FRETTING FATIGUE STRENGTH OF Al-Si ALLOY FOR TRUCKS AND BUSES WHEELS

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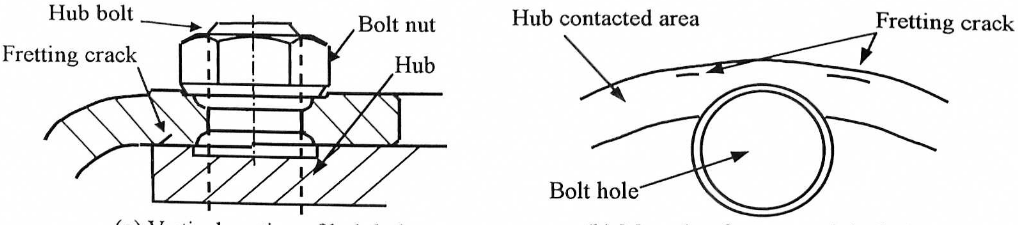
ABSTRACT

In this study, fretting fatigue tests were carried out in air as well as in water to compare the fretting fatigue strength of cast Al-Si alloy (JIS AC4CH-T6) with that of forged aluminum alloy (JIS 6061-T6). According to the test results, although plain fatigue strength of cast Al-Si alloy was lower than that of forged one, fretting fatigue strength of cast Al-Si alloy was almost equal to that of forged one in both air and water. Additionally, the fretting damage of the aluminum wheels mounted in buses or trucks and used in the field was also investigated. It was found that fretting fatigue cracks were found only in the forged wheels, but not in the cast wheels.

Keywords: *fretting fatigue, cast Al-Si alloy, forged aluminum alloy, aluminum wheel*

1. INTRODUCTION

Forged aluminum alloy wheels (size:22.5×8.25～19.5×6.75 in.) have been widely used for trucks and buses. Recently cast Al-Si alloy wheels for trucks and buses (size:22.5×8.25～17.5×5.25 in.) have been developed by applying low-pressure casting process and have been in practical use, because this process allows higher freedom in design and lower cost than the forging process. Of course, cast aluminum alloy wheels should have the same or higher endurance and performance than forged one. The dominant damage of trucks and buses aluminum wheels is fretting fatigue cracks initiated on the mounting face which contacts with wheel hub as well as fatigue cracks around the nut seat. Schematic drawing of fretting fatigue crack initiated on the mounting face is shown in Fig.1. Fretting fatigue cracks will initiate in the early stage in the field use and then they will govern wheel life. In this study, fretting fatigue tests were carried out to clarify the fretting fatigue strengths of cast and forged aluminum alloys. In addition, fretting fatigue damage of the wheel, which had been mounted in buses and trucks for a long distance in the field use, was investigated.



(a) Vertical section of bolt hole (b) Mounting face around the bolt hole

Fig.1 Fretting fatigue crack on the mounting face

2. EXPERIMENTAL PROCEDURES

2.1 Fretting fatigue test

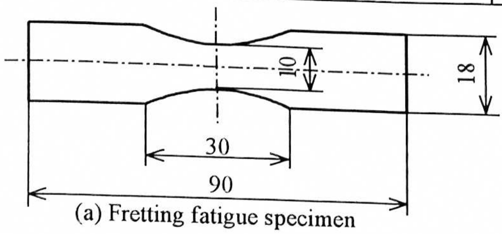
Three kinds of materials were used in this test. Two of them were for specimens and the rest was for contact pad. Chemical composition and mechanical properties of the former two materials are shown in Table 1 and 2, respectively. Spheroidal graphite cast iron (JIS FCD500) was used for the contact pad, since it was used for hub on trucks. Shapes and dimensions of the fretting fatigue specimen and the contact pad are shown in Fig.2 (a) and (b), respectively. All fatigue tests were carried out using a plain bending type fatigue testing machine under the frequency of 15Hz and the stress ratio of -1. Fig.3 schematically shows the fretting fatigue test set-up. The contact pad was pushed against the specimen by using a proving ring during test to give a contact pressure of 50 MPa. The tangential force between the contact pad and the specimen was measured by using strain gauge attached to the neck part of the contact pad holder.

