Fatigue performance of Light metals (A6005C and AZX611) and their FSW joints.

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Fatigue performance of Light metals (A6005C and AZX611) and their FSW joints.

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1 Introduction

Expansion of the application of aluminium alloy A6005C and uninflammable magnesium alloy AZX611 for railway vehicle is expected to reduce the total weight for suppressing the driving energy. To achieve this objection, assurance of the structural integrity, in particular the fatigue performance of these alloys and their joints fabricated by FSW is essential. FSW is a novel joining technology methods for light metals and has advantages comparing with standard arc welding applied for railway vehicle constructions.

Fatigue performance of A6005C and AZX611 and their FSW joints investigated by high speed cantilever type rotating tests and axial fatigue tests are reported in this paper. Some topics for fatigue test, which correspond to the effect of specimen surface roughness, the temperature elevation effect in high speed rotating test and the difference loading mode, are discussed.

2 Preparation of specimen and test conditions.

Two kinds of materials, which are aluminium alloy A6005C and uninflammable magnesium alloy AZX611 and their FSW joints, were used. Chemical composition and mechanical properties of applied materials are shown in Tables 1 to 3.

Table 1 Chemical composition of A6005C used (wt%)
(a) Cantilever type specimen for base metal.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.57	0.05	0.10	0.07	0.66	0.05	0.00	0.01

Applied to cantilever type specimen for base metal.

(b) Cantilever type specimen for FSW joint, Ono-type specimen and axial loading specimen.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.59	0.05	0.11	0.08	0.67	0.04	0.00	0.01

Table 2 Mechanical properties of A6005C used.
(a) Cantilever type specimen for base metal.

0.2% proof strength (MPa)	Tensile strength (MPa)	Elongation (%)
238	279	8.0

(b) Cantilever type specimen for FSW joint, Ono-type specimen and axial loading specimen

0.2% proof strength (MPa)	Tensile strength (MPa)	Elongation (%)
282	256	12.6

Table 3 Chemical composition of AZX611 used (wt%).
(a) Cantilever type specimen for base metal.

Al	Zn	Mn	Si	Cu
6.00	0.56	0.33	0.02	<0.002
Ni	Fe	Mg	Ca	
<0.002	<0.002	Rem.	1.0	

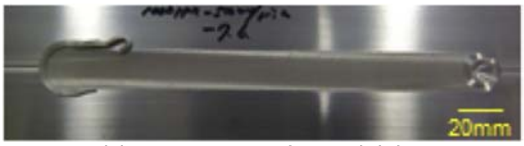
(b) Cantilever type specimen for FSW joint, Ono-type specimen and axial loading specimen

Al	Zn	Mn	Si	Cu
5.93	0.98	0.23	0.02	0.01
Ni	Fe	Mg	Ca	
0.00	0.00	Rem.	0.84	

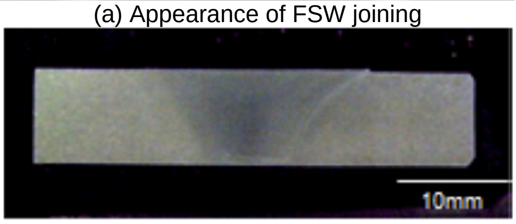
FSW joining conditions for each material are shown in Table 4. Tensile strength of A6005C FSW joint applied to fatigue tests was 215 MPa, which corresponds to 76% obtained by base metal specimen, and the breaking position in tensile test specimen was HAZ. Appearance and cross-section of each joint are shown in Figs.1 and 2.

Table 4 FSW joining conditions.

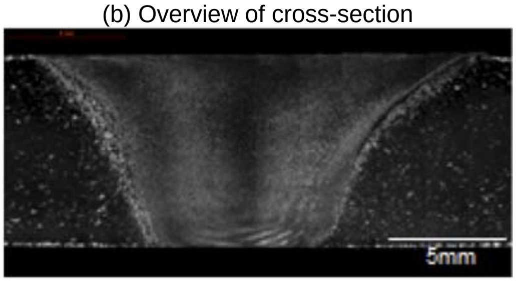
Conditions	Materials	
	A6005C	AZX611
Tool shoulder diameter (mm):	20mm	
Tool probe:	M8, Right-hand thread	
Tool advancing angle (degree):	0.5	0
Tool rotational direction:	Anti-clockwise	
Travel speed (mm/min)	500	100
Tool rotational speed (rpm)	1,000	400



