Development and Several Additional Performances of Dual-Spindle Rotating Bending Fatigue Testing Machine GIGA QUAD

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Abstract In order to investigate the fatigue characteristics of metallic materials experimentally, a long period of time is required to get sufficient number of S-N data. In recent years, in order to overcome this difficulty, multi-type rotating bending fatigue testing machine whose name is GIGA QUAD has been developed by Yamamoto Metal Technos Co., Ltd., in which four specimens can be tested simultaneously.
In this time, some additional new functions have been developed as follows;
(1) 'high and low temperature environmental testing unit' whose target temperature is in a range of 600 deg.C and -150deg.C, (2) 'constant temperature/humid environmental testing unit' combined with the conventional corrosive cell, (3) ‘fracture alarm unit’, and (4) ‘2-step variable loading unit’.
By combining these new functions with the machine of GIGA QUAD, one can perform the fatigue tests efficiently corresponding to the respective requirements for researchers in both of academic and industrial sectors.
Keywords High temperature environmental testing unit, Low temperature environmental testing unit, Constant temperature/humid environmental testing unit, Fracture alarm unit, 2-step variable loading unit

1. Introduction

One of difficulties in fatigue tests for structural materials is to take a long time to perform the fatigue test. Fatigue tests are usually conducted toward the loading cycles of $N=10^7$, but the fatigue property in gigacycle regime is also focused as an important subject in recent years[1]-[8]. In such a long life region, a tremendous long period is required to perform fatigue tests. If the fatigue test is performed at the loading frequency of 50Hz, it takes more than 200 days to reach 10^9 cycles of the load application. It means that it takes very long term for us to obtain one S-N curve.
In addition, since the fatigue life of any metallic material has a distinct scatter, sufficient number of specimens should be tested to obtain the reliable fatigue property. An example of such fatigue test data for a bearing steel in very high cycle regime are shown in Figure 1 as an S-N diagram[5]. Type I indicates the conventional bearing steel, whereas Type II indicates the high purity bearing steel.

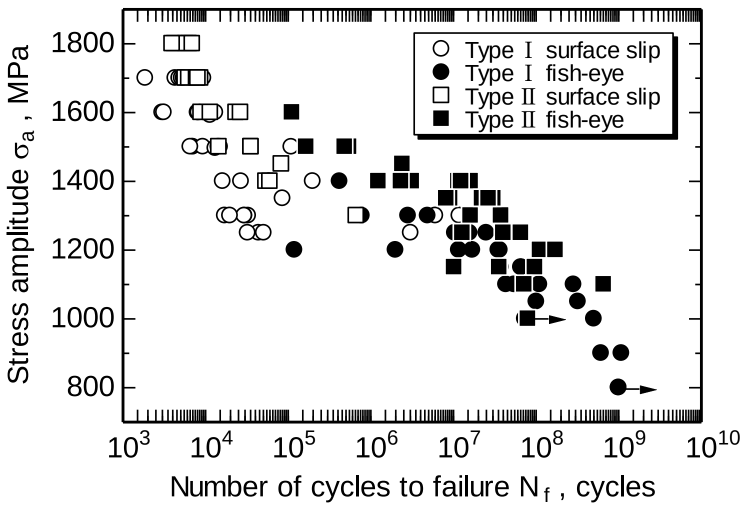


Figure 1. Typical example of fatigue test data for bearing steel in very high cycle regime

Open marks indicate the data in the surface initiated fracture, while solid marks give those data in the interior inclusion initiated fracture. In order to complete a series of fatigue tests to obtain all the data in Fig.1, it takes several years for one kind of metallic material. This circumstance introduces a serious difficulty to every researcher in the area of “*Metal Fatigue*” from technological and economical backgrounds.
If the high loading frequency such as ultrasonic fatigue test was accepted to save the testing time, temperature raising of the specimen due to the internal friction would take place and some cooling system or intermittent loading system should be furnished to examine the original fatigue property[9-12]. Thus, the acceleration fatigue test by ultrasonic technology would cause new difficult subjects as the fatigue testing method to obtain the fatigue property at the usual frequency.
In order to overcome these difficulties, authors have developed special types of fatigue testing machines in rotating bending, in which four specimens can be tested simultaneously[13,14]. Thus a series of fatigue tests even in gigacycle regime can be carried out within a reasonable time period. Based on this advantageous performance, the name of “GIGA QUAD” was accepted for this new machine. By using this machine of GIGA QUAD, fatigue tests can be performed much quickly comparing with the conventional testing machines, even if it is used with various environment options. Accordingly, this machine is useful to file up a number of fatigue test data in gigacycle regime for various kinds of metallic materials, and such databases can provide the fundamental design data for mechanical structures in the wide variety of the engineering application.

