
 논문

A Study on the Fatigue Life of Semi ADI

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Abstract

본 연구는 ADI의 기계적 성질을 개선하고자 오스테나이트화 과정에서 초기 변태온도를 900°C (γ 구역)에서 시작하여 800°C까지 ($\alpha + \gamma$ 구역) 일정한 냉각제어에 의해 오스텝퍼링을 한다. 여기서 Full ADI에서 생성되는 고탄소 오스테나이트 조직을 저탄소 오스테나이트로 유도하고 미세한 침상의 Full ADI 조직을 연성이 높은 조대한 아공석 페라이트 조직이 생성되도록 하여 Semi ADI를 만든다. Full ADI와 Semi ADI의 기계적 성질 및 피로강도를 연구한 결과 Full ADI와 Semi ADI의 정적강도는 유사하지만, 피로강도는 Semi ADI의 기지조직의 변화에 기인하여 Full ADI보다 피로강도가 높게 나타났다. 이러한 현상은 Semi ADI의 조대한 페라이트가 균열개구 저항력이 낮아 초기에는 쉽게 개구되지만, 균열개구와 동시에 균열선단에서 큰 소성역이 발생되어 균열성장이 지연하는 효과로 판단된다.

Key words : Fatigue life, Austempered Ductile Iron, Crack growth rate

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1. Introduction

Ductile cast iron is heated up to A1 transformation temperature and the matrix structure is transformed to austenite, and again the temperature is lowered rapidly to 300°C~400°C and isothermal transformation treatment is applied and then the matrix structure is transformed to bainite. ADI is used widely in automobiles, industrial equipment, construction machines, etc. and extensive researches are being made throughout the world [1~3]. In this study, we developed Semi-ADI [4] using a special heat treatment method with the object of developing new ductile cast iron that meets the requirements of both high static strength and superior fatigue characteristic. We examined the fatigue characteristic of the developed Semi-ADI by comparing it with full-ADI.

2. Experiment

2.1 Preparation of specimens

The material used in our experiment was GCD45 ductile cast iron, and its chemical components are as in Table 1. Specimens were prepared in two forms to in order to test static strength (Fig. 1 (a)) and fatigue life (Fig. 1 (b)).

2.2 Heat treatment

Full-ADI was prepared according to the heat treatment presented in Fig. 2(a). In addition, Semi-ADI was prepared

using the method presented in Fig. 2(b). A characteristic of this method is that cooling starts from the γ area but cooling control (20°C/10 min) is applied to segment c-d in the ($\alpha + \gamma$) area. This method transforms high-carbon austenite to low-carbon one and forms composite matrix structure of highly ductile and coarse hypoeutectoid ferrite instead of fine needle-shaped ferrite.

2.3 Static strength test and fatigue life test

In order to examine the mechanical properties, we tested tension at displacement rate of 2 mm/min. Strength was measured for each phase at 200 g and on a 30-point scale using the micro-Vickers hardness. Fatigue tests were performed under computer control on servo hydraulic testing machines in laboratory air and at room temperature. The load form was the sinusoidal constant amplitude at frequencies from 15 Hz. All essential requirements of the standard ASTM E647 were satisfied.

3. Results and Discussion

3.1 Metal structure and static strength characteristic

The structure of Semi-ADI and Full-ADI was compared with cast structure in Fig. 3. (a) is typical bull's eye structure,

Table 1. Chemical compositions (wt. %).

C	Si	Mn	P	S	Mg	Fe
3.75	3.0	0.15	0.03	0.015	0.04	Bal.

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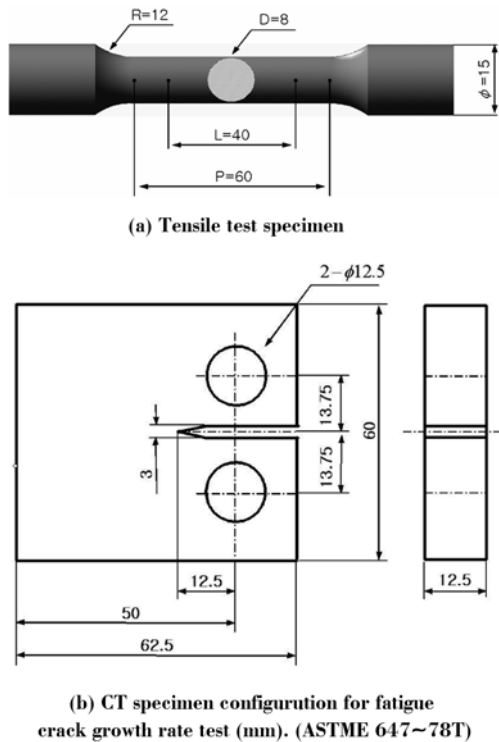


Fig. 1. Geometry of the tensile test and fatigue life test specimen.

and (b) shows two-phased structure of ferrite and bainite resulting from delay in the growth of nuclei in process C-D in Fig. 3(b). (c) shows the single-phased structure of bainite

resulting from full transformation in austenitization. Thus, we obtained intended Semi-ADI through the special heat treatment method as in Fig. 3(b). Mechanical properties are presented in Fig. 4. In full-ADI, static strength was enhanced considerably compared to the cast material, but ductility decreased a lot. In Semi-ADI, however, the decrease of ductility was somewhat reduced while static strength was still improved. This shows that static strength is determined by the bainite content, and ductility by the ferrite content.