(a) Appearance of FSW joining

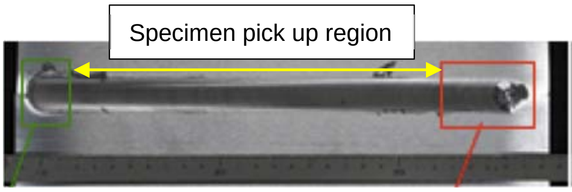


(b) Overview of cross-section

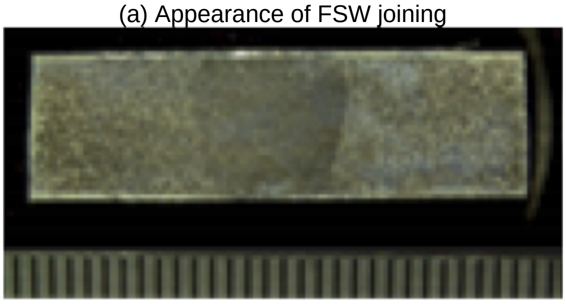


(c) Macroscopic observation of cross-section

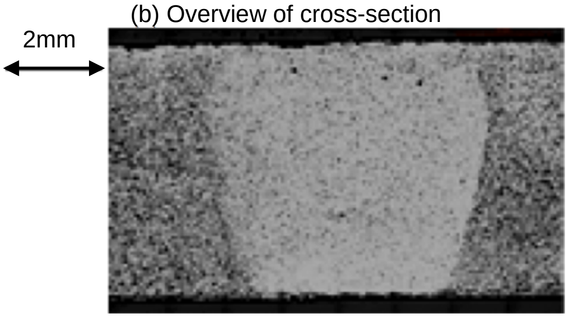
Fig.1 Appearance and cross-section of A6005C FSW joint.



(a) Appearance of FSW joining



(b) Overview of cross-section

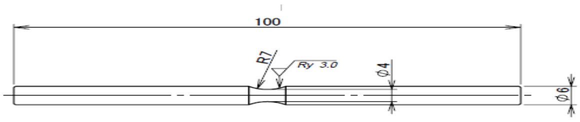


(c) Macroscopic observation of cross-section

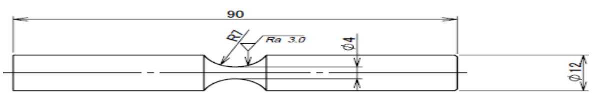
Fig.2 Appearance and cross-section of AZX611 FSW joint.

Three types of loading method, which are high speed cantilever type rotating test, conventional Ono-type rotating test and axial loading test, were applied. Specimen configurations used are shown in Fig.3. Stress concentration factor of each specimen arranged to 1.08.

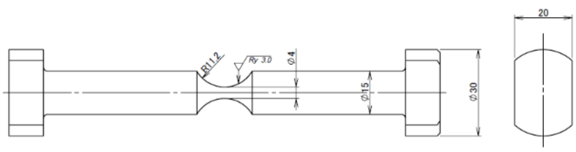
The high speed cantilever type rotating test system was proposed by one of authors [1] to save test period and materials. This loading method is positioned as the main fatigue test method in this study.



(a) Cantilever type rotary bending specimen (K_t=1.08).



(b) Ono-type rotary bending specimen (K_t=1.08).



(c) Axial loading test specimen (K_t=1.08).

Fig.3 Specimen configurations used.

Rotating speed of cantilever type and Ono-type rotating test was 3,000 rpm (50Hz) and 3,100 rpm (52Hz), respectively. Loading frequency of axial loading test was 20Hz.

3 Fatigue test results of A6005C

3.1 Effect of specimen surface roughness

Effect of surface roughness for fatigue test result was investigated. Specimens for cantilever type with three different surface roughness were prepared. Average roughness of each stage is R_z= 1.6 μm, 12.5 μm and 25.0 μm. R_z= 1.6 μm is standard surface roughness in this research.

S-N curves of each fatigue test are shown in Fig.4 and these results suggest that the degree of difference in the specimen surface roughness examined in this study does not affect the fatigue life.

