Pamukkale Univ Muh Bilim Derg, XX(X), XX-XX, 20XX

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Investigation of microstructures, mechanical properties, wear behavior and machinability of EN-GJS-500-7 (GGG50) grade ductile cast irons having modified chemical composition

Geliştirilmiş kimyasal bileşime sahip EN-GJS-500-7 (GGG50) kalite küresel grafitli dökme demirlerin mikroyapısının, mekanik özelliklerinin aşınma davranışının ve işlenebilirliğinin incelenmesi

Mehmet YILDIRIM[1], Hüseyin GÜMÜŞ[2], Mehmet Emin ÖZCAN[2]*

[1]Department of Metallurgical and Materials Engineering, Faculty of Engineering and Natural Sciences, Konya Technical University, Konya, Türkiye.
myildirim@ktun.edu.tr
[2]Mesa Machinery, Konya Industrial Zone, Konya, Türkiye.
huseyin.gumus4242@gmail.com, emin.ozcan@mesamakina.com.tr

Received/Geliş Tarihi: 12.12.2024 Revision/Düzeltme Tarihi: 13.04.2025 doi: 10.5505/pajes.2025.79958
Accepted/Kabul Tarihi: 22.05.2025 Research Article/Araştırma Makalesi

Abstract

Ductile cast irons (DI) are promising candidates for forged steels due to their lower density (10-15 %), lower production cost and good specific strength. The mechanical properties of DIs are heavily influenced by matrix (ferrite, pearlite, or ferrite+pearlite), type and concentration of alloying elements (Si, Cu, Sn. Cr, Ni. etc). The pearlite phase, which is stronger and harder than ferrite phase, depends not only on the chemical composition but also the cooling rate of sections having various section thickness. In this situation non-uniform microstructure and mechanical properties occur between the thick and thin sections of the parts. In this manner solid solution strengthened (with Si) ferritic DIs become prominent with more uniform microstructure and mechanical properties. In the present study, the microstructural properties, mechanical properties (tensile properties, hardness, and impact energy), wear resistance and tool life (turning machining operations) of EN-GJS-500-7 grade ductile cast irons, having modified composition (increased amount of Si, decreased amount of C and pearlite former), are studied in detail. The resultant microstructures and mechanical properties are compared with those for having traditional composition. For modified composition, the ferrite (solid solution strengthened with excess Si) amount considerably increases, and so the cast part exhibits uniform hardness distribution among the surface layer and center regions). In addition, the yield strength and the ultimate tensile strength (UTS) of the modified composition is slightly lower than those for traditional composition. In addition, modified composition exhibits better wear resistance (lower wear loss and friction coefficient) and longer tool life compared to those for traditional composition. As a result, an alloy with improved mechanical properties and good machinability has begun to be applied industrially.

Keywords: Ductile cast iron, Chemical composition, Microstructure, Mechanical Properties, Wear behavior

Öz

Küresel grafitli dökme demirler (KGDD), düşük yoğunlukları (%10-15), düşük üretim maliyetleri ve iyi özgül mukavemetleri nedeniyle dövme çelikler için aday malzemeler olarak düşünülmektedir. KGDD'lerin mekanik özellikleri matris tipine (ferrit, perlit veya ferrit + perlit), alaşım elementlerinin türü ve konsantrasyonuna (Si, Cu, Sn. Cr, Ni. vb.) bağlıdır. Ferrit fazına göre daha güçlü ve daha sert olan perlit fazı sadece kimyasal bileşime değil aynı zamanda farklı kesit kalınlığına sahip parçalarda soğuma hızına da bağlıdır. Bu durum parçaların kalın ve ince bölümleri arasında farklı mikroyapıların oluşmasına ve farklı mekanik özelliklerin ortaya çıkmasına sebep olmaktadır. Bu durumda katı çözeltiyle güçlendirilmiş (Si) ferritik KGDD'ler daha homojen mikroyapı ve mekanik özelliklere sahip olarak öne çıkmaktadır. geliştirilmiş bileşime sahip (arttırılmış Si miktarı, azaltılmış C miktarı ve perlit oluşturucu) EN-GJS-500-7 kalite KGDD'lerin mikroyapısal ve mekanik özellikleri (çekme özellikleri, sertlik ve darbe enerjisi), aşınma direnci ve takım ömrü (tornalama sırasında) detaylı biçimde incelenmiştir. Elde edilen mikroyapılar ve mekanik özellikler, geleneksel bileşime sahip KGDD'lerin mikroyapı ve mekanik özellikleri ile karşılaştırılmıştır. Geliştirilmiş bileşim için, ferrit (fazla Si ile güçlendirilmiş katı çözelti) miktarı önemli ölçüde artmakta ve bunun sonucunda döküm parçanın yüzey bölgeleri ile merkez (çekirdek) arasında düzgün bir sertlik dağılımı elde edilmiştir Ek olarak, geliştirilmiş bileşimin akma ve çekme mukavemeti , geleneksel bileşime göre çok az daha düşüktür. Buna ilaveten, geleneksel bileşime kıyasla geliştirilmiş bileşimin daha üstün aşınma direncine (daha düşük aşınma kaybı ve sürtünme katsayısı) sahip olduğu ve talaşlı imalat süreçlerinde uzun takım ömrünü uzattığı tespit edilmiştir. Sonuç olarak, geliştirilmiş mekanik özelliklere ve iyi işlenebilirliğe sahip bir alaşım endüstriyel olarak uygulanmaya başlanmıştır.

