Development of Titanium Exhaust Pipe

Takeshi MUNEMURA*　Hiroshi YAMADA*　Takayuki OHNUMA**

ABSTRACT

This paper discusses the use of titanium exhaust pipes for Formula One race cars in weight reduction. Newly developed processes for titanium material including heat treatment providing an acicular structure, oxidation resistant coating, sandwich press forming, and investment casting manufacturing have achieved a 20% weight reduction. This specification was not applied to race cars but provides technology for lightweight titanium exhaust pipes.

1. Background and Objective

Exhaust pipes are mounted on the upper part of Formula One race cars, and their component weight is high. Therefore, weight reduction has a large effect on enhancing chassis performance. Normally Inconel 625 (specific weight of 8.5 kg/cm^3), which has good high-temperature strength and workability, is used for exhaust pipes. In this research, titanium alloys, which have low specific weight (specific weight of 4.5 kg/cm^3), were selected as substitute material, in association with a variety of development efforts such as controlling the micro structure, enhancing oxidation resistance, and establishing casting and press forming method to reduce the weight of exhaust pipes.

2. Technology Developed

2.1. High Temperature Strength

Figure 1 shows the structure of an exhaust system. The exhaust pipe is made up of a primary pipe, collector, and tail pipe. The materials used are KS Ti-9 plate material manufactured by Kobe Steel, Ltd. and investment casting Ti-64.

The strength of titanium alloys is lower in high temperature environments exceeding 600°C. In order to enhance high temperature strength and creep resistance, heat treatment providing an acicular structure was carried out at 1000°C on the final process and structural control was performed. As shown in Fig. 2, specific fatigue strength is higher than Inconel 625 at temperatures lower than 800°C and so material replacement was feasible.

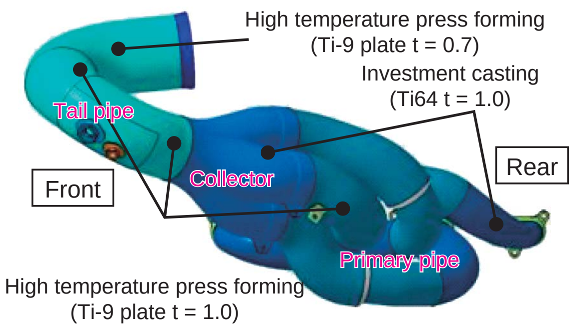

Fig. 1　Structure of exhaust pipe

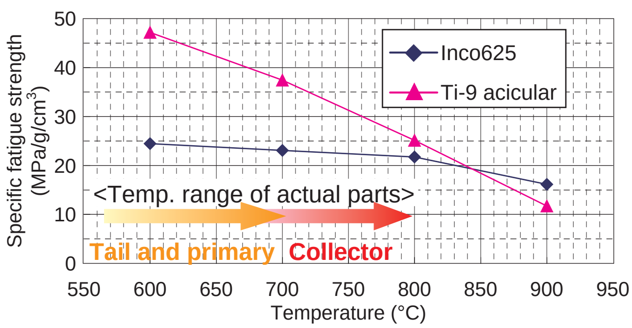

Fig. 2　Specific fatigue strength

* Automobile R&D Center
** Honda Engineering Co.,Ltd.

2.2. Oxidation Resistance

The oxidation of titanium alloys accelerates in high temperature environments so an oxidation-resistant coating became necessary. An internal dispersion process of aluminum was developed, enabling a titanium aluminum layer to be formed on the surface, and providing good oxidation resistance characteristics for atmospheric exposure at 950°C. Figure 3 shows processes for applying both a stable thick oxidation-resistant coating over the entire surface, including the inside of the pipes, and heat treatment for material structure control. A 30 μm stable titanium aluminum oxidation-resistant coating as shown in Fig. 4 was achieved.

2.3. Workability

In order to reduce thickness and weight and enhance design freedom in the shape, press formed parts and investment casting parts were welded together.