2. Dual-Spindle Rotating Bending Fatigue Testing Machine

This machine has two spindles and two specimens can be mounted at both ends of each spindle as indicated in Fig.2 and Fig.3. Each spindle is driven by an electric motor via a V belt and the number of revolution is counted by means of photo-sensor. Thus, this machine can perform fatigue tests for 4 specimens simultaneously. In order to apply the testing load, the corresponding weight is suspended through a helical spring attached to the outer bearing block. The rotating speed of the spindle, that is, the testing speed is 3,150rpm (52.5Hz)
GIGA QUAD has two types of ‘YRB200’ and ‘YRB200L’ according to the loading capacity (Maximum load). The maximum load of YRB200 is 20kg, whereas the load of YRB200L is 80kg.

Table 1. Specification of the Device

	YRB200	YRB200L
Motor	0.2kw-4P	0.4kw-4p
Power	380V	380V
Collet Chuck	Φ5~10	Φ10~16
Max Load	20kg * 4	80kg * 4
Spindle Speed	3,150rpm	3,150rpm
Weight	140kg	170kg
Size	470*400*1050	800*660*1100
Spindle Number	2	2

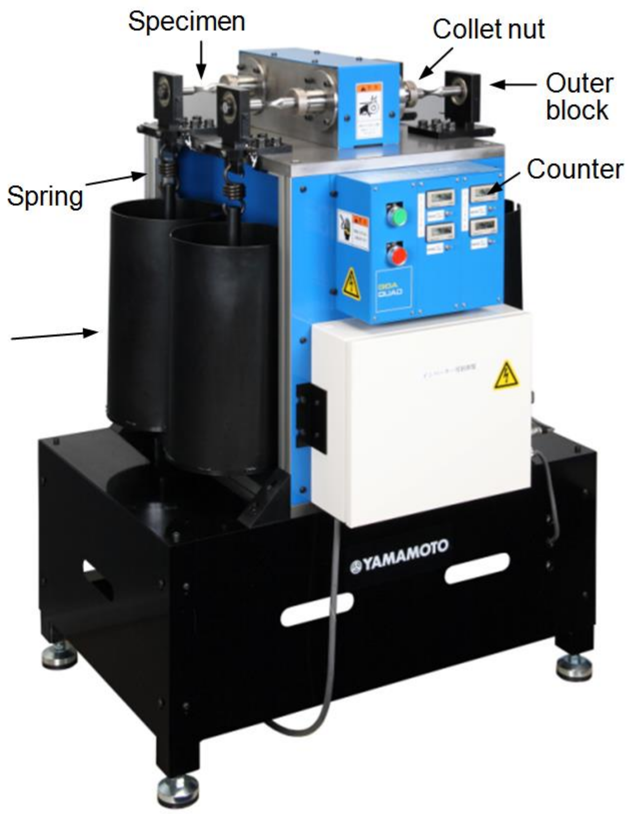


Figure 2. GIGA QUAD YRB200

Figure 3. GIGA QUAD YRB200L

Hourglass type of specimen as shown in Fig.4 is accepted as a formal specimen. Diameter of the critical section 'Φβ' is designed as to give the reasonable stress level for the each material, while the diameter of the specimen grip 'Φγ' may be decided by user freely. Collet chucks with different diameters such as 6mm, 8mm and 10mm are prepared in advance. Among them, the user can choose the most preferable collet chuck depending on the individual circumstance for the testing material.