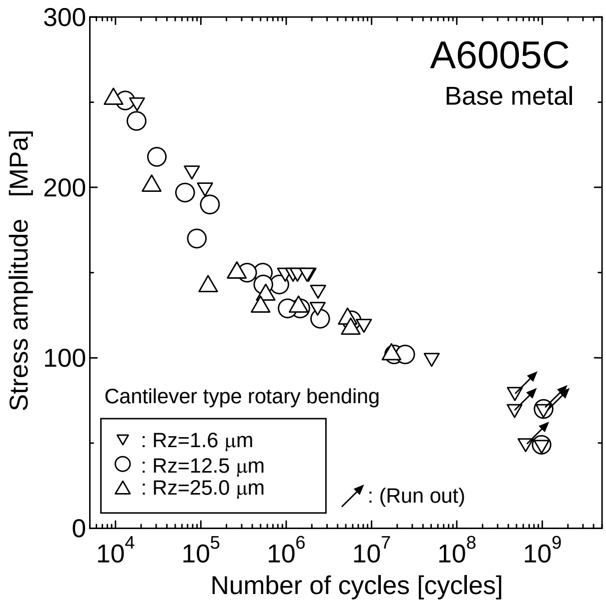


Fig.4 S-N curves of A6005C base metal with different surface roughness.

3.2 Effect of loading mode

S-N curves of each fatigue test are shown in Fig.5. These results suggest that effect of the difference of loading mode applied in this research could be ignored by considering the scatter occurring in general fatigue tests.

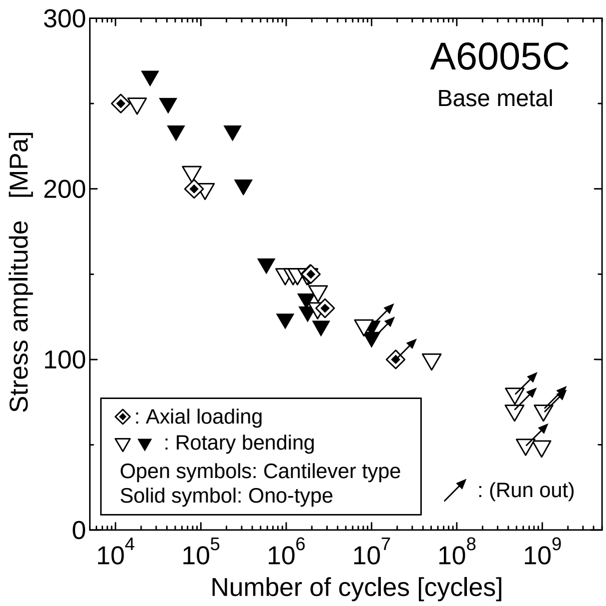


Fig.5 S-N curves of A6005C by the different loading modes.

3.3 Comparison of fatigue performance of FSW joints with base metal

Fatigue test results by applying FSW joints taken from the Thermo-Mecanically Affected Zone (TMAZ) and the Heat Affected Zone (HAZ) were compared with ones of base metal. These results are shown in Fig.6.

It is confirmed from Fig.6 that the fatigue performance of FSW joint taken from TMAZ has comparable to base metal. On the other hand, fatigue performance of FSW joint taken from HAZ has slightly inferior than base metal.

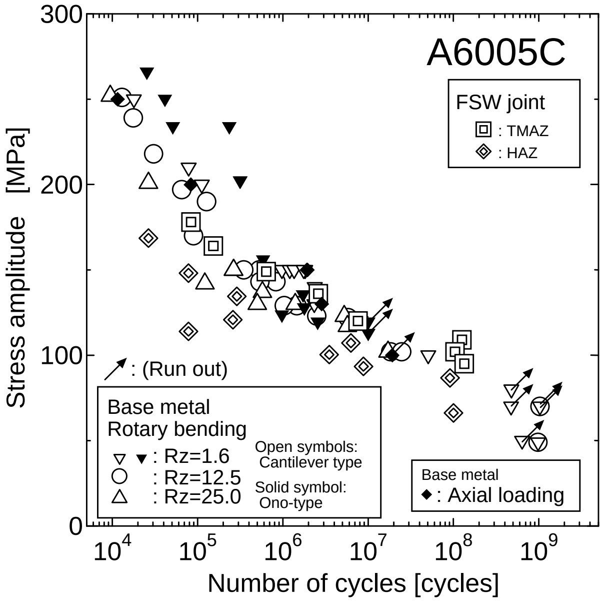


Fig.6 Comparison of S-N curves of FSW joints taken from TMAZ and HAZ with base metal made of A6005C.