3.2 Fatigue crack propagation properties

Fig. 5 shows a-N curve obtained from testing the fatigue life of each specimen. It shows that the fatigue life was improved considerably through austempering and the improvement was higher in Semi-ADI = 1.5×10^6 than in full-ADI = 1×10^6 . This suggests that the some degree of recovery of ductility contributes to the rise of the fatigue limit in Semi-ADI. This is the effect of hypo-eutectoid ferrite in the matrix structure and the effect is expected to delay the growth of fatigue cracks. Fig. 6 shows da/dN-ΔK curve obtained from testing the Fatigue crack propagation properties of each specimen. The crack growth rate is faster in Full-ADI than in Semi-ADI. This phenomenon is more obvious at a high ΔK range. This suggests that Semi-ADI is

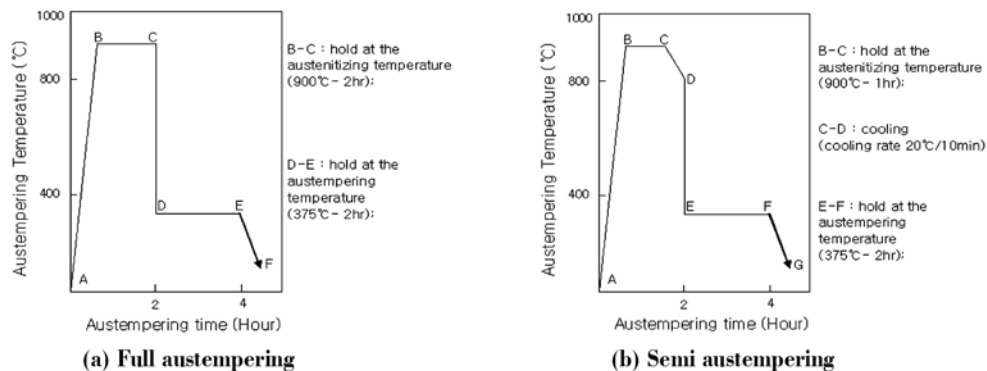


Fig. 2. Heat treatment condition for austenitizing and austempering of ductile cast iron.

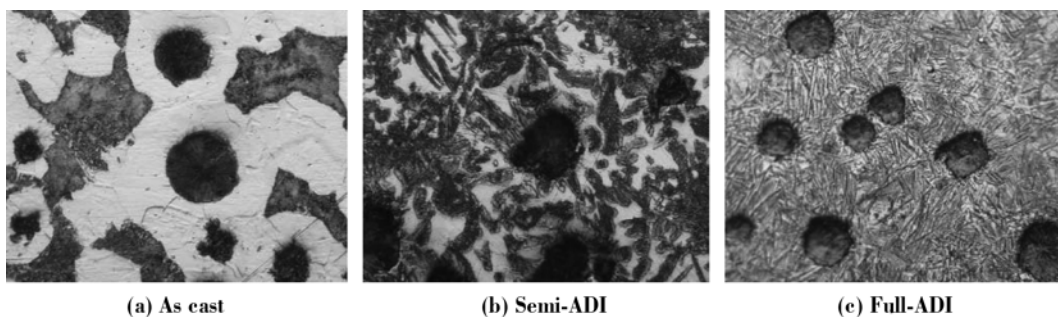


Fig. 3. Typical microstructure. Magnification 500×.