Anahtar kelimeler: Küresel grafitli dökme demir, Kimyasal bileşim, Mikroyapı, Mekanik Özellikler, Aşınma Davranışı

1 Introduction

Ductile iron (DI) is a well-known ferrous alloy composed of mainly Fe, C and Si [1]. DIs have a very wide application field such as crankshafts, heavy-duty engine parts, railway brake systems, pistons, wind-turbine parts, pumps, valves due to their good mechanical properties, high castability, good machinability, moderate fatigue, and wear resistance [1-9]. Compared to steels, DIs have lower production cost and lower densities (10%) [2]. Therefore, the quality, lower weight and lower cost make DIs suitable candidates for steels. The lower specific weight of DIs enables the casting of thinner-sectioned parts with good mechanical properties [4]. On the other hand, DIs can exhibit the best combination of mechanical properties

*Corresponding author/Yazışılan Yazar

(strength, ductility, and fracture toughness) among other cast irons (gray and white cast iron) [10,11].

The matrix of the DIs can be ferritic, pearlitic, or a combination of ferritic and pearlitic. The type of the matrix is responsible for the variations in mechanical properties [3,12]. The chemical composition of the DIs strongly affects the microstructure which further controls the resultant mechanical properties [13]. Moreover, the chemical composition may be responsible for the formation of casting defects such as exploded graphite, chunky graphite, dross, graphite flotation, nodule alignment, shrinkage, and gas porosity [14-17]. The DIs are designated as EN-GJS (European Standard for ductile cast iron) grades [18]. EN-GJS-500-7 is a traditional grade with ferritic/ pearlitic matrix containing 3.85-3.95 % C and 2.30-2.40 % Si. In addition, Cu or Sn is added as pearlite forming elements. The Cu_{eq} of EN-GJS-500-7 grade is in the range of 0.35-0.45 % [19]. EN-GJS-500-7 castings having various section thicknesses may result in strongly various pearlite concentrations which further lead to important differences in hardness values throughout the casting. The amount of pearlite phase is influenced not only by the chemical composition but also by the cooling behavior. The thick sections of the casting contain relatively lower amounts of pearlite due to slower cooling rate and as a result relatively softer. On the other hand, the thin sections of the casting contain relatively higher amounts of pearlite due to faster cooling rate and exhibit higher hardness values. The important differences between the hardness values have some disadvantages: (i) difficulty in achieving similar hardness tolerances, and (ii) poor machinability [18].

Researchers have been making efforts to develop a ductile cast iron that exhibits the best combination of mechanical properties and improved machinability. In this sense, solid solution strengthening of ferrite phase with high amount of Si seems to be the most effective way to obtain uniform mechanical properties throughout the casting [20-28]. Recently, a previous work [29] stated a new DI grade of EN-GJS-500-14. Compared to conventional EN–GJS–500-7 grade, this new grade is a solid solution strengthened ferritic DI. The new composition possesses higher tensile strength, higher elongation and better machinability than conventional grade. These outstanding features of the new grade can be ascribed to the relatively high Si concentration. Furthermore, it is also reported that this new grade can be a candidate for steel. Thus, this study aims to investigate the microstructural properties, mechanical properties (yield strength, ultimate tensile strength, ductility, impact toughness and hardness), wear behavior and machinability of EN-GJS-500-7 (GGG50) grade ductile irons having modified chemical composition. In this manner, two different ductile irons are cast. One of them has the traditional EN-GJS-500-7 (GGG50) chemical composition and the other one has modified composition with decreased C and Cu_{eq} (pearlite former) and increased Si amount. In addition, this study mainly emphasizes the comparison of microstructural and mechanical properties of ductile irons having traditional and modified compositions.

