Development of Hollow Titanium Connecting Rod

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ABSTRACT

It is necessary to reduce the reciprocating mass in order to increase the engine speed and power of Formula One engines. The project discussed in this paper therefore set out to increase the section modulus of the shaft of the connecting rod while maintaining its rigidity and achieving weight savings. To this end, the diffusion bonding method was optimized, and a process of manufacturing a hollow connecting rod was developed. The developed connecting rod is lighter in weight and higher in rigidity than a rod with a conventional I-type section produced by forging, and has contributed to enabling engines to be increased in speed.

1. Introduction

As one of the main kinetic components enabling the operation of high-speed and high-power Formula One engines, connecting rods (conrods) are the subject of a constant quest for weight reductions and increases in strength and rigidity. For this reason, titanium alloys displaying high specific strength were applied in their manufacture. In 2000, weight savings were achieved through the use of a β-rich α+β titanium alloy, SP-700[1], which possesses 25% higher fatigue strength than that of the formerly used 6A14V titanium alloy. However, responding to demands for further weight savings exclusively by means of increasing strength was bringing materials close to the limit of rigidity design, a situation which necessitated a new technological breakthrough.

The potential for the use of a hollow conrod structure as a means of achieving weight savings while maintaining a geometrical rigidity was therefore studied.

2. Developed Technology

2.1. Study of Method for Hollowing Conrod

A variety of potential methods of realizing a hollow conrod structure were studied. One suggested method was to form a hollow shaft extending from the big end by means of electrochemical or mechanical machining, which would then be cover-welded using electron beam welding (EBW), thus forming a hollow structure. However, this method was unable to resolve the issue of the strength of the joints. Issues of reduced strength also arose in the cases of casting and wax soldering.

Diffusion bonding, as employed in the manufacture of aircraft turbines, involves the diffusion of a solid phase, and therefore does not affect the base material by heating. In addition, titanium displays a high oxygen solubility limit, so oxide layers easily diffuse and disappear on titanium surfaces. Diffusion bonding was therefore focused on, and manufacturing methods for the component were studied on this basis.

2.2. Mechanism of Diffusion Bonding

Diffusion bonding is a bonding method in which the temperature of the materials to be bonded is maintained at 0.7 Tm (Tm = melting point) or more in a vacuum or reductive gas environment, and pressure is applied in order to promote diffusion. Figure 1 shows a model of the diffusion process[2]. In the initial stage of the process, the asperities on the surface to be bonded are deformed and their close adherence promoted by increasing pressure and heat. Next, diffusion causes the grain boundaries at the interface between the materials to migrate and vacancies to disappear. In the final stage of the process, the remaining vacancies disappear through

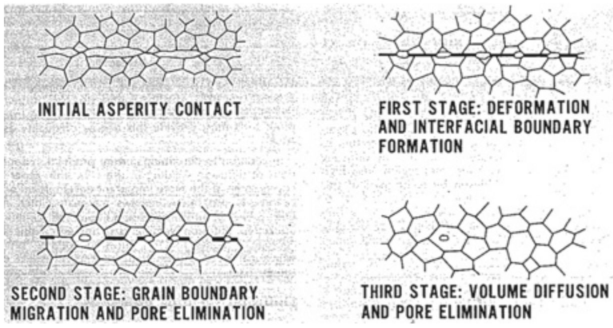

Fig. 1 Model of diffusion bonding process

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volume diffusion, and bonding is completed. Figure 2 shows the bonded microstructure realized in the conrod in this project. A continuous metallic microstructure with no remaining asperities at the bonding interface has been obtained.

2.3. Conrod Bonding Process

Because the conrod is solution-aged at a temperature lower than the β transformation temperature (870 °C) in order to obtain a predetermined level of strength, the bonding temperature was set at 830 °C, equivalent to the solution treatment temperature. The maximum pressure was set at 4.0 MPa, and the diffusion time kept for 5.0 hr. A hot press vacuum furnace owned by Kinzoku Giken Co., Ltd., capable of independent load control in 16 axes, was employed in the diffusion bonding.

Figure 3 shows the process of manufacture of the hollow conrod. A rolled sheet is roughly blanked using a water jet, after which it is machined into a half blank, forming a hollow shaft. These half blanks are superimposed and diffusion bonded.

The use of dowels positioned at the big and small ends controls relative displacement during bonding to within 0.13 mm at the upper limit of standard deviation. The amount of crushing in the direction of thickness was set at 4% of the initial thickness of the material, based on the height of the carbon stopper plates during hot pressing.

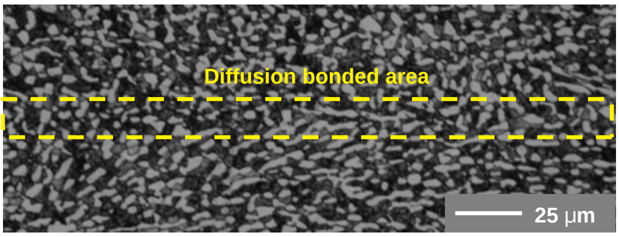

Fig. 2 Microstructure of diffusion bonded area of connecting rod

The level of roughness and cleanliness of the bonding surface affects the mechanical properties of the bonded section. Tests were therefore conducted to determine the effects of these factors using tensile test pieces bonded by means of two joint types (Fig. 4). Figure 5 shows tensile properties for different levels of bonded surface roughness. The level of surface roughness had a particular effect on the elongation and reduction area of the T-joint, and was therefore set at Rt1.6 or below in order to obtain tensile properties equivalent to those of the base material.

