UNEQUIVOCAL RELATIONSHIP OF THERMAL PLASTIC STRAIN ON THERMAL FATIGUE LIFETIME AT DSA TEMPARETURE RANGE FOR SPHEROIDAL DUCTIL CAST IRON

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ABSTRACT

THE FERRITE DUCTILE CAST IRON IS WIDELY USED AS INDUSTRIAL MATERIAL. THEREFORE, MANY RESEARCHERS WERE RESEARCHED TO ADVANCED MECHANICAL PROPERTIES OF DUCTILE CAST IRON HAS BEEN INVESTIGATED AND CLARIFIED (1) - (6). HOWEVER THIS PAPER IS MORE INVESTIGATED AND CLARIFIED TO FATIGUE LIFE AT HIGH TEMPERATURE RANGES. ESPECIALLY, APPLICATION RANGE OF COFFIN-MANSON EQUATION AT DYNAMIC STRAIN AGING TEMPERATURE RANGE. THIS RESEARCH MENTION TO THERMAL FATIGUE TESTS WERE CARRIED OUT FERRITE DUCTILE CAST IRON AT DYNAMIC STRAIN AGING (DSA) TEMPERATURE RANGE WHICH IS START FROM 443(K). AIM TO CLARIFY THE EFFECT OF DYNAMIC STRAIN AGING (DSA) TO ELONGATION AND PREDICTION OF THE THERMAL FATIGUE LIFE. PARTICULARLY, ONE OF AUTHORS REPORTED THAT(1) THE ELONGATION IS 20% AT ROOM TEMPERATURE, BUT REDUCES TO ABOUT 9% AT 443K WHICH IS DSA EFFECT TO THERMAL PLASTIC STRAIN SO IT CONCERN ABOUT EASY TO USE COFFIN-MANSON EQUATION TO PREDICT THERMAL FATIGUE LIFE AT EVERY TEMPERATURE RANGES. VERIFIED TO THE THERMAL FATIGUE LIFE FROM 443K IS FOUND IN THE THERMAL FATIGUE TEST ON FERRITE DUCTILE CAST IRON AND THE UNEQUIVOCAL OF THERMAL FATIGUE LIFE IS PROOFING TO USE COFFIN-MANSON EQUATION. BY DOING SO, THE FEATURE ON THE THERMAL FATIGUE OF FERRITE DUCTILE CAST IRON IS MORE CLARIFIED.

keywords: List the keywords covered in your abstract (max. 5) thermal fatigue life, DSA(dynamic strain aging), Coffin-Manson expression,

INTRODUCTION

The ferrite ductile cast iron (A536 Gr.60) is widely used as industrial material. Therefore, many researchers were researched to advanced mechanical properties of ductile cast iron has been investigated and clarified such as two kinds of serration in cyclic thermal stress, visual crack on specimens and the effect of cyclic temperature on the thermal fatigue life, totally reporting to references (1) ~ (6). This research more investigates and clarified about fatigue life at high temperature ranges. Especially, application range of Coffin-Manson equation at Dynamic Strain Aging Temperature range.

Normally, the relation of thermal plastic strain between the numbers of thermal fatigue life can be predicted by Coffin-Manson equation under the low cycle fatigue. This equation decides to use to the ductile exponent and coefficient. Both exponent and Coefficient are related to plastic deformation volume. Namely, the low cycle fatigue life shall be dominated by the elongation. Here is concerned with it, one of authors reported that [(1)] elongation was 20% at room temperature but elongation was 9% at 443 (K). The elongation at 443(K) reduced half of elongation at room temperature. This phenomenon occur was range of dynamic strain ageing (DSA) which is a fluctuating stress phenomenon due to mutual interference of mobile solid solution atoms and moving dislocations. If applied to ductile exponent and coefficient at room temperature to Coffin-Manson equation, thermal fatigue life at Dynamic Strain Aging temperature range was accurate prediction of fatigue life?
Main purpose of this research to thermal fatigue tests were carried out ferrite ductile cast iron at Dynamic Strain Aging (DSA) temperature range which is start from 443(K). Aim to clarify the effect of Dynamic Strain Aging (DSA) to elongation and prediction of the thermal fatigue life. Particularly, DSA effect to thermal plastic strain so it concern about easy to use Coffin-Manson equation to predict thermal fatigue life at every temperature ranges. Therefore, the thermal fatigue life versus the thermal plastic strain found unequivocal relation around the alpha phase field [(1)]. The unequivocal can also be confirmed directly by the experimental relationship in Coffin-Manson equation. The final aim to this report is easy to finding thermal fatigue life from thermal plastic strain at DSA temperature range that is essential and beneficial to design a structure of machine at elevated temperature.

