18th IFHTSE CONGRESS
International Federation for Heat Treatment and Surface Engineering
IFHTSE

ANAIS
PROCEEDINGS
ISSN 1516-392X

THE INFLUENCE OF THE SUPERFICIAL DEFORMATION ON THE FATIGUE RESISTANCE OF THE AUSTEMPERED DUCTILE IRON[1]

Francis José Saldanha Franco[2]
Maria Teresa Paulino Aguilar[3]
Paulo Roberto Cetlin[4]

Abstract

The austempered ductile iron (ADI) is stronger, lighter and cheaper than forged carbon steels. In addition, ADI displays a higher ductility, toughness and resistance to wear than other cast irons. This work presents an analysis of the effect of induced superficial deformation on the fatigue resistance of samples obtained from a crankshaft. The methodology was completely experimental. The specimens for fatigue testing were machined from the castings (crankshaft) ADI; 30 specimens received no superficial deformation, and other 30 samples were superficially deformed with a compression roller, employing a special device that was built for the study. The results indicated a fatigue strength, under rotational bending, of 439 MPa for the ADI, which was increased by 6% after the superficial deformation.

Key words: Austempered ductile iron; ADI; Austempering; Fatigue resistance; Rotation compression roller.

INFLUÊNCIA DA DEFORMAÇÃO SUPERFICIAL INDUZIDA NA RESISTÊNCIA À FADIGA DO FERRO FUNDIDO AUSTEMPERADO

Resumo

O ferro fundido nodular austemperado (austempered ductile iron – ADI) apresenta resistência mecânica superior à dos aços carbono forjados, dutilidade superior a dos demais ferros fundidos, alta resistência ao impacto e ao desgaste. Neste trabalho estudou-se a influência da deformação induzida superficialmente na resistência à fadiga do ferro fundido nodular tratado. Corpos de prova, fabricados a partir de virabrequins fundidos em ferro fundido nodular, foram submetidos a tratamentos de austempera. A deformação foi induzida através de um dispositivo mecânico especialmente desenvolvido para a realização de rolagem rotativa dos corpos de prova. Os resultados indicaram um limite de fadiga da ordem de 439 MPa para ADI convencional, e que tal limite pode ser aumentado em 6% quando o fundido é submetido a rolagem rotativa.

Palavras-chave: Ferro fundido nodular; ADI; Austempera; Resistência à fadiga; Rolagem.

1 *Technical contribution to the 18th IFHTSE Congress - International Federation for Heat Treatment and Surface Engineering, 2010 July 26-30th, Rio de Janeiro, RJ, Brazil.*

2 *Engenheiro Mecânico, Aluno de Mestrado do Curso de Pós-Graduação em Engenharia Metalúrgica e de Minas, Escola de Engenharia - UFMG, Belo Horizonte; Professor da Universidade de Itaúna ,Itaúna MG. francis@uit.br.*

3 *Dr., Professor Adjunto do Departamento de Engenharia de Materiais e Construção, Escola de Engenharia - UFMG, Belo Horizonte. teresa@demc.ufmg.br.*

4 *Dr., Professor Titular do Departamento de Engenharia Metalúrgica e de Materiais, Escola de Engenharia - UFMG, Belo Horizonte. pcetlin@demet.ufmg.br.*

ISSN 1516-392X

1 INTRODUCTION

The austempered ductile iron, worldwide known as ADI, is currently considered a competitive engineering material, and is employed in the automobile, rail and war industry. It's also employed in the production of equipment for mining, earth moving, construction and agriculture. The combination of appropriate mechanical properties, and lower density and cost of production than those of forged steel has earned for ADI the preference in many markets that are usually closed to conventional ductile iron. In Brazil there are excellent conditions for the production of ADI, due to the availability of raw materials, and to the capacity of the country to produce high quality castings. In general, there is a great interest in the automobile industry to employ ADI; to do so, however, it is necessary that the mechanical properties of the material be specified.