Table 1 Chemical composition of the material used for the specimen

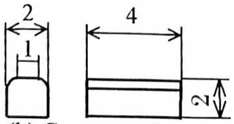
	Si	Fe	Cu	Mn	Mg	Cr	Zu	Ti
AC4CH	6.6	0.12	0.03	0.02	0.36	0.03	0.03	0.13
6061	0.57	0.35	0.29	0.04	0.87	0.18	0.03	0.02

Table 2 Mechanical properties of the materials used

	Tensile strength σ_B(MPa)	Elongation Φ(%)	Hardness (Hv)
AC4CH	218	3.0	110
6061	354	11.5	140



(a) Fretting fatigue specimen



(b) Contact pad

Fig.2 Fretting fatigue specimen and contact pad

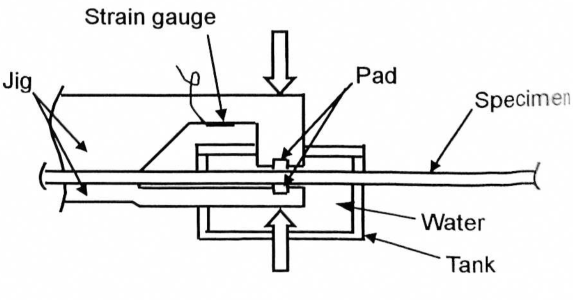


Fig.3 Schematic drawing of fretting test

2.2 Investigation of fretting damage on the wheels used in field

Fretting damage on the wheel in field use at two local wheel users was investigated. One user was a passenger traffic agent, who owned the large-sized buses, which were highway buses (between Tokyo and Fukuoka, Osaka and Fukuoka). The other user was a transport agent, who used the large-sized trucks. Their buses and trucks were mounted on both the cast and forged wheels.

The investigation was carried out for the front wheels because the fretting damage tended to occur more frequently at front wheels. As shown in Table 2, the tensile strength of the cast Al-Si alloy is lower than forged one. To make up for the difference, cast Al-Si alloy wheels were reinforced by the following methods.

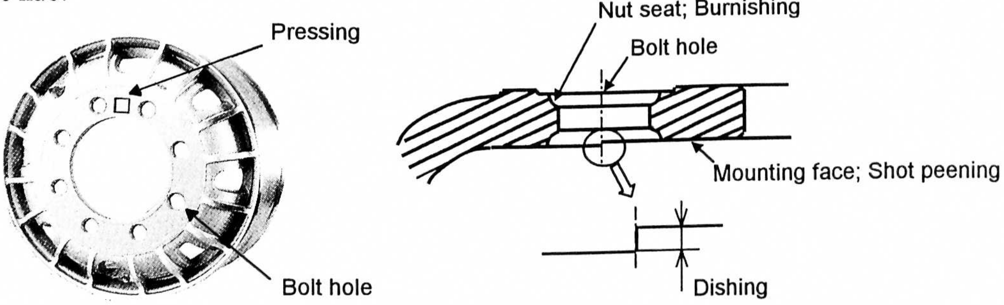
(1) Pressing; Pressing the area between bolt holes, which is shown in Fig. 4. Pressing introduces compressive residual stress around the nut seat. Therefore, it can suppress crack propagation from the nut seat.

(2) Burnishing; Compressive residual stress is also induced to the nut seat by burnishing. The layer from the surface to 300 μ m depth is hardened by 20~25 points (Hv 10g).

(3) Shot peening; The mounting face is shot-peened by stainless steel cut wire to suppress fretting fatigue crack propagation. In fatigue test, fatigue life of shot-peened specimen showed six times longer than that of unpeened one at a stress amplitude of 150 MPa.

(4) Dishing; Dishing is a dent of mounting face, as shown in Fig.4. It makes the contact area between mounting face and hub more even and distant from the center hole, thus decreasing stress amplitude and relative slip amplitude between mounting face and hub.

After running of 200,000~500,000 km, the penetrant test of the front wheels was carried out to check the fretting fatigue crack initiation at mounting face. In addition, the wear depth of the mounting face in contact with the hub and that of hub in contact with the wheel mounting face were measured in order to clarify the difference of wear characteristics between cast and forged wheels and the hub.



(a) Cast aluminum wheel (b) Dishing at mounting face

Fig.4 Schematic drawing of bolt hole section

3. RESUITS AND DISCUSSION

3.1 Fretting fatigue test

3.1.1 Fretting fatigue strength

S-N curves for plain and fretting fatigue in air and water are shown in Fig.5. Although plain fatigue strength of the cast alloy was lower than that of the forged one, fretting fatigue strength of the cast alloy was almost equal to that of the forged one in both air and water. In order to check the fretting fatigue crack initiation, fretting fatigue test was interrupted at 10 % of the number of cycles to failure at a stress amplitude of 140MPa. The fretting fatigue crack propagation from the fretted surface was confirmed for both the cast and forged specimens in air and water. Relationship between tangential force coefficient, F/P, which is defined as the ratio of frictional force F and contact load P, and stress amplitude is shown in Fig.6. Tangential force coefficient of both cast and forged alloys increased with increasing stress amplitude and attained a constant value (around 0.8 in air, 0.4 in water).