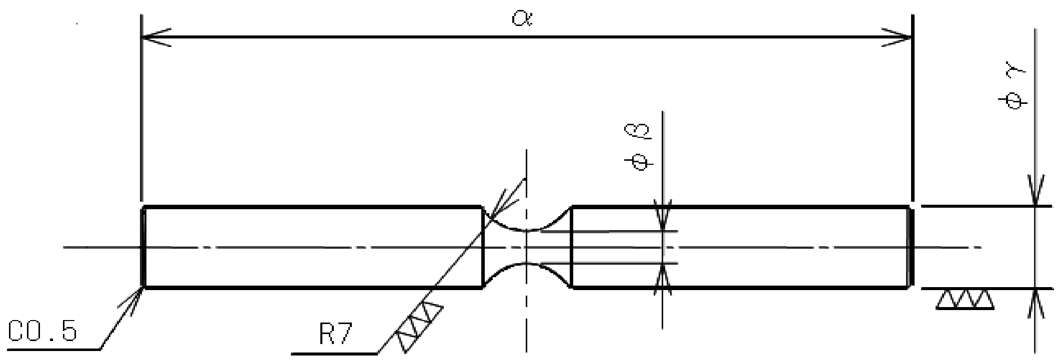


Figure 4. Shape and dimensions of the specimen

3. Support for Environmental Testing

3.1. High temperature environmental testing unit

In the applications of metallic materials to power and energy plants, the key components always work in a high temperature. For example, in the design of gas turbines, it is important to increase gas temperatures in order to attain a high thermal efficiency. For jet engines, an increased temperature realize higher loads, higher speed and a greater output range. In the case of power generating gas turbines, the increase of temperature leads to lower fuel consumption, pollution and cost.

Thus, it is necessary to clarify the reliability property of structural materials at high environmental temperature. Then a high environmental temperature unit was developed as an option for the fatigue testing machine YRB200 and YRB200L. The unit is expected to contribute to clarify the fatigue property and fracture mechanism at high environmental temperature.

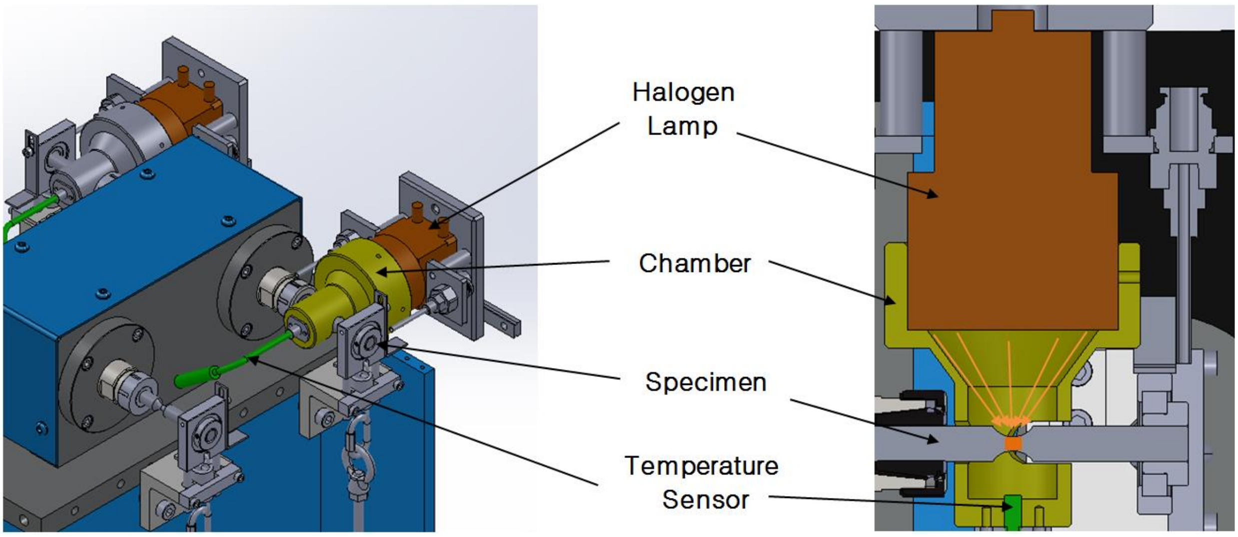


Figure 5. High temperature environmental testing unit

A spot light-condensed heating method is adopted in the developed high temperature unit. The light emitted from the halogen lamp is reflected and condensed to the small spot in the center of specimen. The center of the specimen can be heated rapidly to the temperature of 600 deg.C. A temperature sensor is used to measure the temperature inside the chamber. And the temperature inside the chamber is controlled to keep a given value set by the temperature control panel, through adjusting the input voltage of the lamp automatically. A water cooling system is used to protect lamp power components from over-heating. An air cooling system is used to cool the bearing of the adapter in the end of the specimen.

