

Analysis of Fatigue Life and Crack Propagation Characterization of Gray Cast Iron under Normalizing Process

By Nukman Nukman

PAPER • OPEN ACCESS

28

Analysis of Fatigue Life and Crack Propagation Characterization of Gray Cast Iron under Normalizing Process

1

To cite this article: Hendri Chandra *et al* 2019 *J. Phys.: Conf. Ser.* **1198** 032006

View the [article online](#) for updates and enhancements.

You may also like

10

- [Research on Cost-effective New Alloy Cast Iron](#)

Deng Sun, Lingfeng Zhang, Yi Xiong *et al.*

5

- [Meta-analysis of the influence of different element contents on selecting the prediction model of gray cast iron's elastic modulus](#)

Chunyang Hu, Qi Liu, Yutong Du *et al.*

6

- [Transmissibility, Isolation Region and Damping Characteristics of Gray Cast Iron and Aluminium Composite](#)
T.G.T. Nindhia



18



244th Electrochemical Society Meeting

October 8 – 12, 2023 • Gothenburg, Sweden

50 symposia in electrochemistry & solid state science

Abstract submission deadline:
April 7, 2023

Read the call for papers &
submit your abstract!

13 Analysis of Fatigue Life and Crack Propagation Characterization of Gray Cast Iron under Normalizing Process

Hendri Chandra¹, Nukman², Baoadi Sianturi³

⁹ Department of Mechanical Engineering, Faculty of Engineering, University of Sriwijaya, 30662, Indonesia

E-mail : hendrichandra@ft.unsri.ac.id

Abstract ⁷ Fatigue is a phenomenon of material damage due to repeated loading, it is known that when a metal is subjected to repetitive stress the metal will fracture ²¹ at much lower stress than the stress required on static load. This study discussed the effect of normalizing process on the fatigue resistance of gray cast iron material, by comparing the value of S-N curve between material which without heat treatment and under normalizing process. On The normalizing process specimens were preheated at 400°C for 10 minutes, then heated to 910°C for 60 minutes and 90 minutes respectively, then cooled in the opened air. Fatigue testing ⁹ was performed using repeated torsion fatigue testing machine. The fatigue fracture surface of the test were observed by using scanning electron microscope (SEM) to identify crack propagation characteristics. The Inspection results showed that specimen with 60 minutes normalizing process has the highest cycle of 15600 cycles, 12200 cycles without normalizing, and 9850 cycles with normalizing 90 minutes. SEM inspection results also showed that the beginning of the crack initiate from the graphite structure of cast iron, this is because by the structure of the graphite are sharp at the tip. So that the stress concentration occurred at the tip of graphite. This condition promoted the initiation of crack and than propagated until fracture.

Keywords: Cast Iron, Graphit, Normalizing, Fatigue, Crack, SEM.

1. Introduction

The influence of heat treatment on fatigue life of material has been not completely studied yet. Fatigue strength of material is very important in application in the construction or machine elements. Small stress level working at elastic condition will give dangerous effect. Normalizing process is one of type of heat treatment commonly used in low alloy steel and alloy steel. It is done on the metal by heating the metal above the critical temperature (approximately 800-950°C), then after reaching the heating temperature, It was held for a given time and than cooled by air medium. The purpose of this process is to eliminate the microstructure uniformity, eliminate the residual stress, improve uniformity and refining the grain size.

Gray cast iron is one of the important engineering materials because it has many uses, its production cost is relatively inexpensive, capable of excellent machines, wear-resistant, and ¹² a dampening effect vibration (damping capacity). In general, gray cast iron has a carbon content ^{2.5 -}



3.5)%, silicon (1.5 to 3.0)%, manganese (from 0.5 to 0.8)%, sulfur (max. 0.15 %), and phosphorus (max 0.25%). (Situngkir Haposan, 2010).

Gray cast iron formed from iron and carbon alloy with the cooling rate of the medium (the matrix in the form of perlite) and slow cooling (in the form of a ferrite matrix) in the production process, gray cast iron are not costly and relatively inexpensive, but it is now gray cast iron is one of the important material because it has many uses such as: being able to machine very good, wear-resistant, and has the effect of vibration damping.