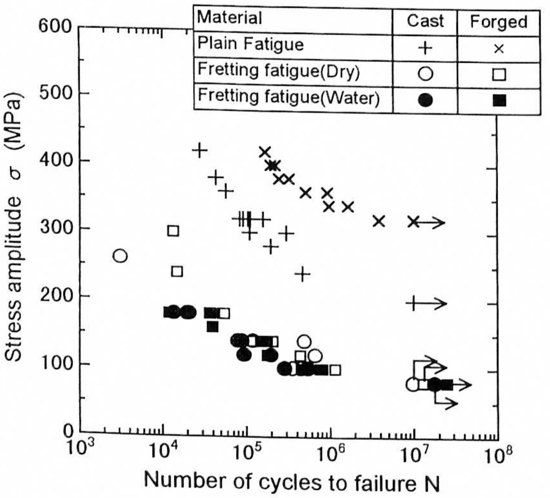


Fig.5 S-N curves

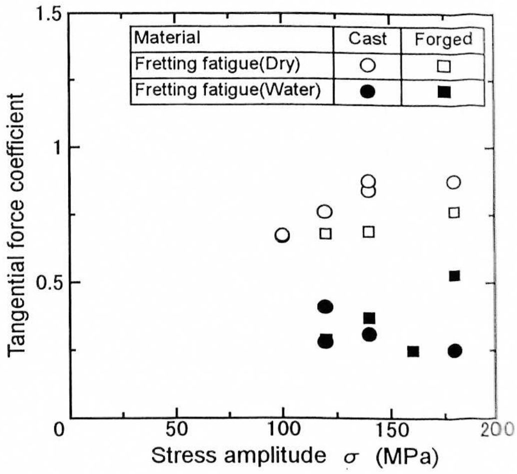


Fig.6 Relationship between stress amplitude and tangential force coefficient

3.1.2 Crack propagation characteristics

Crack propagation curves of both cast and forged alloys in air are shown in Fig 7. The crack propagation curves of the cast and forged alloys coincided with each other. It is considered that the crack initiation and propagation due to fretting action would be delayed in water because tangential force coefficient was lower in water than in air. On the other hand, it is presumed that the crack growth rate may be accelerated in water. Consequently, fretting fatigue strengths in water coincided with those in air.

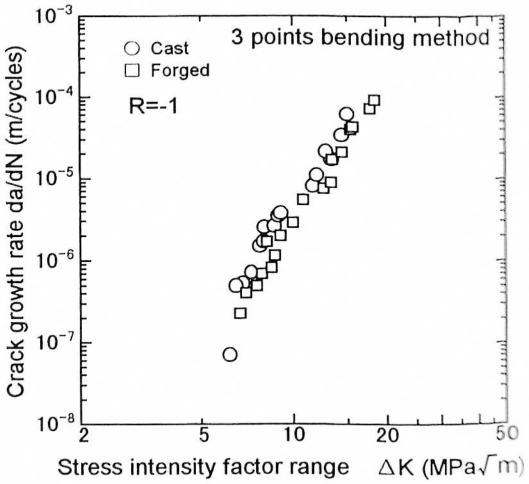


Fig.7 Fatigue crack growth curve

3.2 Investigation of fretting damage on wheel in field use

3.2.1 Fretting fatigue crack (Data at the passenger traffic agent)

The result of penetrant test is shown in Table 4. The wheels were demounted from the buses after running of 500,000 km and they were checked by penetrant test to find cracks. Photographs of the mounting faces of cast and forged wheels after checking are shown in Fig 8. Fretting fatigue cracks were found on the mounting face of the forged wheels, while they were not observed in the cast one. Since these wheels were mounted again on the same vehicles for the successive monitoring, detailed observation by optical and scanning electron microscopes could not be applied. The cast wheel has dishing at the mounting face. In the past experiments on steel wheels, it was found that dishing decreased the stress amplitude at the mounting face and decreased the relative slip amplitude between the mounting face and the hub. These results are caused by that the real contact area between the mounting face and the hub is increased and the contact pressure becomes even due to dishing. Therefore, the rigidity between the mounting face and the hub is improvement.

Table 4 Results of the penetrant test of the wheels used in the field

Wheels	Bus NO.	Running (km)	Penetrant test results			
			Left		Right	
			S	M	S	M
Cast	1	around 500,000	○	○	○	○
	2		○	○	○	○
Forged	3		○	×	○	×
	4		○	×	○	×

S: Surface of the wheel, M: Mounting face of the wheel, ○ : no crack, × : fretting fatigue crack