Kandemir et al. [30] investigated the wear behavior of various DIs having various pearlite and ferrite amounts with respect to section size and chemical composition. They showed that the alloy showing minimum wear loss did not exhibit the highest strength. Emre Aydın [31] investigated the mechanical properties, wear performance, machinability and corrosion resistance of EN-GJS-500-7 grade DIs having various ferrite and pearlite amounts. Like Kandemir et al. [30], Emre Aydın [31] also stated that the composition having the highest pearlite exhibited the best mechanical properties, but the lowest wear loss was not observed. Moreover, he also showed that the composition having highest amount of ferrite encountered lowest cutting forces during machining. On the other hand, Björkegren and Hamberg [32] compared the tool lives of traditional EN-GJS-500-7 and relatively high Si (3.27 %) containing DIs. They showed that under cutting speed of 240 m/min the tool lives of traditional and high Si containing DIs until flange wear were determined as 12 and 17 minutes (nearly 1.5 times longer), respectively. They also presented that surface roughness is lower for high Si containing DI.

Recently, there is an increasing tendency to develop DIs by exhibiting the best combination of mechanical properties, physical properties, machinability and wear resistance [29]. Therefore, we have tried to design and develop a modified composition, which can be considered as the originality of the present study. The modified chemical composition of the EN-GJS-500-7 DI is developed by our research team.

The chemical composition of the modified composition is determined considering the castability, solidification defects and resultant mechanical properties. The DIs having good castability, sufficient mechanical properties, reduced shrinkage and non-formation of other solidification/casting defects should have a carbon equivalent (CE) close to the eutectic composition of 4.3 %. High CE (> 4.3%) have several artefacts: (i) if the composition has an excess C content, primary graphite can form and results in a harmful influence on mechanical properties due to the graphite flotation as a casting defect on the upper regions of parts, (ii) if the composition has an excess Si content, the brittle to ductile transition temperature increases, ferrite phase becomes brittle (rapid drop of elongation) and exploded graphite forms as a result of lower solidification rate. In the modified composition, firstly, it is aimed to decrease the amount of pearlite to obtain a uniform distribution of hardness between thick and thin sections (or surface and center of specimens). Thus, the amount of pearlite forming elements Cu and Sn is reduced. Secondly, the hardness lose due to the decrease in the amount of pearlite can be compensated by solid solution strengthening of softer ferrite phase by increasing Si content. Hence, the amount of Si is increased. However, Si content is not much increased since the detrimental effects of high amount of Si. Thirdly, the C content is decreased to ensure CE to be close to 4.3.

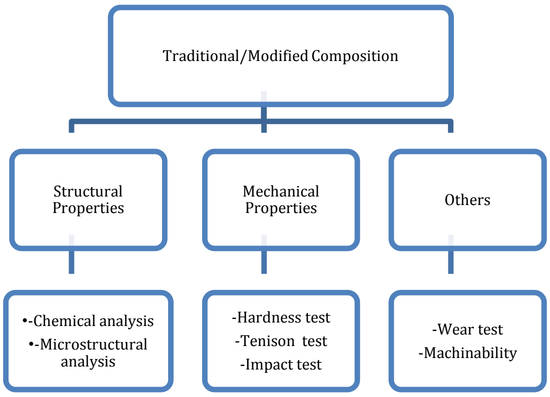
2 Experimental procedures

2.1 Production of the specimens

The GGG-50 (EN-GJS-500-7) ductile cast iron is produced utilizing a medium frequency induction furnace with a 1500 kg capacity at Mesa Machinery (Konya, Turkey). The charge is composed of pig iron, foundry return scraps (runners, risers, etc.) and steel scraps. The spherodization is done with FeSiMg7 utilizing the tundish ladle method. Then, the melt is inoculated with FeSi75 alloy (containing 2-3% Ba). Finally, the molten material is poured into sand molds shaped like standard keel blocks.