4 Fatigue test results of AZX611

Fatigue test result of AZX611 base metal and its FSW joint taken from the stir zone (SZ) are shown in Fig.7. All of the breaking locations of FSW specimens were not the location with the minimum cross-section but the clamping positon. No fracture generating sources, e.g. notches caused by the clamping, initial defects or impurity inclusions, were confirmed after SEM observations over each fracture surface. Although the reason why all of FSW specimens broke at the clamping position have not identified yet, it is confirmed from Fig.7 that the fatigue performance of FSW joint made of AZX611 has comparable to base metal. It should be piled up more test data of FSW joints to confirm the fatigue performance of FSW joint. In addition, it is strongly recommended to perform the fatigue tests of FSW joints by using the specimens taken from TMAZ or HAZ.

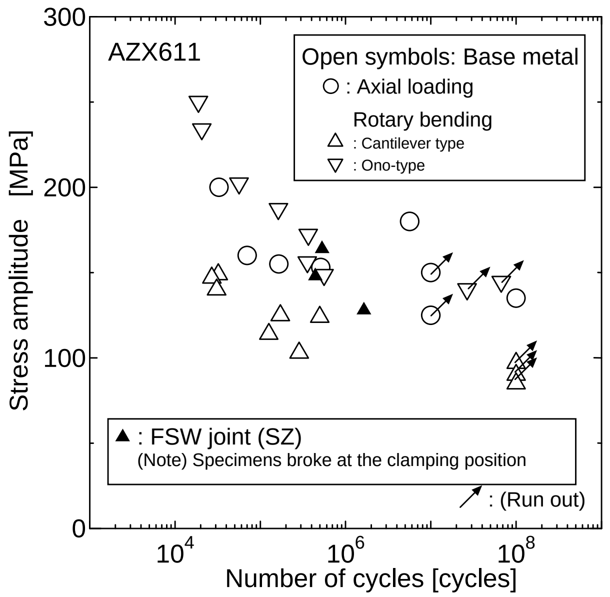


Fig. 7 S-N curves of AZX611 base metal and its FSW joint taken from SZ.

5 Local temperature rises during the fatigue test

To save the test period, it is expected to raise the loading frequency of fatigue test. It is, however, worried that the local temperature rises near the fracture location caused by the cyclic plastic work might affect the fatigue test results.

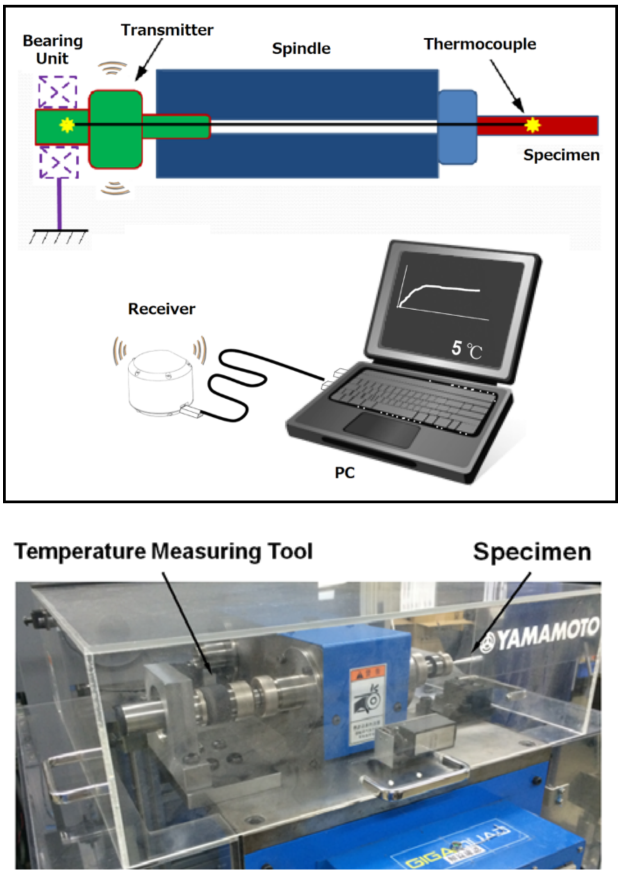


Fig.8 Local temperature measuring system used.

Local temperature rise generated in the specimen by the high speed cantilever type loading was measured. Applied material is A6005C used in the fatigue test mentioned above section. Overview of measured apparatus is shown in Fig.8. Thermo-couple was inserted in near the minimum cross-section of specimen and temperature measuring tool was set at the specimen rotating spindle part. Temperature history was transferred by wireless and was measured in real time. Schematic illustration of temperature measured specimen is shown in Fig.9. Diameter of tunnel to insert thermos-couple is 0.5mm.