THEORITICAL DETAIL

Already mention to on author wrote to elongation of Spherical ductile cast iron was normally 20% at room temperature but around 423(K) – 443(K) elongation was dramatically decrease. Finally, 9% was minimum elongation at 443 (K). This phenomenon occurs was range of dynamic strain ageing (DSA) which is a fluctuating stress phenomenon due to mutual interference of mobile solid solution atoms and moving dislocations. Because it can say in 443K that an original mechanical property of the cast iron is not provided, it is supposed when it is dangerous temperature of the cast iron.
However, everybody knows Coffin-Manson equation and plastic strains can predict to fatigue life. The Coffin-Manson equation shows (1).

$$\varepsilon_p = C_{pi} N_f^{K_{pi}} \qquad \text{Coffin-Manson equation (1)}$$

Next deformation of equation (1) then substitution K_{pi}=0.5

$$N_f^{0.5} = \frac{C_p}{\Delta\varepsilon_p} \qquad (2)$$

$$N_f = \left(\frac{C_p}{\Delta\varepsilon_p}\right)^2 \qquad (3)$$

Compare with elongation of 443 (K) and 323 (K) was 1/2 thus $\varepsilon_{f443}=1/2\varepsilon_{f323}$. Then substitute to equation (4).

$$C_{p323} = \frac{1}{2} \cdot \varepsilon_{p323} \qquad (4)$$

$$C_{p443} = \frac{1}{2} \cdot \varepsilon_{p443} = \frac{1}{2} \cdot \frac{1}{2} \cdot \varepsilon_{p323} \qquad (5)$$

$$C_{p443} = \frac{1}{2} \cdot C_{p323} \qquad (6)$$

The elongation is 1/2 becoming C_p is 1/2 also. Then substitute to (2) and (3). The equation becomes (7). Finally, deformation (7) to (8)

$$N_{f443}^{0.5} = \frac{1}{2}\left(\frac{C_{p323}}{\Delta\varepsilon_p}\right) \qquad (7)$$

$$N_{f443} = \frac{1}{4}\left(\frac{C_{p323}}{\Delta\varepsilon_p}\right)^2 = \frac{1}{4} N_{f323} \qquad (8)$$

N_f : Thermal fatigue life, ε_p : Thermal plastic strain, C_p : Ductile coefficient, κ_p : Ductile exponent.

Result is equation (8), if exponent is α =0.5, start temperature 443K of prediction fatigue life is 1/4 of fatigue life of start temperature of 323K.
Namely, if the unequivocal condition is existent, the equation of Coffin-Manson equation shall be established in whole DSA temperature ranges and the thermal plastic strain shall unequivocal dominate thermal fatigue life.

EXPERIMENTAL AND MATERIAL DETAIL

Test material

Round test specimens (Diameter: 30mm, length: 210) of ASTM A536 Gr.60 were used for the test. The chemical component and microstructure of transverse section is shown in table 1 and figure 1. The tension and fatigue test specimen of technical drawing was processed as shown in Figure 2.

C	Si	Mn	P	S	Cr	Mg	Zn	Al	Sn	Cu
3.83	2.55	0.18	0.023	0.008	0.029	0.038	0	0.003	0	0.04

Table.1 Chemical component of test specimen

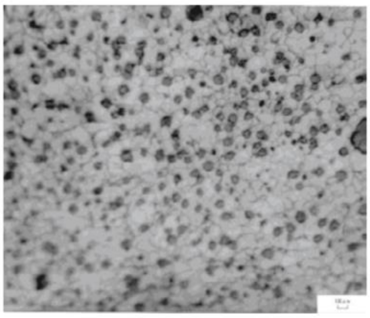


Fig.1 Microstructure of transverse section

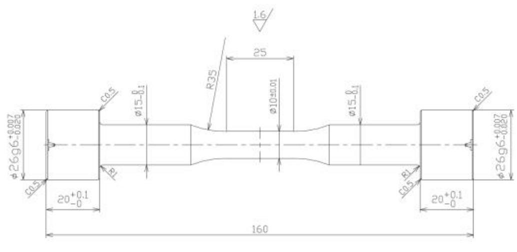


Fig.2 Tecnical drawing of specimen

Figure.3 shows the stress – strain curve as obtained from the tenssion test. The data are shown in Table.2 also. So, it was confirmed that the test specimen within the range of ASTM.