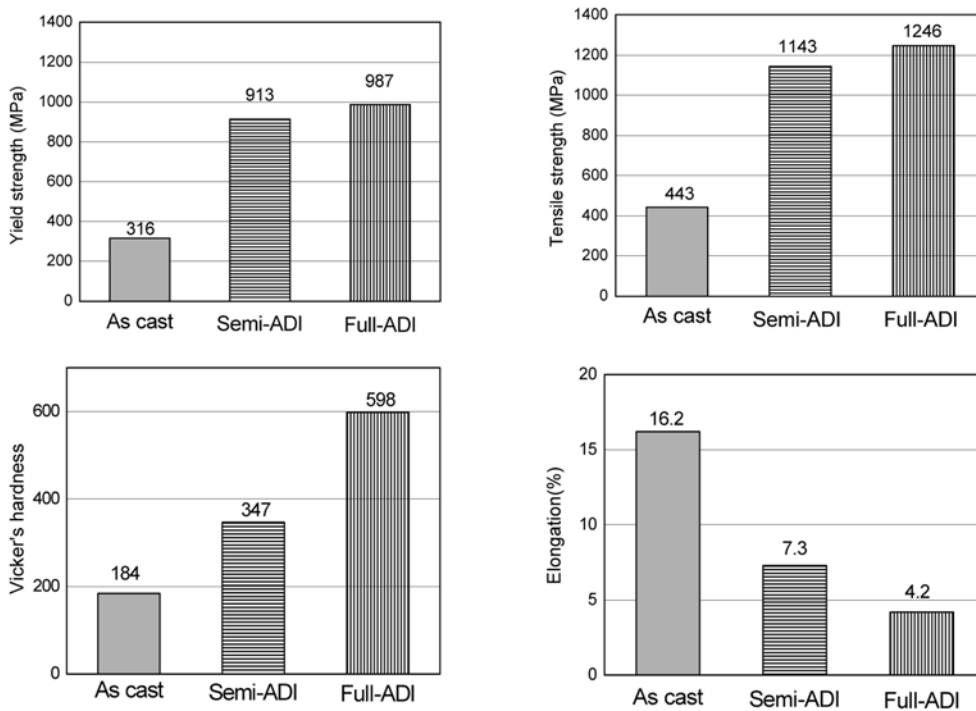


Fig. 4. Mechanical properties of specimen.

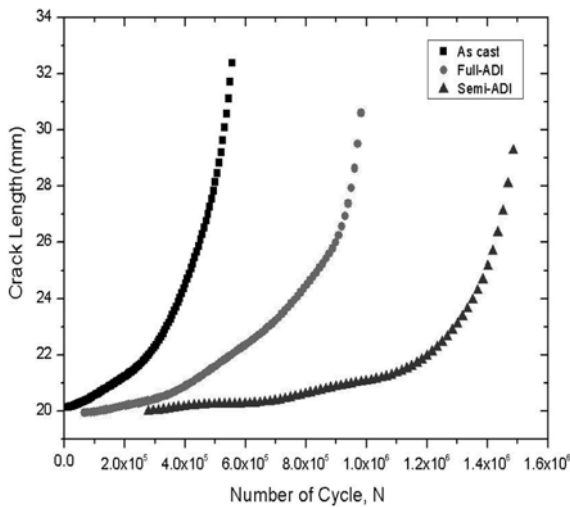


Fig. 5. Crack length vs. number of cycles.

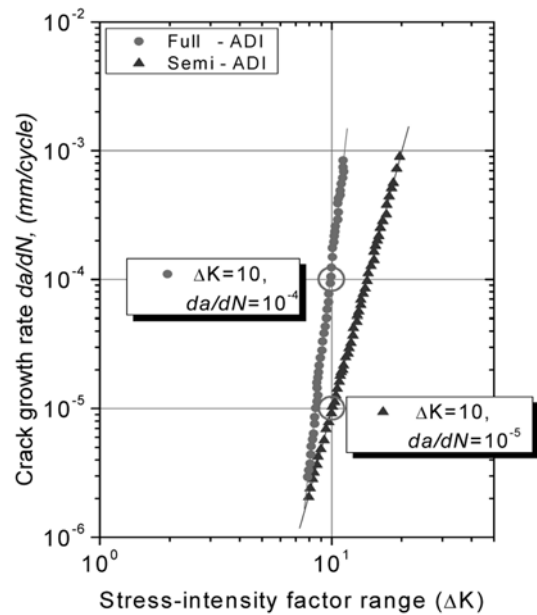


Fig. 6. Crack growth rate vs. stress intensity factor range.

superior to Full-ADI in fatigue crack propagation properties. As presented in Fig. 4, Semi-ADI is considered a material with ideal fatigue characteristic without causing the loss of static strength. To compare crack growth rate between Full-ADI and Semi-ADI, we observed them at a specific range of stress intensity factor. The crack growth rate was 10^{-5} in Semi-ADI and 10^{-4} in full-ADI. The possible reason for the slow crack growth rate in Semi-ADI is that crack growth is inhibited by the matrix structure of Semi-ADI.

4. Conclusions

- (1) In static strength assessment, Semi-ADI showed yield strength = 913, tensile strength = 1143, hardness = 347 and elongation = 7.3. Full-ADI showed yield strength = 987, tensile strength = 1246, hardness = 598 and elongation = 1.86. Strength

was similar between Semi-ADI and full-ADI, elongation was 1.86 times higher in Semi-ADI.

(2) In fatigue life assessment, fatigue life was longer in Semi-ADI ($N_f = 1.5 \times 10^6$ cycle) than in Full-ADI ($N_f = 1 \times 10^6$ cycle).

(3) In the same range of stress intensity factor, the crack growth rate was 10^{-5} in Semi-ADI and 10^{-4} in full-ADI.

(4) In Semi-ADI, both static strength and fatigue strength were high. This is because its matrix structure resulting from anneal inhibits crack growth.

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