【Specification】
Testing Temperature: Fe 100~600 deg.C
Al 100~250 deg.C
Temperature Control: PID / Power Control
Input ±5 deg.C
Temperature Measurement: 1 deg.C(resolution)
Size of Control Panel: W500*D500*H1400mm
Specimen: YRB200- Φ10 (Standard)
Number of Chambers: 2 (Separate control)

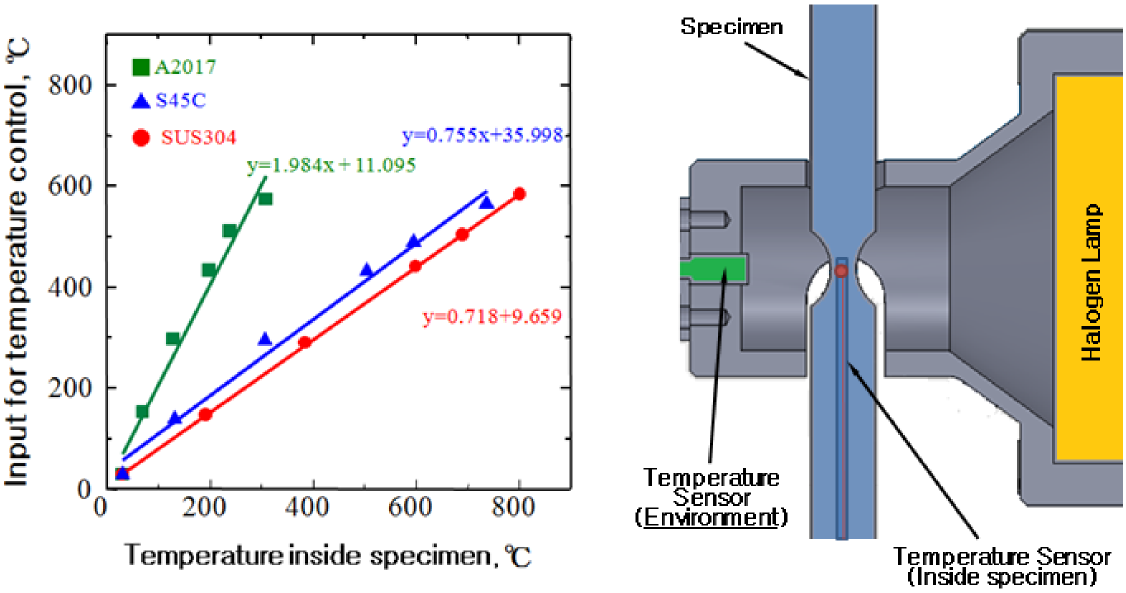
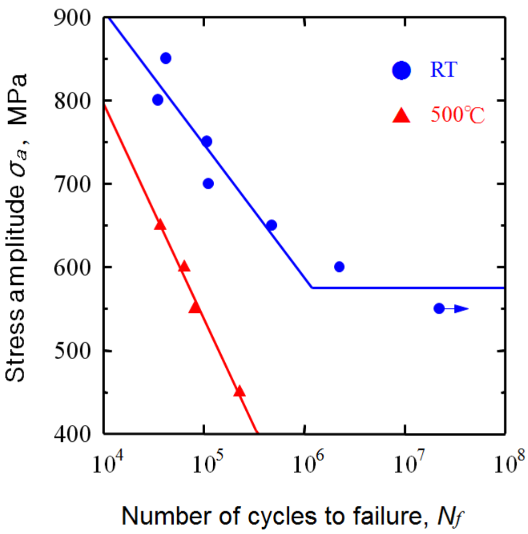


Figure 6. Temperature setting

The light from halogen lamp is condensed to the center of the specimen. The environmental temperature inside the chamber is measured and controlled to a given value. However, the temperature inside the specimen is different from the set environmental temperature. The difference between temperatures inside the specimen and the environmental chamber is governed by the heat conductivity of the specimen. For example, when the specimen should be tested at the temperature of 200 deg.C, the environmental temperature should be set as 400 deg.C for aluminum alloy while the temperature for SUS steel is about 170 deg.C. Based on the calibration diagram in Fig.6, one can set the temperature of the specimen.



【Testing condition】

Loading Mode: Rotating bending

Loading Frequency: 52Hz

Material: S45C

Machine: YRB200

① Environmental Temperature: Room

② Environmental Temperature: 500 deg.C

【Specimen】

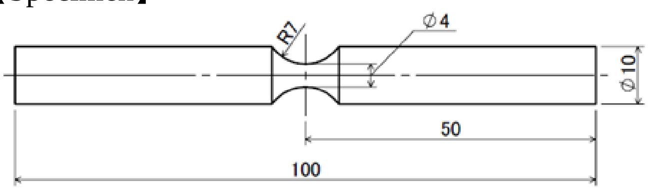


Figure 7. Example of fatigue test result obtained by using the present unit

In order to compare S-N curves at room temperature and 500 deg.C, fatigue tests were carried out for the S45C steel. In this work, fatigue tests were performed by using the rotating bending fatigue machine of YRB200 for both temperature conditions. The S-N curve at room temperature is plotted by the blue line, whereas another S-N curve 500 deg.C is plotted by the red line. A remarkable difference between the S-N curves of room temperature and 500 deg.C is confirmed.