The treatment employed to obtain the austempered ductile iron consists of cooling the casting previously treated down to the austempering temperature, where the material remains for the time it would take for the austenite to turn into acicular ferrite and stable austenite with a high level of carbon. The material with this microstructure is cooled to the room temperature before the bainitic reaction takes place; as a result of this process we obtain a microstructure that is made of acicular ferrite and austenite, which is stable due to the level of carbon. Although the ADI may be obtained from an austempering treatment, the microstructure of this cast iron, which combines excellent resistance and ductility is not the bainite, but the acicular ferrite and high carbon austenite.

The fatigue resistance and other mechanical properties of the ADI is strongly influenced by microstructure, which depends on the quantity, size and distribution of phases. The microstructure is also deeply linked to solidification, which determines the graphite morphology (quantity, size and distribution) and casting defects (porosities, inclusions, segregations, second phase particles or eutectics).

The available information about fatigue resistance of ADI and its correlation to microstructure is scarce, as pointed out Greno et al,[1] Lin and Pai,[2] James and Wenfong[3] and Dai et al.[4] Keough[5] (even says that much research is done on the object, but is not published. The authors are unanimous in stating that the use of ADI in machinery and equipment subjected to fatigue depends upon the availability and reliability of information about its behavior. Lin et al.[6] investigated the influence of microstructure on the high cycle fatigue in many varieties of austempered casting irons, highlighting the influence of the quantity and morphology of graphite and of the quantity of retained austenite. The authors concluded that the initiation of high cycle fatigue failure in ductile casting irons, both with and without austempering treatment involves the breaking of graphite nodules, which then display micro-cracks that coalesce into a main crack. The nucleation of cracks was also observed in casting defects, such as inclusions, micro-shrinkages, and degenerated graphite. However, the ability of ADI to endure the beginning of crack formation to the fatigue process may be greatly increased through induction of compressive tensions on the surface of the material after treatment. These tensions may be easily induced by compressive strains applied on the material through superficial treatments that cause enough deformation to provoke the transformation of stable austenite.[7]

It is believed that the growth of the fatigue crack may be delayed by the occurrence of the transformation of austenite into martensite in the area around the crack, favoring the phenomenon of crack closure through plastic deformation,

ISSN 1516-392X

also causing the relaxation of compressive tensions generated by the superficial treatment and the ones caused by the transformation of the austenite into martensite, as considered by Meneses et al.[8]

2 MATERIAL AND METHODS

The chemical composition of the ductile cast iron analyzed is shown in the table bellow. The chemical analysis was obtained with material taken from the cast before the austempering treatment.

Table 1. Chemical composition of ductile casting iron

Elements	C	Si	Mn	S	Cu	Ni	Mo	P	Mg
%	3,45	2,35	0,10	0,006	0,50	1,00	0,20	0,02	0,035

Eight-flange crankshafts were manufacturesd with the material. After producing the cast, they were austempered to the temperature of 350°C. The cycle of treatment recommended in literature,[1] and already tested in previous research[9] would be 2 hours. However, it was decided to use a cycle of 1,5 hour aiming at obtaining a coarser austenite, which would make future mechanical treatment of rolling easier. Samples were then taken from the crankshaft flanges, as displayed in Figure 1.

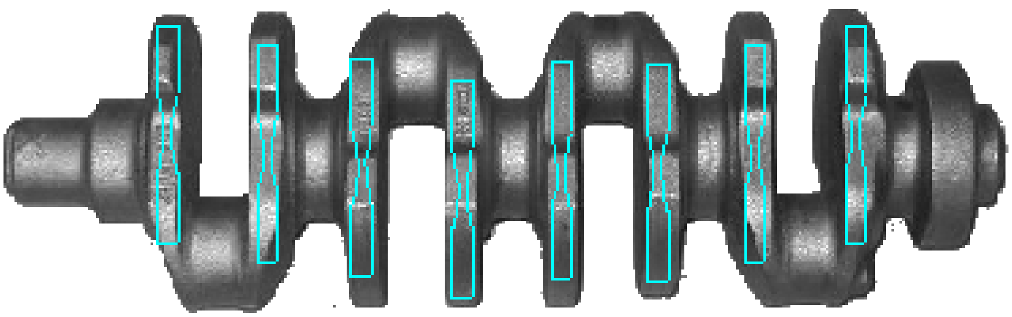


Figure 1. Location of the specimens in the crankshaft.