2.2 Characterization

Scheme 1 lists all analyses and tests applied to the traditional and modified EN-GJS-500-7 compositions. The chemical compositions (traditional and modified) of the specimens are analyzed utilizing an Oxford Foundry Master model optical emission spectrometer (OES). The microstructural investigation of the samples is performed utilizing a Nikon Eclipse MA 100 model inverter type optical microscope. Prior to the microstructural examination, the specimens are prepared using standard metallographic sample preparation techniques. Firstly, disc shape specimens (40 mm diameter and 10 mm height) are cut using an abrasive cutter. Then The specimens are mechanically ground using SiC emery papers (ranging from 180 to 1200 grit), polished with a 1 µm alumina suspension, and finally etched with a 3% Nital solution. In addition, the fundamental microstructural parameters of cast irons such as nodularity, nodule count graphite amount and ferrite/pearlite ratio are determined using image analyzer software.



Scheme 1. The flowchart showing the study plan.

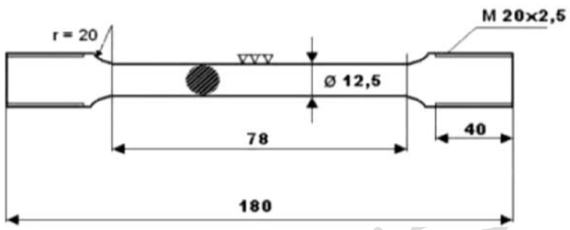


Figure 1. The geometry and dimensions of standard tensile test specimens used in the tensile tests.

Brinell hardness measurements are conducted utilizing a Bulut Machinery BMS 3000-OB model Brinell hardness tester under a load of 3 tons on polished surfaces. The load is applied for 8 seconds. The tensile tests of the specimens (Figure 1) are conducted utilizing an ALSA KTM 600 Model (60 tons/600 kN) hydraulic universal tensile testing apparatus with a deformation rate of 8 mm/min. The tensile tests are performed according to the TS EN 1563 (tension test of metallic materials at room temperature) standard. The yield strength, ultimate tensile strength (UTS) and percent elongation values are determined with tension tests. Charpy impact tests are performed at room temperature using an ALSA ZBC 300 model impact tester in accordance with ASTM E23-18 (Standard Test Methods for Notched Bar Impact Testing of Metallic Materials) standard. The cast specimens are cut and machined to produce standard rectangular un-notched specimens with dimensions of 10 × 10 × 55 mm.

Prior to abrasive wear tests, disc-shaped samples with a diameter of 30 mm and a thickness of 10 mm are prepared by cutting them with an electric saw. The samples are then ground and polished. The abrasive wear tests are performed using a UTS Tribolog tribometer with the reciprocating ball-on-disc method, in accordance with ASTM G133 (Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear). Moreover, the wear tests are performed in dry sliding conditions at ambient temperature and with a relative humidity of 68 %. A WC ball, having 6 mm diameter, is used during the tests. The test parameters are listed in Table 2. The friction force and friction coefficient between the abrasive ball and the specimen are measured during the abrasive wear tests. The frictional force is measured with a load cell, and the coefficient of friction is obtained by dividing this force by the normal load. The 2D wear profile (depth and width) of the wear tracks is examined by a Nanomap LS stylus profilometer [33]. The wear loss is calculated as the volume of wear track. After the tests, the worn surfaces of the samples are investigated by light optical microscopy.

Table 1. The chemical analysis (wt.%) of EN-GJS-500-7 grade ductile irons having traditional and modified compositions.

Composition	Fe	C	Si	Mn	P	S	Mg	Sn	Cr	Cu	Mo	Ni
Traditional	bal.	3.95	2.32	0.152	0.034	0.04	0.059	0.035	0.023	0.066	0.003	0.001
Modified	bal.	3.45	2.80	0.127	0.038	0.012	0.061	0.023	0.020	0.029	0.011	0.001

Table 2. The test parameters of the abrasive wear test.

Force	20 N
Sliding distance	100 m
Frequency	5 Hz
Stroke length	10 mm
Sliding speed	100 mm/s

The effect of different compositions on machinability is investigated by calculating the tool life. Two different specimens (specimen1: 66 mm diameter and 125 mm length, specimen2: 48 mm diameter and 125 mm length) of each composition are considered in turning operations. DNMG150608-PM4 carbide inserts are used in the experiments. Table 3 provides the cutting speed, feed rate, and depth of cut for the specimens. During machinability tests, the total number of specimens were recorded until the cutting tool fails.