3.2. Low temperature environmental testing unit

Markets of structural materials applying to the low environmental temperature will further grow in the near future. The environmental temperature of superconductivity applications is below -150 deg.C. In the progress of the hydrogen society, hydrogen will be transported and stored at a very low temperature. The market of space exploration is growing quite fast in recent years, especially in China. And there is also a quite great market in the cold regions, resource exploration of Siberia and the polar scientific expedition. Thus, it is necessary to clarify the reliable fatigue property of structural materials at low environmental temperature.

Then a low environmental temperature unit was developed as an option for the rotating bending fatigue testing machine YRB200L. The fatigue testing carried out by the YRB200L with this developed low temperature unit is expected to help clarifying the fatigue property and fracture mechanism at low environmental temperatures.

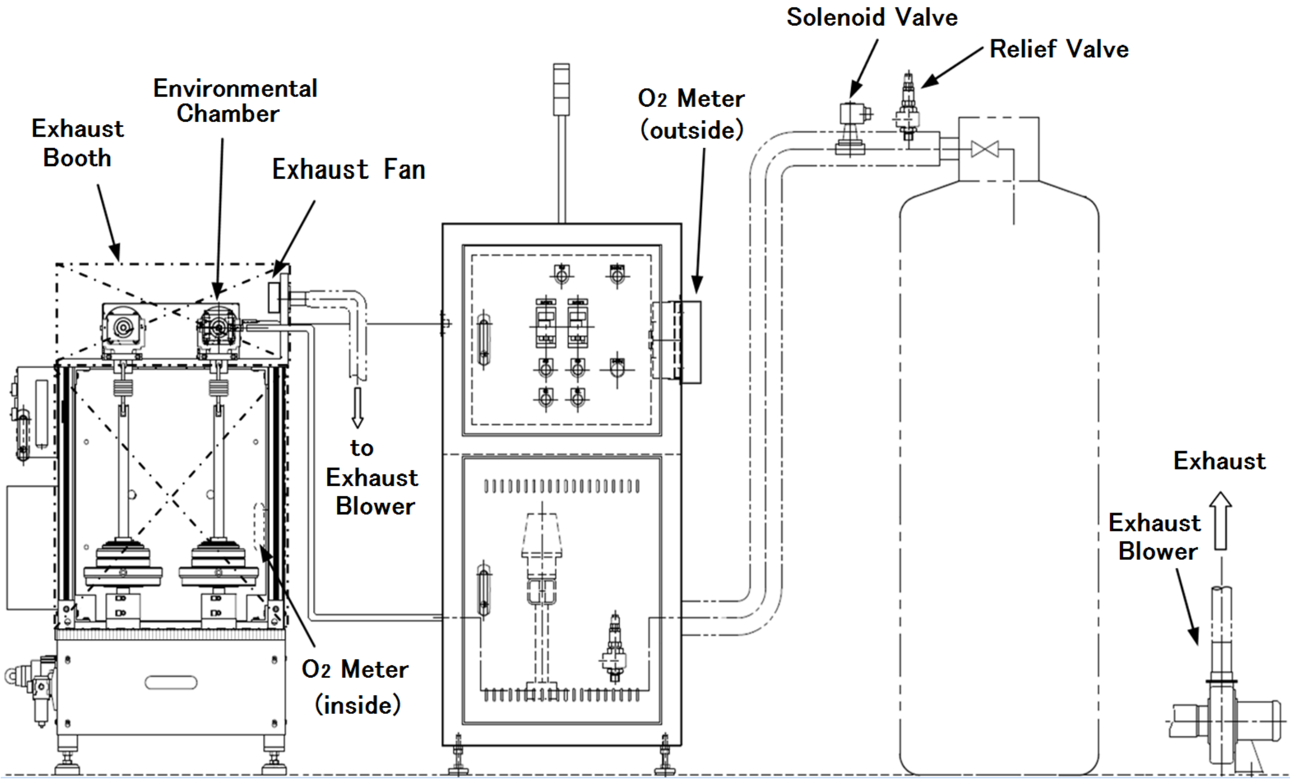


Figure 8. Low temperature environmental testing unit

The nitrogen evaporation is used to cool the testing chamber. Through adjusting the flow quantity of liquid nitrogen provided to the environmental chamber, the temperature inside the chamber is controlled to be a given value set by the temperature control panel. The evaporated nitrogen is discharged out through the exhaust pipe with a fan and a blower. A safety booth is set to prevent the operator breathing in the air with an oxygen concentration lower than the critical value due to the leak of exhaust nitrogen from the low temperature chamber. The O_2 censor inside the booth can detect the decrease of oxygen concentration caused by the trouble in exhaust ventilation system. If the situation exceeds the critical level, charge of the liquid nitrogen is shut down and an alarm is provided. Even if the O_2 censor inside the booth can’t work well, the O_2 censor outside the booth also can detect the decrease of oxygen concentration near the temperature control panel caused by leak of nitrogen from booth. If the critical situation takes place, charge of the liquid nitrogen is shut down and an alarm is given at the moment.