Cast iron has a layer containing graphite-shaped flake so that it has a tensile strength that is not so high and its ductility is so low that it can not be formed in addition to the casting process and machining. When the molten iron is added a little magnesium or cerium, then the graphite will turn into a spheroid that has a higher ductility.

Mechanical properties are one of the most important properties in a material, which can be changed and influenced from the outside by heating certain times and temperatures, so that the microstructure of the metal changes and its mechanical properties are altered by warming (Pradipta Dwija, 2015). Mechanical properties of the metal can be controlled by heating or often referred to as heat treatment, these properties include :

1. Hardness which is the material's resistance to plastic deformation due to local loading on the surface in the form of scratches or stresses
2. Strength is shown by the material's resistance to the load imposed on it, resulting in changes in shape or size.
3. Ductility is a metal's ability to deform. Resilient materials usually have large cross-section shrinkage prior to fracture.
4. Toughness is the ability of a metal to maintain its shape by absorbing the energy that affects it until the fracture occurs.
5. Elasticity
Be defined as material's ability to receive a stress without resulting in permanent deformation after the stress is removed.
6. Fatigue
It is the tendency of the metal to fracture if it receives a cyclic stress whose magnitude is still far below its elastic strength limit.

According to (Callister, 2007) the mechanism of fatigue failure is divided into three phases: crack initiation, crack propagation, and final fracture.

1. Crack initiation
Small cracks formed at several points of high stress concentration as a result of repeated loading
2. Crack propagation
The total cycle causing the fracture failure is the sum of the number of cycles causing the initial crack and the propagation phase. Crack Initiation is developing into microcracks. The propagation or combination of microcracks then forms macrocracks that will lead to failure.
3. Final fracture
Final fracture is the final process of damage to the structure during loading, so the structure fails. When there is a crack propagation, cross-section of the piece is to be reduced. Until the condition in which the cross-section of the piece is not able to withstand the load.

2. Experimental procedure

2.1. Materials Research

Specimens were made from gray cast iron, The specimens obtained the normalizing heat treatment process as well as the specimen without getting the heat treatment (as-cast). The chemical composition of the specimen as shown in Table 1.

Table 1. Chemical composition of Gray cast Iron (% weight)

| Si | Mg | Mn | C | P | S |
|-------|-------|-------|------|--------|--------|
| 0,846 | 0,516 | 0,342 | 2,38 | 0,0182 | 0,0174 |

For standard size dimensions fatigue testing machine fatigue testing Repeated Torsion and Bending Fatigue Machine with JIS Z 2273 as shown in Figure 3.1

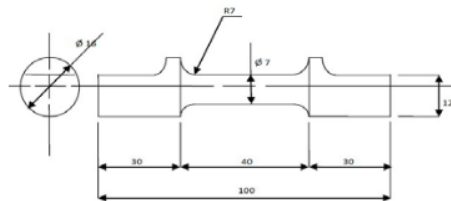


Figure 1. Dimensions of Fatigue Test Specimen

The test sample before being given a normalizing heat treatment process at a temperature of 910 °C holding time of 60 minutes and 90 minutes, is done first initial heating process at a temperature of 400 °C for 10 minutes to avoid cracks on the surface of the test sample. Then the specimen was cooled with open air.

The sample was divided into three types and given a specific code with the following modifications:

1. Sample A is cast iron does not get heat treatment.
2. Sample B is cast iron which gets normalizing heat treatment with temperature 910 °C for 60 minutes.
3. Sample C is a cast iron which gets a normalizing heat treatment with a temperature of 910 °C for 90 minutes.

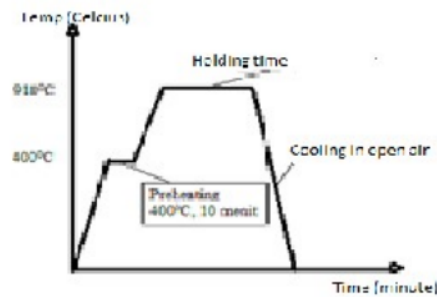


Figure 2. Schematic of Normalizing Process

25

3. Results and Discussions

3.1. Fatigue Test Results Data

Data of fatigue test results are shown in Table 4.1, Table 4.2, and Table 4.3. The needed data to make fracture the cast iron specimens.