Table 3. Cutting parameters used in the machinability tests.

Specimen 1	Cutting Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)
Specimen 1 (ϕ66, L125)	850	0.16	5
Specimen 1 (ϕ48, L125)	1000	0.25	3

3 Results and discussion

The chemical compositions (wt.%) of the traditional and modified EN-GJS-500-7 nodular cast irons are displayed in Table 1. Compared to the traditional composition, % C is reduced and % Si is increased somewhat. In addition, Sn, which is used as a pearlite former, also decreased in the modified composition. The carbon equivalents (CE) for studied compositions are calculated by the equation given below.

$$CE = \%C + \frac{\%Si + \%P}{3} \quad (1)$$

The calculated CE values for the traditional and modified EN-GJS-500-7 nodular cast irons are 4.435 and 4.396, respectively. To obtain a nearly constant CE value, the increase in Si content is compensated for the decrease in C content.

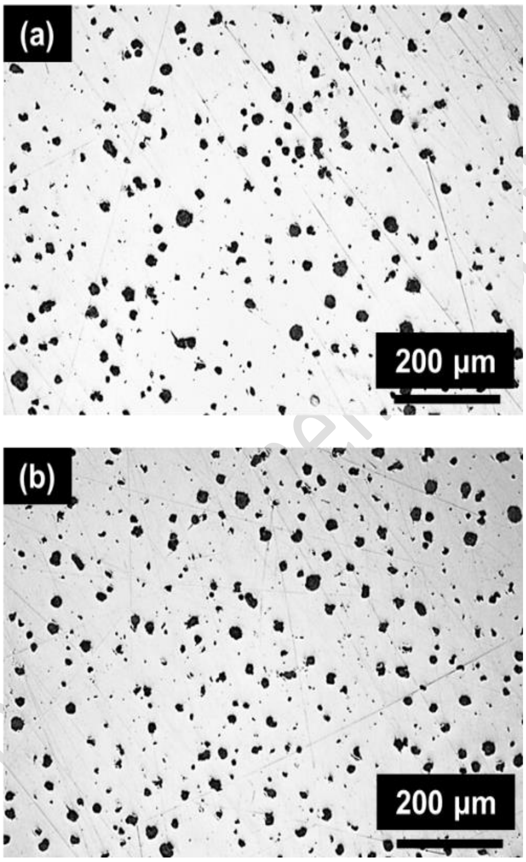


Figure 2. The optical micrographs showing the distribution of spheroidal graphite for (a) traditional, and (b) modified compositions.

The optical micrographs of surface regions (Figure 3) clearly indicate the microstructural differences between traditional and modified compositions. For modified composition (Figure 3(b), the amount of ferrite (white regions) is evidently greater than that of traditional composition (Figure 3(a). For the center part of the casting (Figure 4), the amount of ferrite (white regions) and pearlite (dark non-spherical regions) seem to be similar. Moreover, the difference between the determined ferrite/pearlite ratio of modified and traditional compositions (Table 1) is more pronounced in the surface regions. Thus, it can be concluded that the optical micrographs and determined microstructural features via microscopy software are consistent with each other.

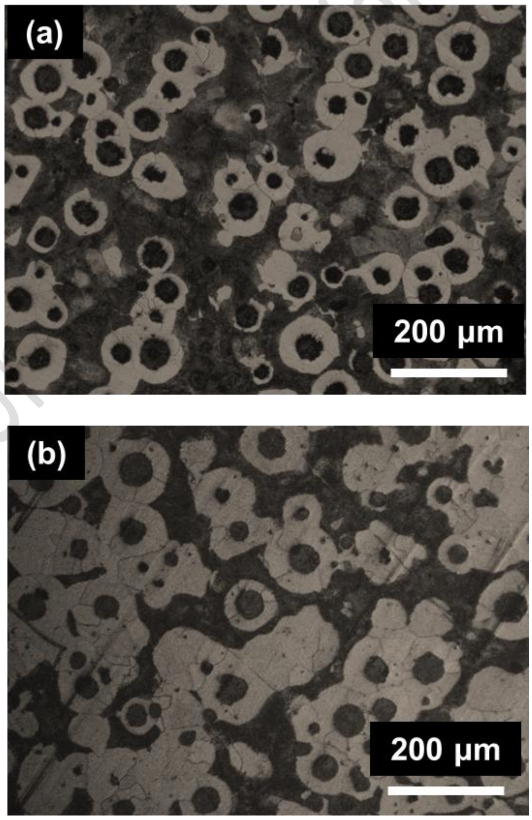


Figure 3. The optical micrographs of the near surface layers of (a) traditional, and (b) modified compositions.