Some of the samples were utilized for optical micrography, and others for tensile and high cycle fatigue tests. First, the test of rotational bending fatigue was performed without the superficial deformation. Later, the same test was applied to the specimens that were superficially deformed with a compression roller, employing a special device that was built for the study, as can be seen in Figure 2. It is possible to observe that this device is made of two pulleys, one over the other, loaded by a helical spring. This way, one could avoid one-sided deformation of the specimens. The spring applies a force of 800N to the pulleys during compression. The device is put together in a lathe and then the compression is applied to the specimens, as shown in Figure 3.

Figure 2. Device for rolling specimens.

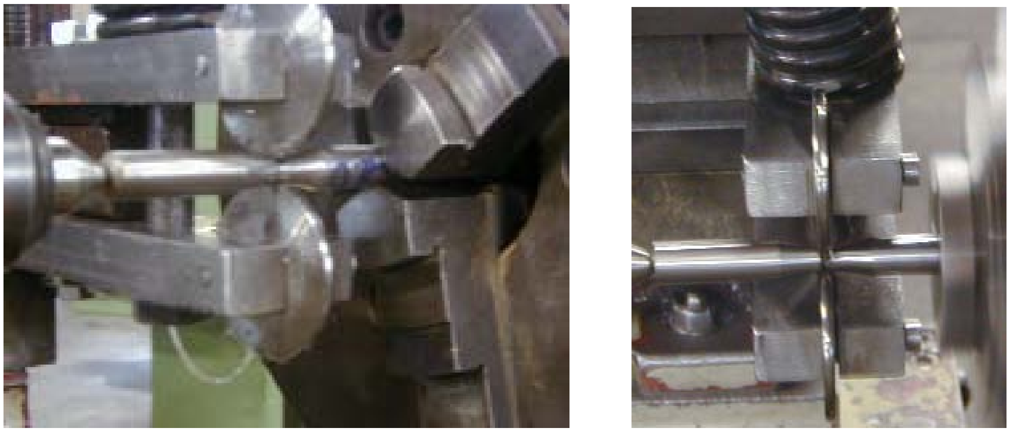
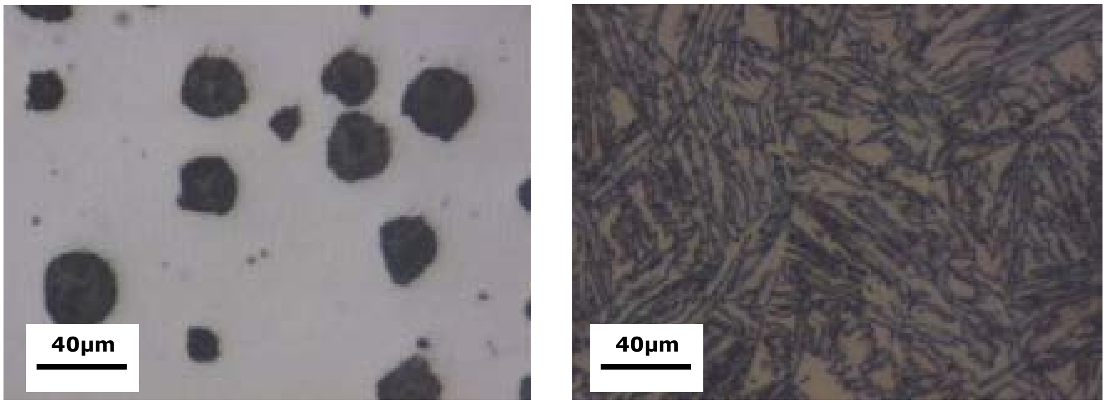


Figure 3. Rolling of specimens in a lathe.