Table 2. Data of Testing Results Without Heat Treatment

| Angle (θ) | t (s) |
|--------------------|-------|
| 1° | 244 |
| 2° | 13,7 |
| 3° | 10,6 |
| 4° | 6 |

Table 3. Data of Testing Results With Normalizing for 60 minutes

| Angle (θ) | t (s) |
|--------------------|-------|
| 1° | 312 |
| 2° | 40 |
| 3° | 33 |
| 4° | 13 |

Table 4. Data of Testing Results With Normalizing for 90 minutes

| Angle (θ) | t (s) |
|--------------------|-------|
| 1° | 197 |
| 2° | 27,5 |
| 3° | 15,9 |
| 4° | 4 |

To calculate the stress on the fatigue test using the following formula (HEARN, 1997):

$$\tau = \frac{R \cdot G \cdot \theta \text{ (radian)}}{L}$$

R = Radius of specimen = 0,0035 mm

G = Shear modulus (MPa)

θ = Angle of fatigue testing (radian)

L = Length of specimen = 0,04 mm

For the specimen stress value of 1°

$$\tau = \frac{R \cdot G \cdot \theta \text{ (radian)}}{L}$$

$$\tau = \frac{0,0035 \text{ m} \times 38750 \text{ MPa} \times 0,01744}{0,04 \text{ m}}$$

$$\tau = 59,15 \text{ Mpa}$$

3.2. S-N curve

From the data of calculation of fatigue test is known N (cycle) and Stress (MPa) for each specimen, then the fatigue test result data then plotted into curve S-N fatigue test to know the limit of fatigue resistance of material

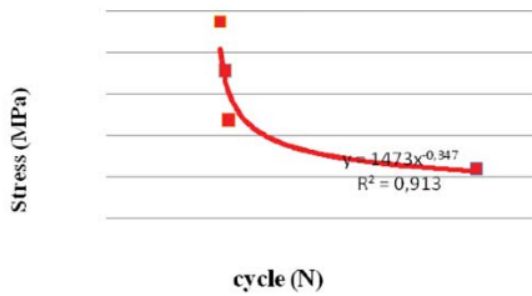


Figure 3. Curve S-N Fatigue Testing Specimens Without Treatment

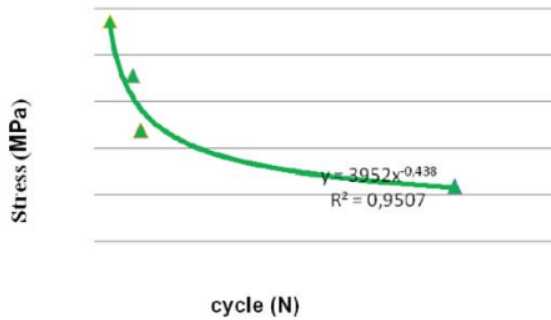


Figure 4.S-N curve Fatigue Testing Specimens With 60 min Normalizing

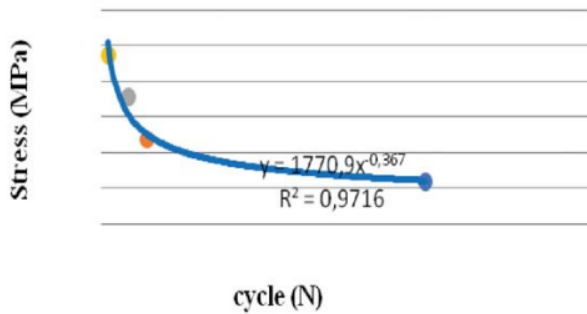


Figure 5.S-N curve Fatigue Testing Specimens With 90 min Normalizing

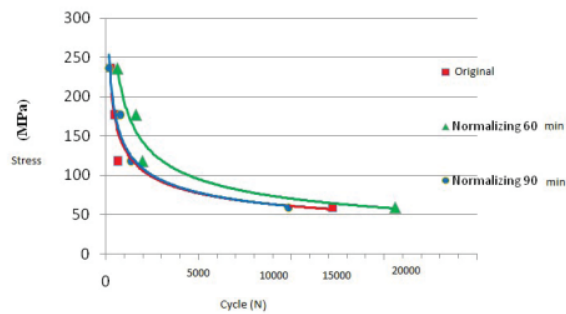


Figure 6.S-N curve combined Fatigue testing between specimens without treatment, normalizing 60 minutes, and 90 minutes