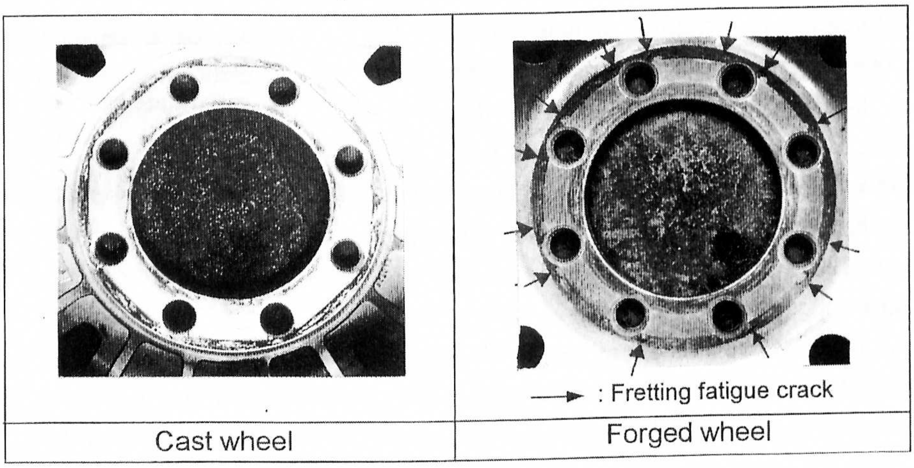


Fig.8 Mounting faces after checked by penetrant test

3.2.2 Wear of fretted area of wheel and hub (Data at the transport agent)

Wear depth on the mounting face in contact with the hub is shown in Fig.9. Wear depth of cast wheel was about one third of that of forged one. Wear depth of the hub is also shown in Fig.10. Wear depth of the hub contacting with the cast wheel was less than that contacting with forged one. Relationship between relative slip amplitude and wear weight for cast and forged aluminum alloy specimens is shown in Fig 11. There was no significant difference of wear weight between cast alloy and forged one. The wear weight tended to increase with increasing relative slip amplitude.

Accordingly, the difference of wear depth between cast and forged wheels will be mainly due to the difference of relative slip amplitude between the mounting face of wheel and the hub.

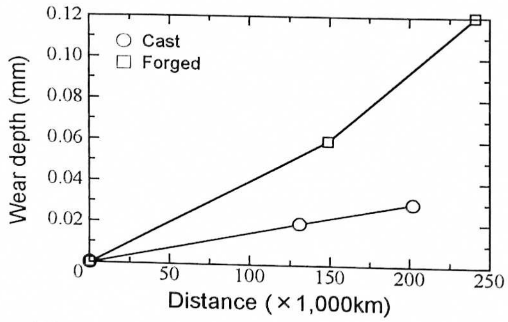


Fig.9 Wear depth of the mounting face

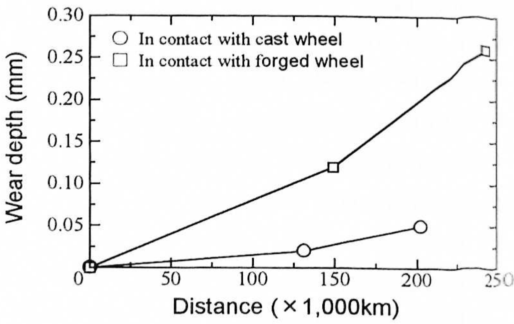


Fig.10 Wear depth of the hub

3.3 Fretting fatigue strength of cast Al-Si wheel

It is well known that fretting fatigue strength decreases with increasing relative slip amplitude, and almost attains a constant value with above a certain value of relative slip amplitude[1)~3)]. Therefore, it is considered that the difference of the relative slip amplitude between cast and forged wheels influences the fretting fatigue crack initiation behavior. Since fretting fatigue cracks were not found in cast Al-Si wheel in this investigation, it is presumed that decrease in relative slip amplitude by dishing as well as compressive residual stress by shot-peening contributes to suppress the fretting fatigue crack initiation and propagation.

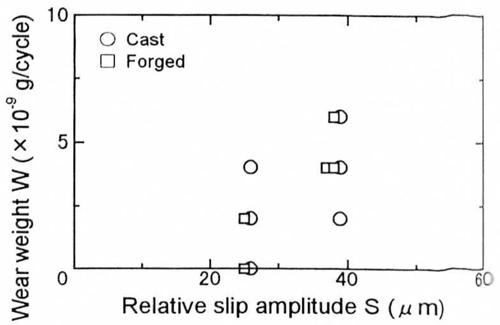


Fig.11 Relationship between relative slip amplitude and wear weight

4. Summary

Although plain fatigue strength of cast Al-Si alloy was lower than that of forged one, fretting fatigue strength of cast Al-Si alloy was almost equal to that of forged one in both air and water. Fretting fatigue damage of the aluminum wheels that had been mounted on buses or trucks and used in the field was also investigated. Fretting fatigue cracks were observed only in the forged wheels, but not in the cast wheels after running of 500,000 km. Reduction of relative slip amplitude between the wheel and the hub due to dishing and the compressive residual stress by shot-peening will contribute to suppress the crack initiation and propagation in the cast Al-Si wheels.

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