【Specification】
Temperature Control: PID / Input ±5 deg.C
Precision of Temperature Measurement: 0.1 deg.C
Size of Control Panel: W600 * D400 * H1300 mm
Number of Chambers: 2 (Separate temperature control)
Specimen: YRB200L - Φ12 (Standard)

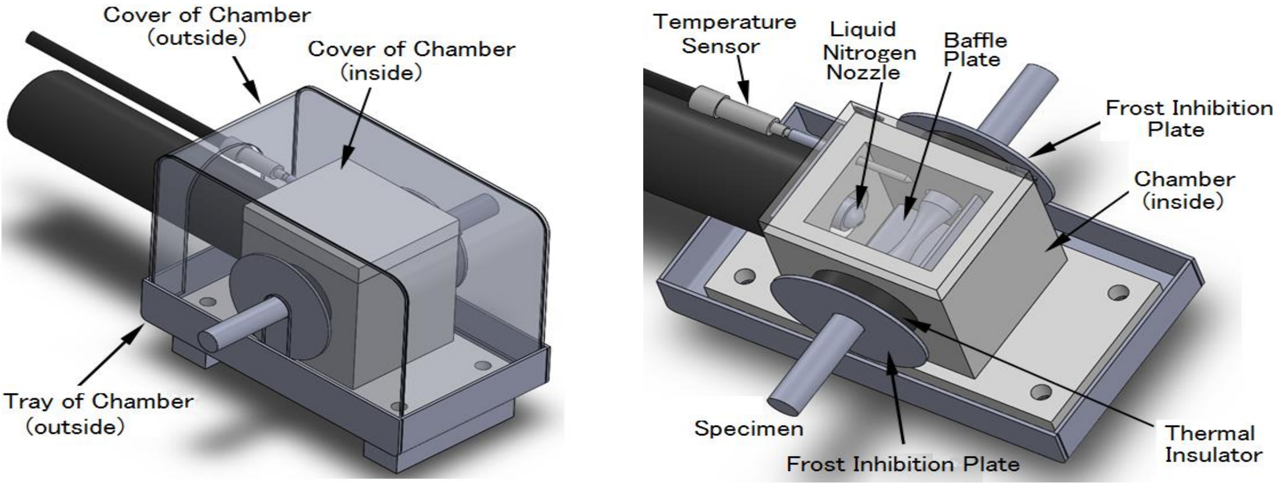


Figure 9.Construction of duplex chamber

A duplex chamber structure is adopted to decrease the growth speed of the frost inside and outside the low temperature chamber. Liquid nitrogen is sprayed to the center of the specimen to keep a given testing temperature. The evaporated nitrogen then flows out from the inner chamber to the outer chamber through a gap between the specimen and the inner chamber. When the nitrogen flows out from the outer chamber, the gas is mixed with the air and the mixed gas is discharged out through the exhaust ventilation system.