2.3.1. Press forming

As the elongation of titanium alloys at room temperatures is small, hot press forming of 600°C or higher was necessary, under which the material elongation is equivalent to that of Inconel material. However, the heat capacity of the thin plate material is low and the temperature dropped quickly after it has been taken off from the furnace, so cracking could not be avoided. Press forming was enabled through sandwiching using stainless steel plates on both sides to hold temperature constant (Fig. 5). In order to achieve both holding temperature and press dimension accuracy, a thickness of 1.0 mm was used for the stainless steel plates. These stainless steel plates prevent direct contact between the die and the titanium alloy plates and so they also help to control galling.

2.3.2. Investment casting

There had been no major accomplishment in thin wall casting of a complex shaped collector and lost wax casting is unable to meet the short term delivery of shape modifications required for racing. The requirements for casting were met using a Rapid Prototyping (RP) model, and by applying the LeviCast method (suction method by negative pressure). A thickness reduction by chemical milling was also utilized, and together these methods made it possible to reach the target plate thickness of 1.0 mm and a 30-day delivery time. Figure 6 shows a summary of the process and Fig. 7 shows the external appearance of the parts.

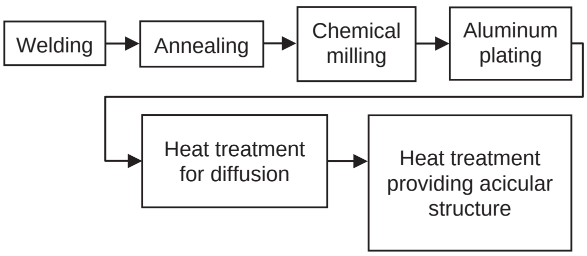

Fig. 3 Process of coating and heat treatment

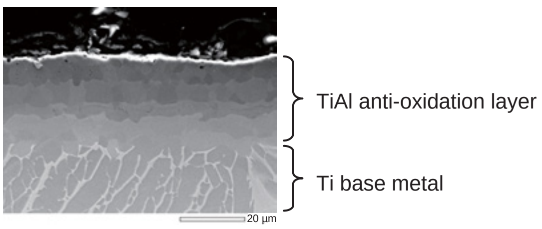

Fig. 4 Cross section of anti-oxidation coating

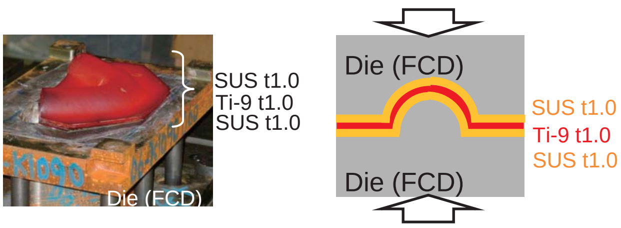

Fig. 5 Process of press forming

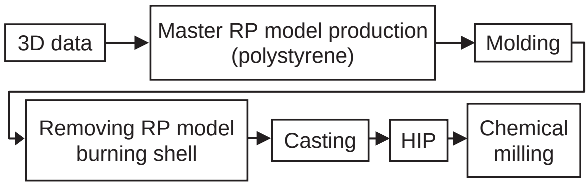

Fig. 6 Process of casting

Fig. 7 Casting collector and primary transitional pipe

3. Results

This development achieved a weight reduction of 1400 g (20%) per exhaust pipe assembly (Fig. 8).

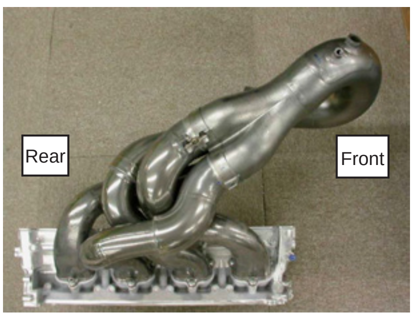

Fig. 8 Full titanium exhaust pipe assembly

4. Conclusion

The exhaust pipe for the 2007 specification had a unique layout: the exhaust pipe extending toward the engine in the forward direction, then loops back toward the rear. The loop-back area was broken during a track test and so this was not used for the race. However, in the 2006 specification (normal type; straight toward the rear of vehicle), the exhaust system based on this technology was used for 1200 km, confirming the durability of the technology.

This has shown that weight reduction is feasible by converting the exhaust pipe to titanium and optimizing the component shape.

■ Author ■

Takeshi MUNEMURA

Hiroshi YAMADA

Takayuki OHNUMA