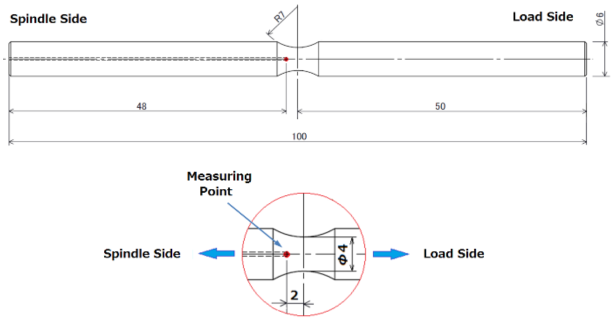
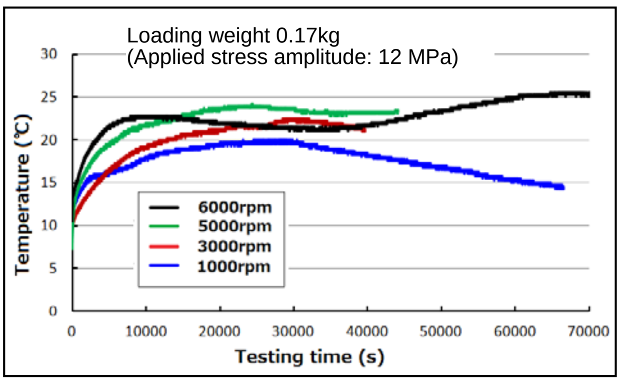


Fig.9 Temperature measured specimen configuration.

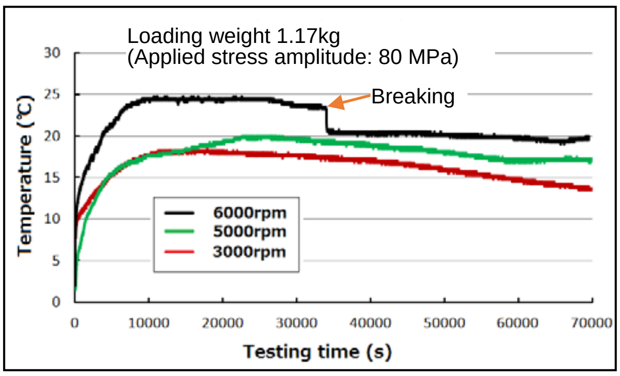
Four rotational speeds and three loading weight were applied for the experiments. Test conditions are summarized in Table 5

Table 5 Test conditions.

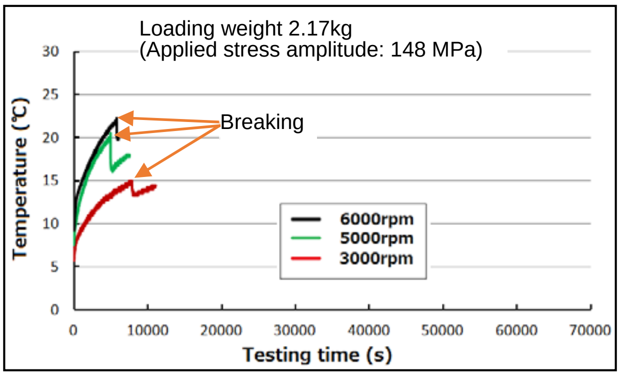
Rotational speed (rpm):	1,000, 3,000, 5,000, 6,000
Loading weight (kg):	0.17, 1.17, 2.17



(a) Loading weigth 0.17 kg.



(b) Loading weight 1.17 kg.



(c) Loading weight 2.17 kg.

Fig.10 Measured temperature histories.

Figure 10 is the time history of measured temperature under the conditions of different rotational speeds and loading weights. It is confirmed from Fig.10 that the temperature rises by increasing rotational speed. In addition, measured temperature rises are less than 30 degrees. Measured temperature rises might be caused by not only the plastic hysteresis in the specimen but also the rotating bearing in the spindle and the specimen clamping adapter. Then, pure temperature rises caused by the plastic hysteresis might be less than measured results.

By considering these results, it is expected to increase the rotational speed at least 6,000 rpm when the high speed cantilever type loading test system is applied for the fatigue test.

6 Activity to establish new fatigue test standard in Japan

Saving of fatigue test period and cost is one of important factors for designing new light weight vehicles. Recently, more than 10^7 cycle fatigue strength should be evaluated to satisfy the structural integrity of the vehicle. Evaluation of 10^8 cycle fatigue strength for the design might be requested in the near future.

