treatment parameters of HIP process are as follows:

1 200-1 300℃/140-160 MPa/4-6 h

Because TiAl alloy has very low ductility at room temperature and the value is always below 1% even down to 0%, the specimens in the study were processed by heat treatment (HT) to increase ductility of TiAl alloy at ambient temperature as well as its mechanical properties at high temperature. The heat treatment process is as follows:

1 250-1 400℃/1-3 h → 900-1 150℃/3-8 h

2 Results and discussion

2.1 Centrifugal casting of TiAl vortex agitator

The fluidity of liquid TiAl alloy is lower than that of liquid Ti6Al4V alloy, so the shell mould is usually hard to be fully filled by gravity pouring, especially for thin-walled castings, and as a result, the casting defects such as misruns and cold shuts always exist. In order to ensure liquid TiAl alloy rapidly fill into shell mould, the ratio of section areas of sprue, runner and gate of pouring system, 1: 2: 4, is favorable. Applications of centrifugal pouring and ceramic shell with preheating can increase filling ability of liquid TiAl and reduce chilling of shell mold, to prevent the TiAl casting from occurring such defects as misruns and cold shuts. The preheating temperature for the shell should not be over 400℃ because reaction between liquid TiAl and ceramic shell could become more serious with higher shell temperature.

Because TiAl is so brittle at room temperature that castings after knocked out of shells often have cracks. High pressure water jet cleaner was used to break the shells for the castings. This method can greatly reduce impaction on castings, consequently, the quality of TiAl castings are significantly improved.

With applications of centrifugal pouring, ceramic shell and core, the TiAl vortex agitator has been successfully cast. Figure 3 shows a TiAl vortex agitator casting of Φ 60 mm-20 mm with minimum wall thickness of 3 mm and 8 fine boss holes with 2 mm diameter.

Fig. 3 TiAl vortex agitator casting

2.2 HIP and HT of TiAl vortex agitator casting

Both heating temperature and gas pressure are main parameters of HIP process applied in the TiAl alloy casting treatment. When heating temperature or gas pressure is too low, the TiAl alloy is still under high strength condition and defects as the internal shrinkage and gas holes etc. can not be eliminated. On the other hand, when heating temperature or gas pressure is too high, the TiAl alloy microstructure will tend to grow up, the alloy strength will fall and the casting will be easily distorted. From the experiments, it was found that the positive results of the TiAl alloy by HIP were achieved with parameters of heating temperature between 1 200 and 1 300℃ and gas pressure between 140 and 160 MPa.

The fine full laminar layer structure in the TiAl alloy castings is good for tensile strength, ductility and creep strength. In this research, β phase stabilizing elements Cr, Nb were added in the TiAl alloy. These two elements lead to the formation of B2 phase that is very brittle and harmful to ductility of TiAl. In the circumstances, HT is one of effective ways to eliminate the harmful B2 phase and form the fine laminar layer structure. It was found that the homogenizing treatment applied in the experiments is enabled to obtain fine full laminar layer structure. Heating time versus heating temperature is another pair of major parameters. The parameters affect dissolution of β stable elements Cr, Nb into B2 phase and the quantity of B2 in TiAl. If temperature was not enough high or heating time was not enough long, B2 phase could not be eliminated substantially and laminar layer size could not become finer.

It can be seen from some results of mechanical properties of the TiAl castings after treated by HIP and HT, as shown in Table 3 and Fig. 4 that the elongation at ambient temperature was increased to 1.16%-1.43% and its 760℃ mechanical properties increased significantly. Because the TiAl alloy ambient temperature elongation was over 1%, the TiAl castings and specimens were easily machined. The TiAl high temperature tensile strength was over 500 MPa and its elongation was over 9%.

3 Conclusions

(1) VAM (Vacuum Arc Melting) process is suitable to produce TiAl alloy and the chemical composition distribution of the TiAl alloy is homogeneous.

(2) By a combination of investment molding and centrifugal pouring, the TiAl vortex agitator casting has been successfully produced. Fine boss holes with 2 mm diameter inside the castings are easily cast.

(3) After treated by HIP and HT, both mechanical properties and machinability of TiAl castings are significantly improved. Especially ambient temperature elongation is increased to 1.16%-1.43%, and its 760℃ tensile strength is more than 500 MPa and elongation is over 9%.

(4) With the melting and casting processes in the study, the improved mechanical properties and machinability indicate that the TiAl alloy has potential to be a competitive and alternative material to superalloy.

Table 3 Mechanical properties of TiAl casting by HIP+HT

Specimens	Temp.	R_m MPa	$R_{p0.2}$ MPa	A_5 %
223-1	Room Temp.	535	417	1.16
223-2		502	386	1.43
224-2	760°C	540	346	9.60
224-1		566	359	13.30

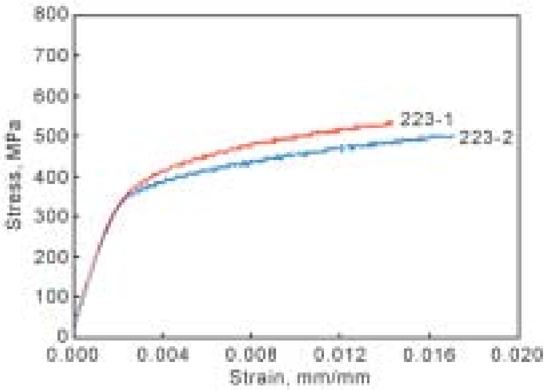

Fig. 4 Stress-strain diagram for TiAl casting at room temperature

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