3 RESULTS AND DISCUSSION

The chemical composition shown in Table 1 is typical of a ductile cast iron.[8] The results of metallographic analysis of the material are shown in Figure 4. Figure 4a allows the anlysis of the graphite morphology, whereas Figure 4b displays the microstructure of the matrix.



a) b)

Figure 4. Micrography of ADI: a) appearance of graphite in the sample. (without attack); b) appearance of the metallic matrix in the sample (attacked with NITAL 3%).

Figures 4 indicate that the material has a homogenous ausferritic matrix and a nodular structure of the graphite with a certain degree of heterogeneity. The typical ausferritic microstructure observed is according to ASTM A 897.[10] Using an adequate image analysis software one can evaluate the heterogeneity of the graphite. The results regarding the shape, quantity and size of nodules of three samples are shown in Table 2.

Table 2. Graphite analysis

Specimen	1.A	8.A	6.E
Graphite nodules / mm^2	292	367	304
Nodularity	88,22%	91,95%	90,53 %
Size of Graphite (ASTM A 247)	6 (20 – 40µm) 46.1% 7 (10 – 20µm) 35.7%	6 (20 – 40µm) 30.4% 7 (10 – 20µm) 52.4%	6 (20 – 40µm) 50.1% 7 (10 – 20µm) 33.6%

The above data indicate that the material has a satisfactory quality of a nodular basis for the austempering treatment.[9] The shorter treatment cycle apparently did not affect the material microstructure. The tensile test indicated that the ductile cast iron that was treated had the average values shown in Table 3. The conventional yield point was determined at a deformation of 0.2%, according to ASTM A 536.[11]

Table 3. Average numbers obtained in traction lab tests

UTS (MPa)	Yield strength (MPa)	Elongation (%)
849	685	7.3

The values of UTS limit and elongation fit the material into the class 1 of ASTM A 897,[10] but the elongation is lower that that of class 1. This fact is probably related to the reduction of the time the material remained at the temperature of 350°C, during the austempering treatment. The usual cycle of 2 hours was reduced to 1.5 hour. A smaller elongation could mean a smaller ductility, which could affect a possible future mechanical treatment, aiming at a greater fatigue resistance of the treated ductile iron.

18th IFHTSE CONGRESS
International Federation for Heat Treatment and Surface Engineering
ANAIS
PROCEEDINGS
ISSN 1516-392X

Figure 5 shows the S-N curve, built with the results of the rotational bending fatigue,[12] without superficial deformation. The fatigue limit was determined using the Escada Method[12] and assuming the material has an endless life if it can endure more than $5x10^6$ cycles; the result led to a fatigue limit of 438.93 MPa, with standard deviation of 27.35 MPa. These values are within the range mentioned in literature,[1] which indicates that the reduction of the austempering time did not affect the fatigue resistance of ADI.