Although high speed fatigue test method by resonating a specimen was proposed and applied, the effect of local temperature rise and the difference of loading mode by resonating type test for fatigue test result has not clarified yet.

By considering these situations, Japan Light Metal Welding Association has been organizing the research committee (chairman: Prof. Kazuhiro Nakata, Osaka University) supported by Ministry of Economy, Trade and Industry of Japan to propose new fatigue test method for light weight metal on 2014 and will propose new ISO standards in the near future.

7 Conclusion

Fatigue performance of A6005C and AZX611 and their FSW joints by using the high speed cantilever type rotating tests and axial fatigue tests are investigated.

Cantilever type rotating test gives similar S-N curves to Ono-type rotating and axial loading tests. In addition, fatigue test data at 10^9 cycles could be obtained by applying the cantilever type rotating test. Scattering of S-N curves obtained by cantilever type rotating test could be less than other conventional tests.

In addition, high speed fatigue test with 6000 rpm to shorten the test period could be achieved by applying cantilever type rotating test.

8 Bibliography

[1] Yamamoto, T., Kokubo, A., Sakai, T. and Nakamura, Y., Development and Several Additional Performances of Dual-Spindle Rotating Bending Fatigue Testing Machine GIGA QUAD, Proceedings of 13th International Conference on Fracture, Beigning, China, 2013.

Appendix 1. Effect of shape difference on Ono-type rotary bending test

Ono-type rotary bending test specimen applied by this study has different length and minimum cross-sectional diameter of the test section comparing with standard Ono-type specimen. Then, the effect of shape difference of Ono-type specimen was also investigated. Three types of Ono-type specimen, which have different minimum diameter (4mm, 7mm and 10mm) were prepared. One (diameter 10mm) has standard shape, the other has the shape adopted in this research mentioned in section 3. Used material was A5083-O.

Table A Chemical composition of A5083-O used.

(a) Plate thickness 20mm applied to Ono-type specimen with the minimum diameter 10mm.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.13	0.22	0.03	0.64	4.52	0.11	0.01	0.02

(b) Plate thickness 8mm applied to cantilever type specimen and Ono-type specimens.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.06	0.15	0.02	0.66	4.9	0.07	0.01	0.01

Table B Mechanical properties of A5083-O used.

(a) Plate thickness 20mm applied to Ono-type specimen with the minimum diameter 10mm.

0.2% proof strength (MPa)	Tensile strength (MPa)	Elongation (%)
165	317	16.0

(b) Plate thickness 8mm applied to cantilever type specimen and Ono-type specimens.

0.2% proof strength (MPa)	Tensile strength (MPa)	Elongation (%)
148	319	26.0

S-N curves of each fatigue test are shown in Fig. A. Some of the data plotted in Fig. A were obtained by applying cantilever type bending specimen made of the same base material (A5083-O) and its FSW joint picked up the stir zone.

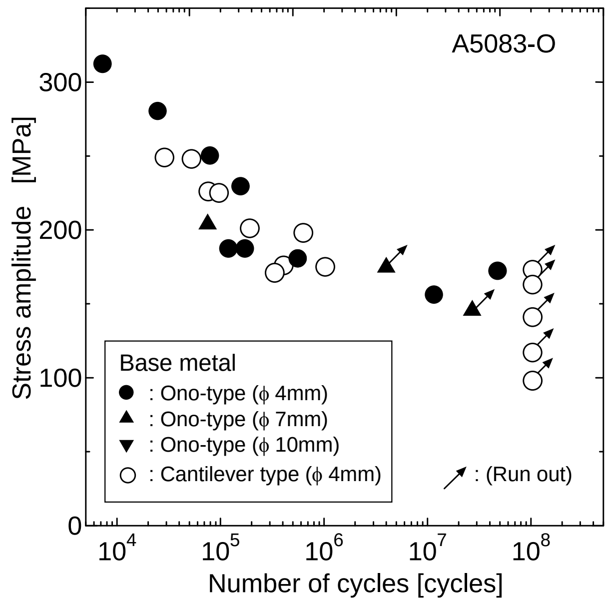


Fig. A S-N curves of A5083-O by Ono-type rotating test with different specimen diameters.

It is confirmed from Fig. A that the shape difference effect for Ono-type test specimen on S-N curves could be ignored.