Table 4. The microstructural features of traditional and modified EN-GJS-500-7 compositions determined with microscopy software.

Parameter	Traditional	Modified
Nodularity (%)	73 ± 1	74 ± 1
Nodule Count ($1/mm^2$)	257.1 ± 7.2	273.4 ± 8.1
Ferrite/pearlite ratio surface	0.35 ± 0.01	0.85 ± 0.02
Ferrite/pearlite ratio center	0.47 ± 0.01	0.90 ± 0.02

The optical micrographs of studied cast irons are shown in Figures 2-4. The microstructures of both compositions are composed of graphite (black spheres), ferrite (light regions) and pearlite (dark regions) phases. Neither carbide formation nor any casting defects (i.e., chunky graphite, exploded (degenerated) graphite, spiky graphite, shrinkage, graphite flotation and dross) are observed in the microstructures of studied alloys. The important microstructural features (Table 4) such as nodularity, nodule count, and ferrite/pearlite ratio are also determined via microscopy software. Ten independent micrographs are considered for each composition (traditional or modified) and each location (surface or center).

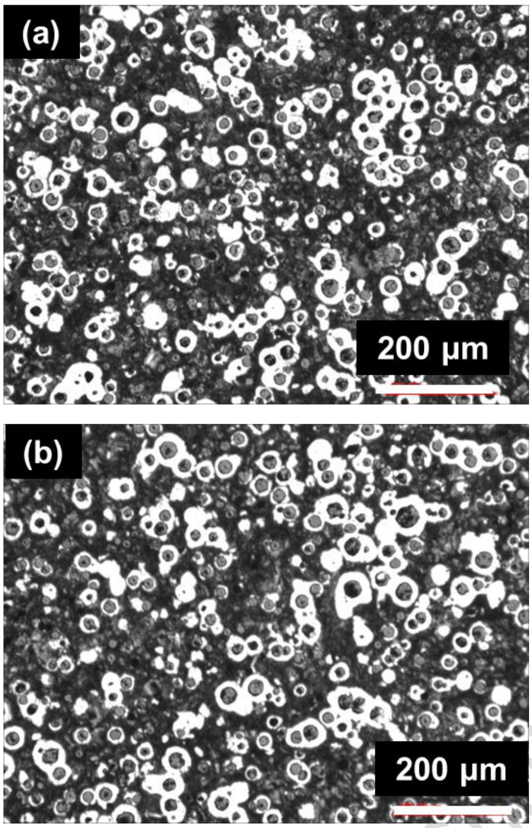


Figure 4. The optical micrographs of the central parts of (a) traditional, and (b) modified compositions.

The Brinell hardness profile of the studied compositions are shown in Figure 5. The overall hardness value of traditional composition is considerably higher than that of modified one. For traditional composition, the center of the specimen is softer compared to the specimen surface. As the specimen surfaces of the cast parts are prone to pearlite formation due to the higher cooling rates, the specimen surface is expected to exhibit higher hardness values. On the other hand, for the modified composition, the situation is vice versa. In this case, the center of the sample is harder than the sample surface and the hardness variation between the surface and center is less pronounced. The results of Brinell hardness measurements confirm the microstructural differences of traditional and modified EN-GJS-500-7 ductile iron compositions. For modified composition, increased ferrite concentration and uniform distribution of ferrite phase among the parts result in a uniform distribution of hardness values. Although the ferrite/pearlite ratio is lower in surface compared to the center for modified composition, the center region is somewhat harder than surface layer. This contradiction can be explained with the chemical analysis of modified composition. The main differences between the chemical compositions of traditional and modified DIs are increased C, reduced Sn as a pearlite former and increased Si. For modified composition, the decrease in Sn and increase in Si lead to a strong decrease in pearlite ratio and solid solution strengthening of softer ferrite phase. It is well-known that Si acts as a strong solid solution strengthener for ferrite phase [20, 21, 34]. Therefore, the hardness of the center region is somewhat higher than surface despite its lower pearlite ratio.