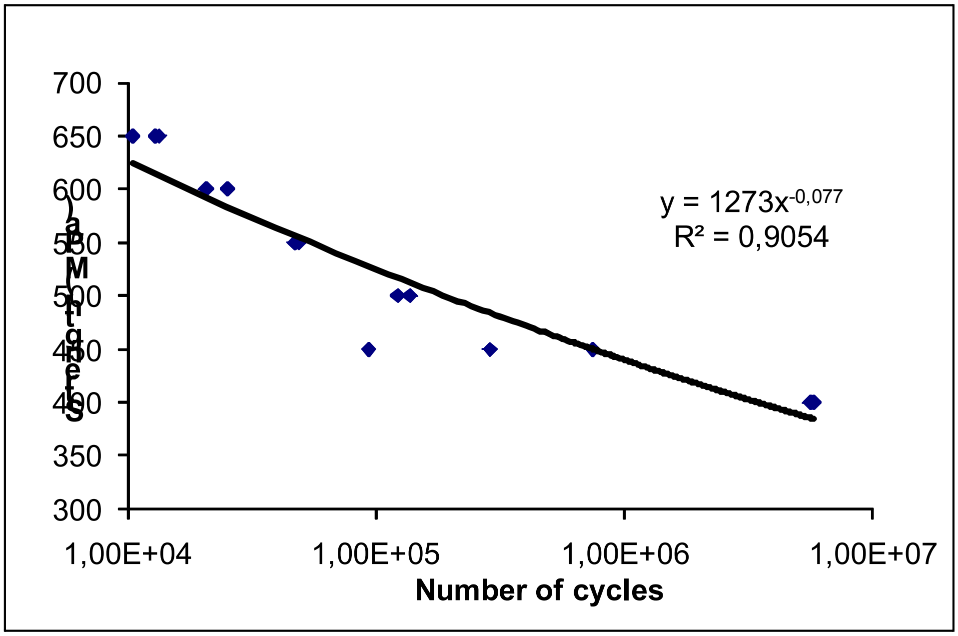


Figure 5. S-N Curve of ADI submitted to rotational bending without superficial deformation.

Figure 6 presents the S-N curve for the tests performed in the specimens with the superficial deformation induced by rolling.

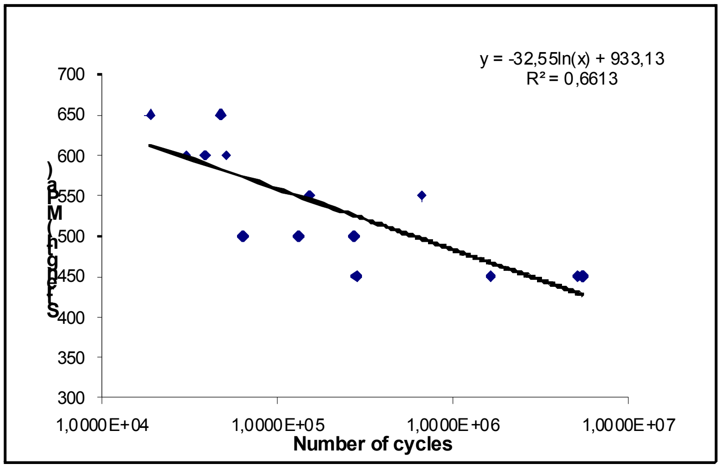


Figure 6. S-N Curve of ADI, submitted to rotational bend with superficial deformation by rolling.

ISSN 1516-392X

The fatigue limit was also determined using the Escada Method, which led to a fatigue limit of 465 MPa, with standard deviation of 2.26 MPa.

Figure 7 shows a comparison of the fatigue curves for specimens with and without rolling; compression rolling in ADI provided an increase of 5.94% in the fatigue resistance limit.