From figures above can be seen that the fatigue resistance for normalizing 60 minutes is increased. This can be seen on S-N curve for different process respectively. From the above data also shows that the specimens of heat treatment normalizing 60 minutes at an angle of one degree have the highest fracture cycle compared to cast iron specimens which normalising 90 minutes and not heat treatment, because at 60 minutes residence time has not caused the emergence of a coarse grain structure contained in the material. It can be seen from the test results Scanning Electron Microscope (SEM) were performed. Meanwhile the holding time (holding time) 90 minutes influence of the grain structure which are material, wherein when the material is heated with a time of 90 minutes causing grains of coarse commonly called cross grain and this causes the material becomes brittle, so when fatigue testing materials will be broken at the lowest cycle.

3.3. Metallographic Inspection

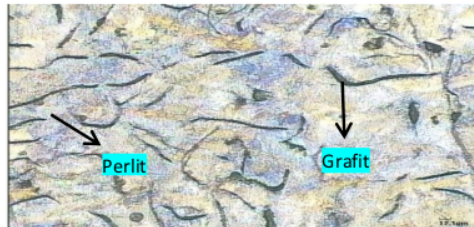


Figure 7.Microstructure of Gray Cast Iron with 200x magnification (2 % nital etching)



Figure 8. Microstructure of Gray Cast Iron with 500x magnification (2 % nital etching)

From the test results shown that the graphite structure of cast iron material is clearly shaped flake (flake) which is characteristic of the gray cast iron. flake graphite cast iron makes the material has a very low level of ductility, even near zero percent. So from the results of exhausted tests conducted specimens quickly broken once.

3.4. Scanning Electron Microscope Inspection

3.4.1. Specimen Non Heat Treatment

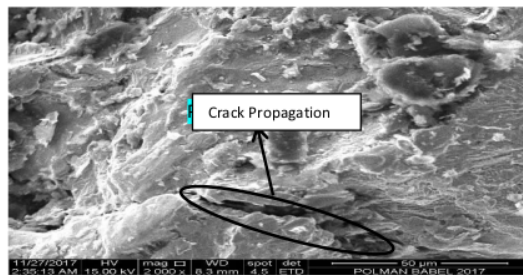


Figure 9.Scanning electron microscope of gray cast iron without heat treatment 2000x magnification

3.4.2. Specimen by heat treatment Normalizing 60 Minutes

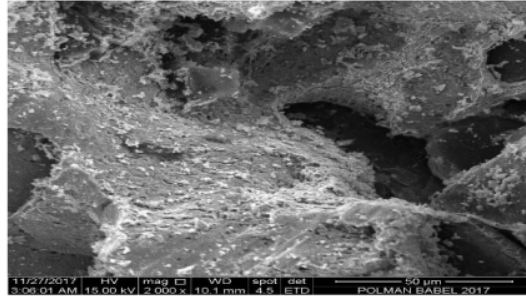


Figure 10. Scanning electron microscope of gray cast iron after normalizing 60 minutes 2000x magnification

3.4.3. Specimen by heat treatment Normalizing 90 minutes

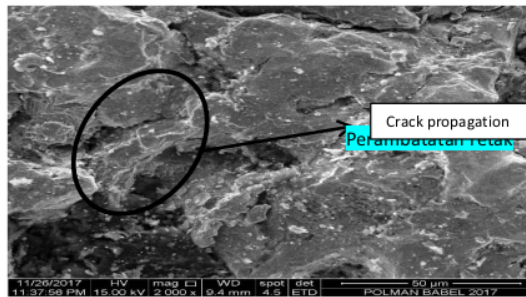


Figure 11. Scanning electron microscope of gray cast iron after normalizing 90 minutes 2000x magnification

²² The results of a Scanning Electron Microscope (SEM) photograph performed on cast iron material representing 10 of each treatment, with 2000x magnification, show that the fracture occurs preceded by the crack initiation present at the end of the cast iron graphite. This is because the structure of the graphite flakes is sharp and pointed causing the stress concentration at the ends when subjected to repetitive stress.