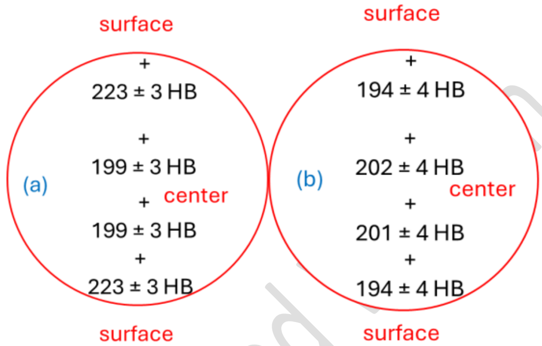


Figure 5. The hardness profile of the (a) traditional, and (b) modified compositions.

Table 5. Tensile properties and impact energies of traditional and modified EN-GJS-500-7 compositions. (The standard data is given for comparison)

Mechanical Property	Traditional	Modified	EN 1563 standard
Yield Strength (MPa)	477 ± 12	461 ± 11	Min. 320
Ultimate Tensile Strength (MPa)	735 ± 18	665 ± 19	Min. 500
% elongation	10.8 ± 0.6	10.9 ± 0.6	Min. 7
Impact Energy (J)	51.2 ± 3.4	57.3 ± 3.8	Min. 70

The results of tension and Charpy impact tests for traditional and modified EN-GJS-500-7 compositions are listed in Table 5. The standard data for EN-GJS-500-7 composition present in EN 1563 standard [19] is also presented for comparison. According to these results, both traditional and modified compositions exhibit better tensile properties (higher yield strength, UTS and percent elongation) than that of standard data. The modified composition exhibits slightly lower strength values and very similar elongation values compared to those for traditional composition. The resultant tensile properties agree well with the obtained hardness values. Additionally, the impact energy for modified composition is also somewhat greater. However, the impact energies of both traditional and modified compositions are considerably lower than the value present in the EN 1563 standard. This situation can be explained with the higher yield and strength values compared to the values present in the standard. For DIs, impact energy values are inversely proportional to strength/hardness values. For example, the softest EN-GJS-400-18 grade exhibits the highest impact energy of 120 J, while the hardest grade EN-GJS-800-2 grade exhibits the lowest impact energy of 15 J.

The mechanical tests reveal that EN-GJS-500-7 ductile iron can exhibit a good combination of mechanical properties with modified composition. Satisfactory yield and tensile strength, high elongation and uniform hardness values would provide better machinability and uniform mechanical properties among the layers having various section thicknesses.