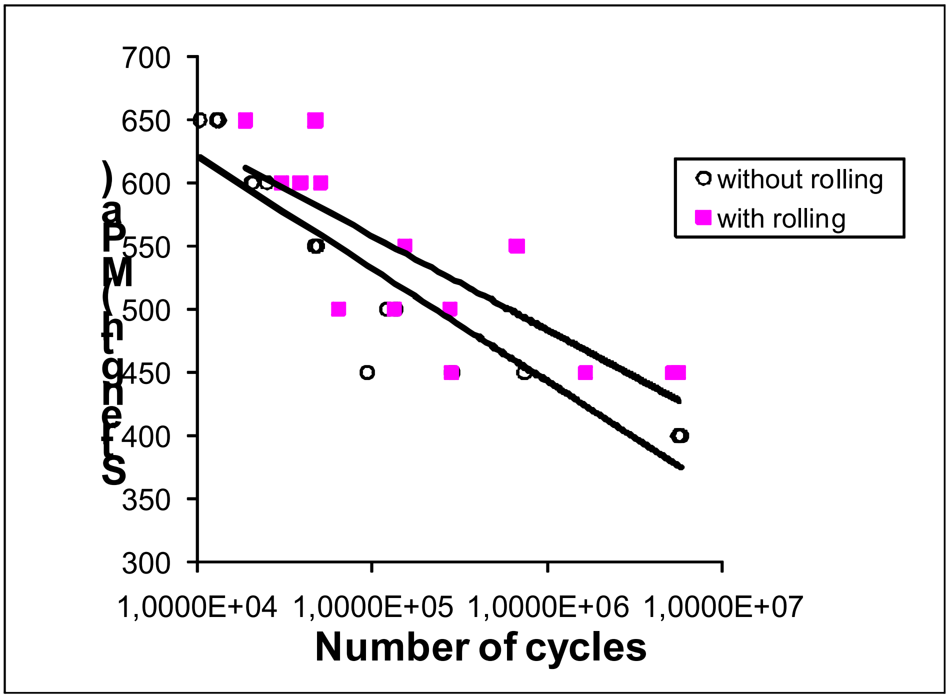


Figure 7. Comparative chart between S-N curves with and without rolling.

4 CONCLUSION

The results of the tests for high cycle fatigue of the ADI, under constant loading, were similar to the ones found in literature.

The induced deformation obtained by using compression rollers on the ADI surface increased its fatigue resistance by 5.94%.

This study indicates that the fatigue resistance with this particular induced superficial deformation is recommended when employing ADI in the production of crankshafts.

REFERENCES

1 GRENO, G. L.; OTEGUI, J.L.; BOERI, R. E. (1998). Fatigue of austempered ductile iron. AFS Casting Congress.

2 LIN, C.K.; LAI, P.K.; SHIH, T.S. (1996) Influence of microstructure on the fatigue properties of austempered ductile iron – I. High-cycle fatigue. International Journal of Fatigue, v.18 (5), p. 297-306.

3 JAMES, M. N. & WENFONG, L. (1999). Fatigue crack growth in austempered ductile and grey cast irons – stress ratio effects in air and mine water. Materials Science & Engineering A, v. 265, p.129-139.

ISSN 1516-392X

4 DAI, P.Q.; HE, Z.R.; ZHENG, C.M., MAO, Z.Y. (2001). In-situ SEM observation on the fracture of austempered ductile iron. Materials Science and Engineering A, v. 319-321, p.531-534.
5 KEOUGH, J.R. (1991) The development, processing and application of austempered ductile iron. In: WORLD CONFERENCE ON AUSTEMPERED DUCTILE IRON, Chicago, 12 a 14 mar 1991. Des Plaines: AFS, 2v. il.. p. 638 – 658.
6 LIN, C.K. & HUNG, T.P. (1996). Influence of microstructure on the fatigue properties of austempered ductile iron – II. Low-cycle fatigue. International Journal of Fatigue, v.18 (5), p. 309-320.
7 VOIGT, R.C.; LEE, Y.H.; TU, C.H. (1991), Use of hardenability data to determine alloy requirements for austempered ductile iron. In: WORLD CONFERENCE ON AUSTEMPERED DUCTILE IRON, Chicago, 12 a 14. Des Plaines: AFS, 2v. il. p. 479 – 514.
8 MENEZES, C.G.; CARMO, D.J.; TAVARES, F.C.L.; DIAS, J.F. (2003). Análise da resistência à fadiga de virabrequins em ferro fundido nodular austemperado (ADI). ABM, IV Seminário de Fundição.
9 DIAS, J.F. Costa E. (1995), Desenvolvimento do Processo de Obtenção do ADI- Uma Experiência Vivida pelo CETEF. CONGRESSO NACIONAL DE FUNDIÇÃO; Associação Brasileira de Fundição São Paulo 1995. P 177-183.
10 AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM A 897; austempered ductile iron castings. West Conshohocken, 1990. P 565-570. V.01.02.
11 AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM A 536. Standart specification for ductile iron castings. West Conshohocken, 1990. P 297-301. V.01.02.
12 SOUZA, S. A. (1982). Ensaios mecânicos de materiais metálicos. Fundamentos teóricos e práticos. Edgard Blücher.