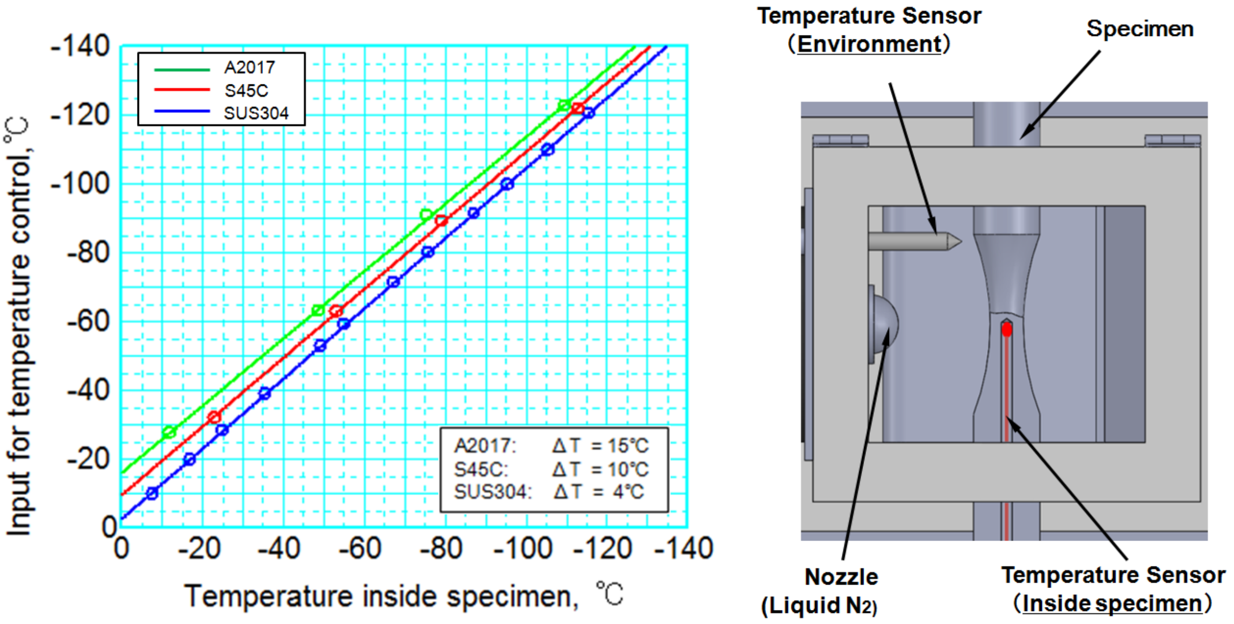
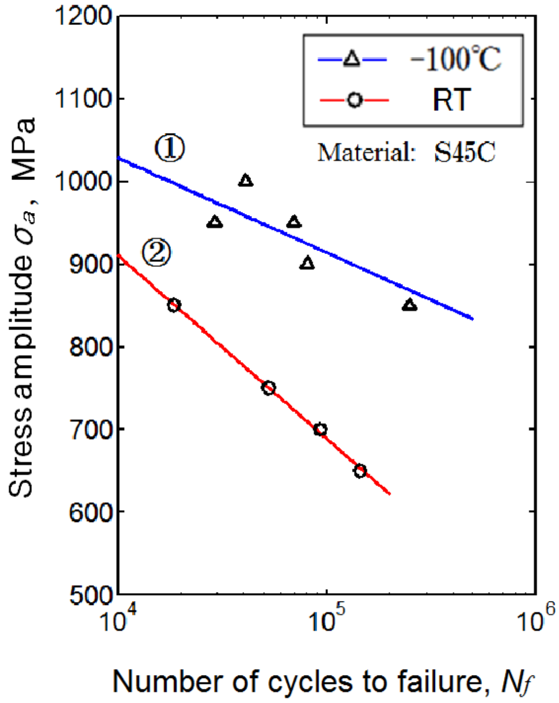


Figure 10. Temperature setting

The liquid nitrogen is sprayed to the center of specimen and the environmental temperature is measured and controlled to a given value. However, the temperature inside the specimen is a little higher than the set environmental temperature. The difference of temperatures between inside and outside the specimen is governed by the heat conductivity of the specimen. Such a difference for the A2017 alloy is about 15 deg.C, while the value for SUS304 steel is about 4 deg.C.



【Testing condition】

Loading Mode: Rotating bending

Loading Frequency: 52Hz

Material: S45C

Machine: YRB200L

① Environmental Temperature: -100 deg.C

② Environmental Temperature: Room

【Specimen】

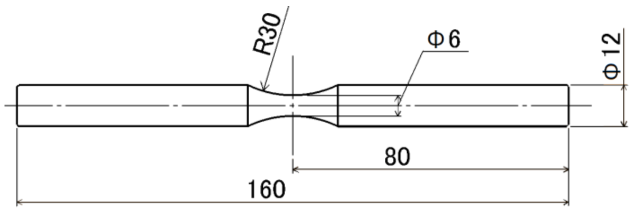


Figure 11. Example of fatigue test result obtained by using the present unit

S-N curves at room temperature and -100 deg.C for the S45C steel are compared with each other. The fatigue tests in both temperature conditions were performed by using the rotating bending fatigue machine of YRB200L. The S-N curve at room temperature is plotted by the red line, whereas the S-N curve at -100 deg.C is plotted by the blue line. A remarkable difference between the S-N curves of room temperature and -100 deg.C is confirmed.