4. Conclusions

- Fatigue resistance of gray cast iron material increased after normalizing heat treatment for 60 minutes. The test results data based on break time and calculations show on cast iron specimens with normalizing 60 minutes heat treatment showed the highest cycle of 15600 cycles ²³ 200 cycles without specimens, and specimens normalizing 90 minutes 9850 cycle.
- From the results of metallographic inspection showed that the graphite structure of flake-shaped specimens that characterize gray cast iron type of pith. Besides the shape fracturing of the specimen showed that the specimens are gray cast iron because of the results of the fatigue testing fracture surface grayed.
- From inspection using SEM showed that crack initiated from the structure of graphite ²⁴ contained in the cast iron, this is because the structure of the graphite flake sharp It induce

the stress concentrations at the tip when subjected to repetitive stress which then propagate until fracture was occurred.

References

- [1] Callister, W., 2007. *Materials science and engineering: an introduction 7th ed.* K. S. Hayton Joseph, Frank Lyman, ed., United States Of America.
- [2] Callister, W.& D.G.R., 2014. Materials Science K. J. Fowley Donald , Sayre Daniel, ed. *Materials Science & Engineering An Introduction*, 9, p.990.
- [3] Chandra Hendri, 2007. *Analisis Fatigue Poros Pompa Vakum*. , p.13.
- [4] Elliott, R., 1988. Chapter 6 - Microstructural Features of Cast Irons. *Cast Iron Technology*, pp.221–238.
- [5] Gross, D., Hauger, W., Schröder, J., Wall, W., and Bonet, J., 2011. *Engineering Mechanics 2*, London New York.
- [6] HEARN, E.J., 1997. Mechanics of. In *MECHANICS OF MATERIALS I*. UNITED KINGDOM, p. 1038.
- [7] Nukman, 2017. *Perlakuan Panas Besi Tuang Nodular Menjadi Austempered Ductile Iron*. Universitas Sriwijaya.
- [8] Panneerselvam, S., Putatunda, S.K., Gundlach, R., and Boileau, J., 2017. Influence of Intercritical Austempering on the Microstructure and Mechanical Properties of Austempered Ductile Cast Iron (ADI). *Materials Science and Engineering A*, 694, pp.72–80.
- [9] Pradipta Dwija, 2015. Pengaruh Pemanasan Austemper Dengan Temperatur Austenisasi 950 C Terhadap Sifat Kekerasan Dan Kekuatan Tarik Besi Tuang Nodular FCD30. , p.9.
- [10] Prastyo, H., 2014. SIFAT MEKANIS MATERIAL BESI COR YANG DIDAUUR ULANG DI PT ANEKA ADHILOGAM KARYA. Jurusan Teknik Mesin Fakultas Teknik Universitas Sriwijaya. , pp.1–7.
- [11] Situngkir Haposan, 2010. *Pengaruh Putaran Cetakan Terhadap Sifat Mekanik Besi Cor Kelabu Pada Pembuatan Silinder Liner Mesin Otomotif Dengan Pengecoran Sentrifugal Mendatar*. Universitas Sumatera Utara.
- [12] Surdia, T. and Saito, S., 1999. *Pengetahuan Bahan Teknik keempat.*, Jakarta: PT Pradnya Paramita.
- [13] Tiastuti Jesi, 2016. ANALISIS PERAMBATAN RETAK FATIK BAJA AISI 1020. , 1020, p.53.