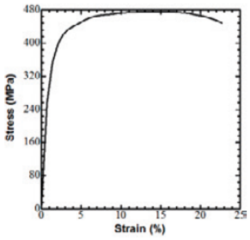


Fig.3 Stress – Strain Curve

Tensile Strength (MPa)	476
0.2% Proof Strength (Mpa)	325
Elongation (%)	20.27
Rate of reduction (%)	13
Young's modulus (GPa)	235

Table.2 Tensile Properties on A536 Gr.60

Test condition

Test condition was high temperature low cycle fatigue tests were carried out by computerized hydric servo pulsar EHF-ED100kN-TF-20L fabricated by Shimazu. The thermal cyclic is given repeatedly from the temperature 443 (K) to the peak temperature selected as a parameter from 673 K to 1023 K at constant rate of 3.1(K/s) with triangular thermal cycle form to the specimen with gage length of 15 mm and diameter of 10 mm. The test holds everything except temperature cyclically between 443 (K) and peak temperature, rising and falling at constant rate. During test detected and recorded were load, strain, number of cycle and temperature, and gage length.

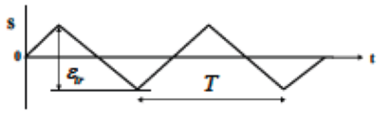


Fig.4 pulsating sawtoothed strain wave for strain controlled fatigue test

Test wave	triangular wave									
Lowest wave (K)	443									
Peak wave (K)	723	873	898	923	973	993	996	1003	1023	1073
Mean wave (K)	583	658	670.5	683	708	718	720	723	733	758
Heating & Cooling rate (K/sec)	3.1									
Holding duration at LT & PT (sec)	0									

Table.3 test condition for thermal fatigue test

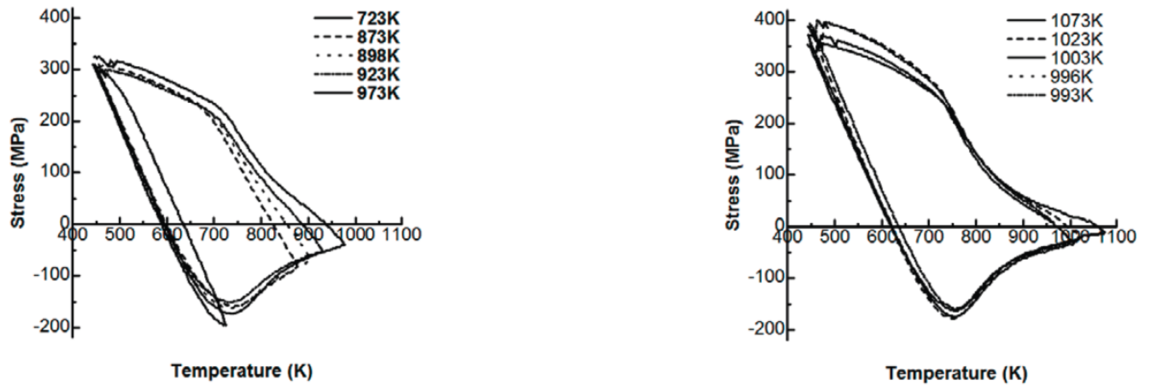
EXPERIMENT RESULT AND DISCUSSION

Shown in Figure 5 were obtained in this experiment "Stress-Temperature diagram." In all experiments, in the vicinity of 450 ~ 520K, saw-tooth behavior was observed. Usually, start from the room temperature of maximum and minimum stress width is larger than the DSA temperature. On the other hand, most cases the stress of the room temperature are placed under harsh conditions to stress of DSA temperature. However, ftigue life of room temerature is longer than fatigue life of DSA temperature.

Shown in Figure 6 were obtained from the experimental "peak stress cycle." Even DSA temperature, there is no significant difference in the maximum and minimum stress. Also seen that the maximum does not change, and a maximum temperature change also minimized by stress.

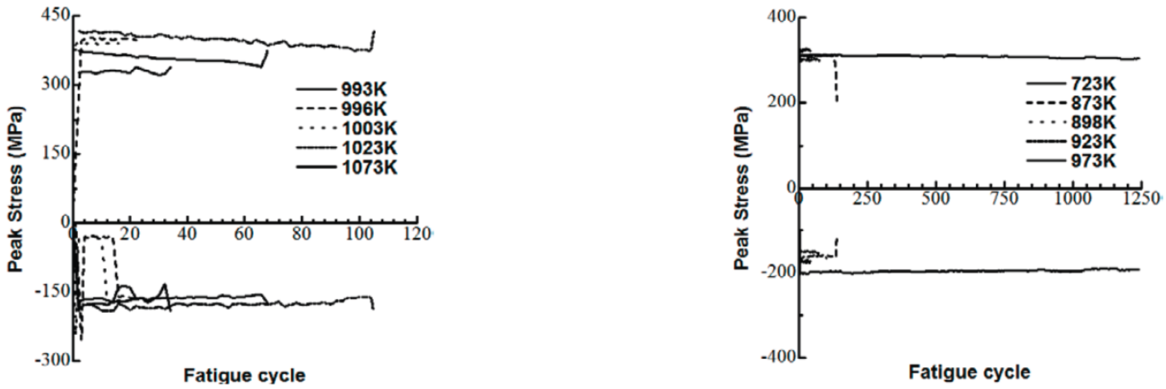
Figure 7 shows the "Peak temperature plastic strain." It also increases the plastic strain as the peak temperature rises.