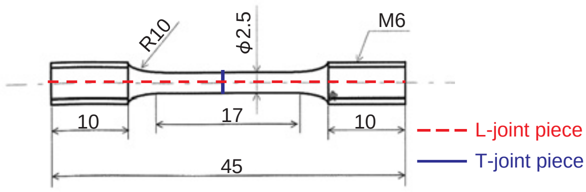

Fig. 4 Diffusion bonded tensile test piece

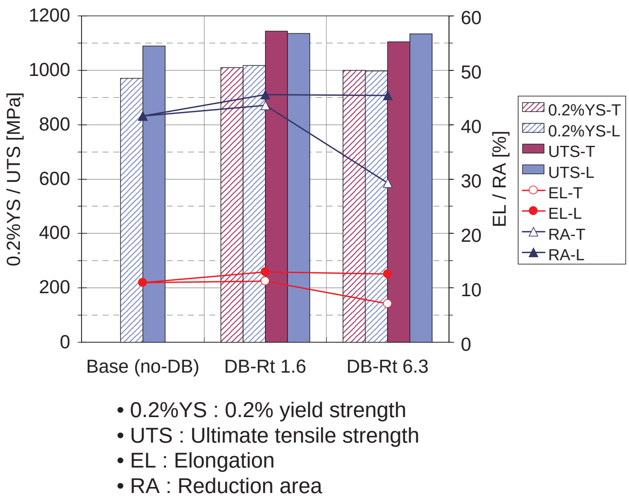

Fig. 5 Effect of surface roughness on tensile properties of diffusion bonded test piece

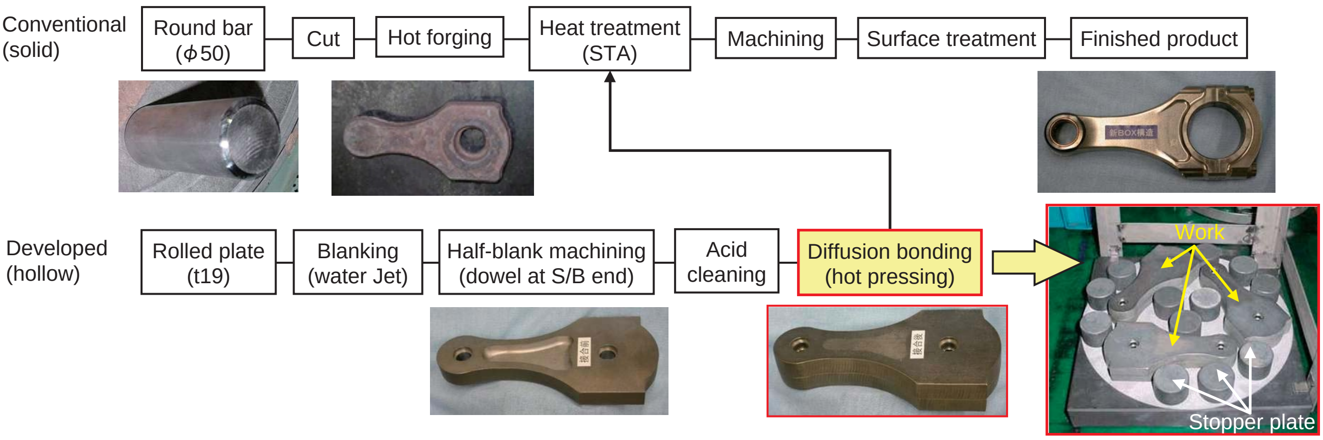

Fig. 3 Developed process of manufacture of hollow connecting rod

3. Achieved Performance

A hollow structure in which diffusion bonding is employed in the central section of the conrod thickness has been developed, as shown in Fig. 6. This has increased the modulus section of the shaft of the conrod while enabling thickness to be minimized. Compared to a conventional I-type section, an 8% reduction in weight, 2.5 times increase in the rigidity of the shaft, and 18% increase in the rigidity of the circulation of the big end have also been achieved. In addition, as a result of the reduction in the load on the conrod bearings, the potential for a 250 rpm increase in engine speed has been demonstrated in durability tests in a real engine.

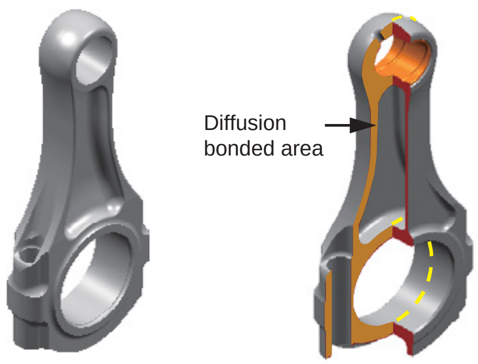

Fig. 6 Comparison of conventional and hollow conrod

4. Conclusion

A method of manufacture of a hollow conrod using diffusion bonding has been developed. The weight savings achieved enabled engines to be increased in speed and power, and the technology was introduced to race engines in 2003.

References

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(2) Owczarski, W. A., Paulonis, D. F.: Application of Diffusion Welding in the USA, Welding Journal, Vol. 60, No. 2, p. 22-33 (1981)

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