Analysis of Fatigue Life and Crack Propagation Characterization of Gray Cast Iron under Normalizing Process

ORIGINALITY REPORT

20%

SIMILARITY INDEX

PRIMARY SOURCES

- | | | |
|---|--|----------------|
| 1 | eprints.whiterose.ac.uk Internet | 108 words — 4% |
| 2 | repo.ur.krakow.pl Internet | 51 words — 2% |
| 3 | repository.its.ac.id Internet | 34 words — 1% |
| 4 | Yuzhou Du, Xiaolong Wang, Dongya Zhang, Xin Wang, Chunpeng Ju, Bailing Jiang. "A superior strength and sliding-wear resistance combination of ductile iron with nanobainitic matrix", Journal of Materials Research and Technology, 2021 Crossref | 28 words — 1% |
| 5 | Chunyang Hu, Qi Liu, Yutong Du, Junjia Zhang, Ou Jiang, Fei Che. "Meta-analysis of the influence of different element contents on selecting the prediction model of gray cast iron's elastic modulus", Journal of Physics: Conference Series, 2022 Crossref | 27 words — 1% |
| 6 | N I Gabelchenko, N A Kidalov, A A Belov, A I Savchenko, N V Grigoreva. "Study of the effect of | 25 words — 1% |

differentiated cooling modes on the structure and mechanical properties of gray cast iron", IOP Conference Series: Materials Science and Engineering, 2020

Crossref

-
- | | | |
|----|---|-----------------|
| 7 | www.aeroengineering.co.id Internet | 25 words — 1% |
| 8 | Akdemir, A.. "Impact toughness and microstructure of continuous steel wire-reinforced cast iron composite", Materials Science & Engineering A, 20090815 Crossref | 22 words — 1% |
| 9 | www.scribd.com Internet | 20 words — 1% |
| 10 | elar.urfu.ru Internet | 18 words — 1% |
| 11 | opus.lib.uts.edu.au Internet | 17 words — 1% |
| 12 | eprints.unsri.ac.id Internet | 16 words — 1% |
| 13 | www.semanticscholar.org Internet | 16 words — 1% |
| 14 | jmrt.com.br Internet | 14 words — 1% |
| 15 | S Darmo, L D Setyana, T Tarmono, N Santoso. "The Effects of Silicon on The Hardness and Wear of Ferritic Grey Cast Iron on Shoe Brake of Train", IOP Conference Series: Materials Science and Engineering, 2018 Crossref | 13 words — < 1% |

| | | |
|----|--|-----------------|
| 16 | etheses.bham.ac.uk Internet | 13 words — < 1% |
| 17 | cauesantos14.wordpress.com Internet | 11 words — < 1% |
| 18 | repository.umi.ac.id Internet | 11 words — < 1% |
| 19 | Roy Elliott. "Microstructural features of cast irons", Elsevier BV, 1988 Crossref | 10 words — < 1% |
| 20 | text-id.123dok.com Internet | 9 words — < 1% |
| 21 | Akdemir, A.. "Investigation of the tensile properties of continuous steel wire-reinforced gray cast iron composite", Materials Science & Engineering A, 20110425 Crossref | 8 words — < 1% |
| 22 | Diah Kusuma Pratiwi, Nurhabibah Paramitha Eka Utami. "Effect of ageing time 200 °C on microstructure behaviour of Al-Zn-Cu-Mg cast alloys", MATEC Web of Conferences, 2017 Crossref | 8 words — < 1% |
| 23 | I. N. Bogachev, V. F. Senkevich, T. M. Petukhova. "Resistance of cast irons to cavitation erosion", Metal Science and Heat Treatment, 1966 Crossref | 8 words — < 1% |
| 24 | N. M. Sytnik. "Mechanism of crystallization of spheroidal graphite in cast iron", Metal Science and Heat Treatment, 1991 Crossref | 8 words — < 1% |

25 Nurhabibah Paramitha Eka Utami, Hendri Chandra. "Mechanical properties analysis of Al-9Zn-5Cu-4Mg cast alloy by T5 heat treatment", MATEC Web of Conferences, 2017 8 words — < 1%
Crossref

26 autodocbox.com 8 words — < 1%
Internet

27 link.springer.com 8 words — < 1%
Internet

28 Bingxu Wang, Gary C. Barber, Rui Wang, Yuming Pan. "Comparison of Wear Performance of Austempered and Quench-Tempered Gray Cast Irons Enhanced by Laser Hardening Treatment", Applied Sciences, 2020 7 words — < 1%
Crossref

EXCLUDE QUOTES OFF

EXCLUDE SOURCES OFF

EXCLUDE BIBLIOGRAPHY OFF

EXCLUDE MATCHES OFF