From that experiment, the plastic strain increases as the peak temperature rises, the plastic strain is fatigue lifes are decreased significantly could be confirmed. The difference between the "plastic strain" and "Fatigue life" had become almost constant relationship. The experiments were carried out limited to high temperature α phase ranges, there can not confirm any transverse section . Therefore, the plastic strain was a influence on fatigue life.



(a) 723 (K) – 973 (K) (b) 993 (K) – 1073 (K)

Fig.5 Stress – Temperature diagram



(a) 723 (K) – 973 (K) (b) 993 (K) – 1073 (K)

Fig.6 Peak Stress – Fatigue life diagram

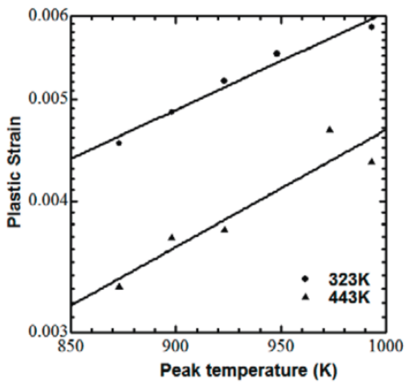


Fig.7 Plastic Strain – Temperature diagram

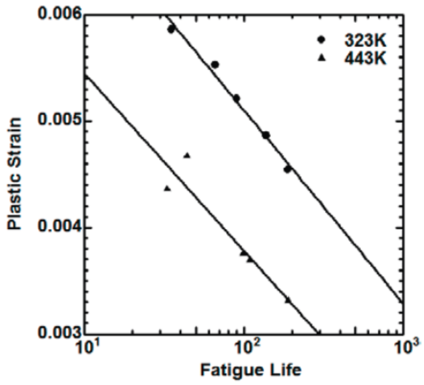
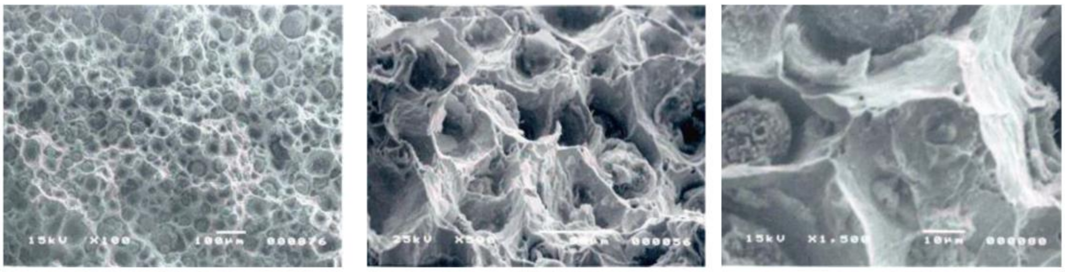


Fig.8 Plastic Strain – Fatigue diagram

FRACTOGRAPHY

From experiment, almost all fractographies are ductile fracture.
Figure 9(a) shows the river of ductile fracture. The figure shows river of the mountain and river of valley is flowing up and down can be confirmed. Enlarged photographs figure 9(a), figure 9 (b) shows a clear that a ductile fracture surface. The figure 9 (c) shows magnified fracture surface. From this picture, ductile fracture can be confirmed . Mountains sharp ductile fracture can be confirmed more specific, it is clear that it is ductile fracture. In addition, there were missing after the graphite.



(a) (b) (c)

Fig.9 SEM Picture at 993 (K)

CONCLUSION

This experiment aim to clarify, the relationship between thermal fatigue life the saw-tooth phenomenon by dynamic strain aging, in DSA temperature range. The thermal low-cycle fatigue test using a spheroidal graphite cast iron, test was repeated heating and cooling from 443K to upper limit temperature.

- All experimental results within 1/4 of the normal fatigue life was not be as theory, with respect to the thermal fatigue life was short life as expected.

- The fractography was observed at all temperatures are ductile fracture. It was found that almost brittle fracture does not appear in this temperature range (high temperature α phase field).

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