3.3. Fracture alarm unit

A fracture alarm unit which can detect the fracture of specimen and inform the fracture to researchers via e-mail has been developed. In the case of fatigue test to obtain the S-N property, the test is repeatedly conducted by using a lot of specimens. In some cases, stress is changed with a definite time span in order to simulate the actual service loading. Since the fatigue life of each specimen has a distinct scatter, it is impossible to know the fatigue life exactly before the fatigue test. Due to this difficulty, every researcher has to come to the testing machine to confirm whether the specimen has failed or not.
If the person does not notice the fracture of the specimen, he/she wastes much time to find the fatigue failure even though the number of cycles to failure is recorded. In order to prevent such a time consumption, this unit was originally developed here. Adopting this unit, the researcher can get the prompt information on the failure immediately after the specimen has failed. Thus, the next fatigue test can be started soon and the above time consumption can be effectively solved. In addition to this advantage, researchers' mental stress to check the fatigue failure can be also reduced.

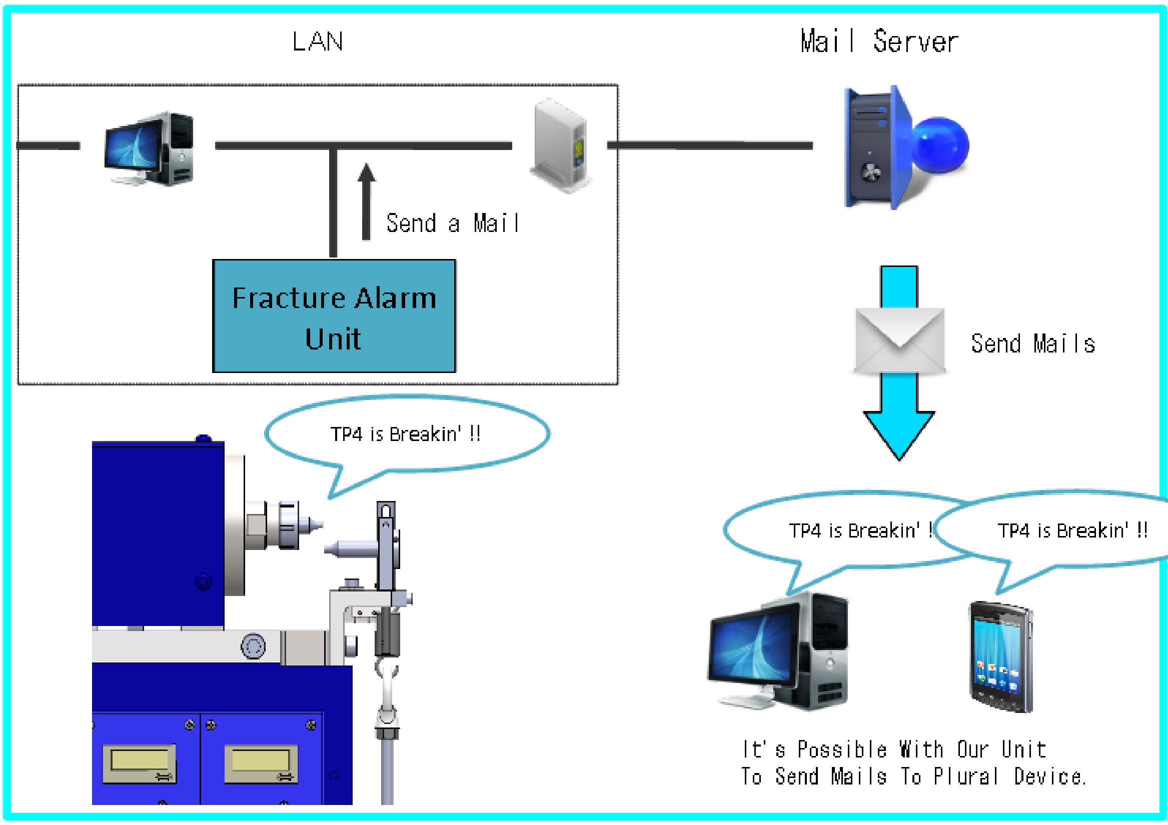


Figure 12. Fracture alarm unit

4. Concluding remarks

Conventional fatigue tests take a long time more than 200days to reach $N=10^9$, and a number of fatigue test data are required as the fundamental data in the mechanical design. In order to solve such difficulties, the high performance fatigue testing machine in rotating bending “GIGA QUAD” has been developed in this work.
Based on a lot of experimental results, the fundamental performance of this testing machine was confirmed. Actually these machines are already being used at many laboratories in universities and industries. Thus, conventional customers and new customers have informed that this testing machine is successfully used to obtain a number of fatigue data within a reasonable short period.

5. References

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