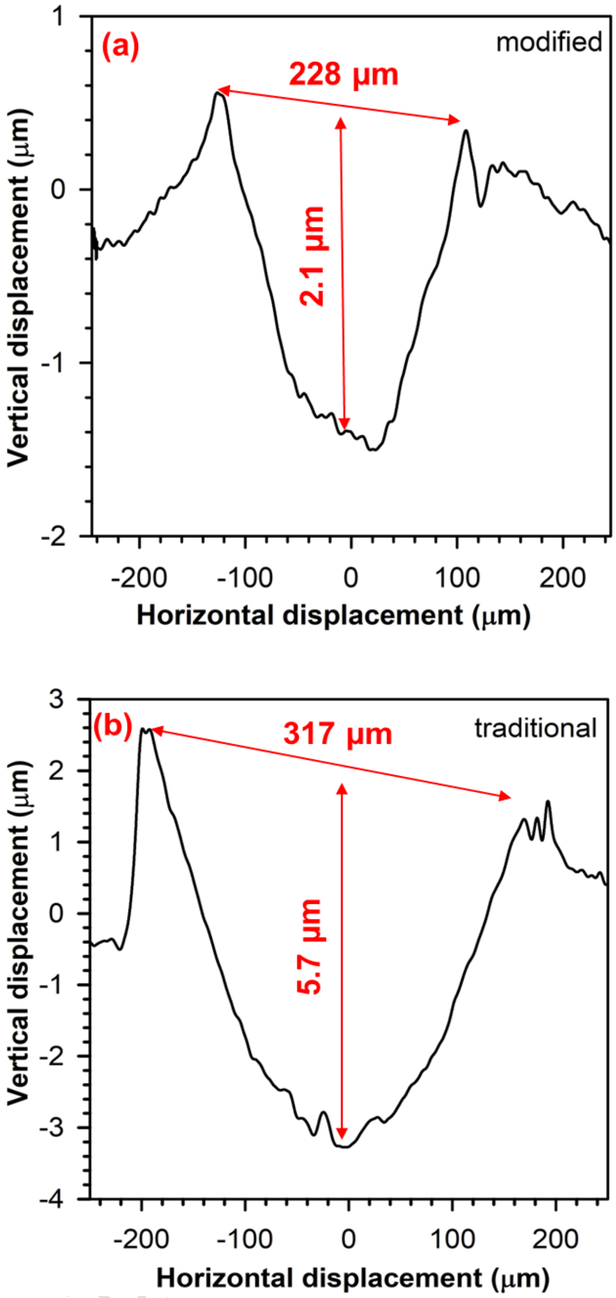


Figure 6. Wear profiles along the vertical direction of wear tracks: (a) modified, and (b) traditional compositions.

The wear profiles along with optical micrographs of worn surfaces of traditional and modified EN-GJS-500-7 DIs are illustrated in Figures 6 and 7. In addition, the volume loss of both specimens is determined from the wear profiles and listed in Table 6. The wear profiles reveal that modified composition, traditional composition shows wider (317 μm) and deeper (5.7 μm) wear profile. Moreover, the average coefficient of friction value (Table 6) is also higher for traditional composition than that of modified composition. The results of the wear tests clearly indicate that the wear resistance of modified composition is considerably higher than that of traditional composition. The results of the wear tests imply that tensile properties significantly affect wear resistance. Due to the higher tensile and yield strength of the modified specimens, they exhibit greater wear resistance and lower volume loss. Specifically, the volume loss in the traditional specimen is 3.7 times higher than that of the modified specimen.

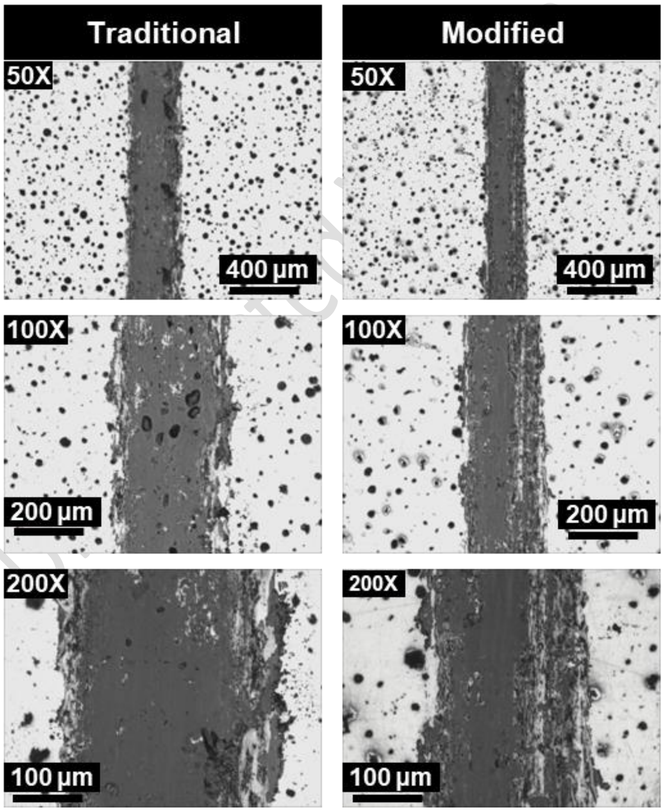


Figure 7. The optical micrographs of worn surfaces after abrasive wear test.

Additionally, the tool life (Table 7) is investigated during the machining (turning process) of the traditional and modified specimens. For the modified composition, the tool life is importantly higher for both investigated specimen geometries. The tool lives are nearly 1.3 times higher in the machining of modified specimens rather than traditional composition. Moreover, the tool life of specimen 2 (48 mm diameter and 125 mm length) is longer than that of specimen 1 (66 mm diameter and 125 mm length). It is believed that the smaller radius of specimen 2 directly influences the tool life.

Björkegren and Hamberg [32] studied the hardness distribution and machinability of DIs having high Si contents (3.27 and 3.72 %) than traditional compositions and compared the results with those for traditional compositions. They showed that there was no uniform hardness distribution between the sections having different thickness for traditional composition. In addition, the matrix phase of traditional composition was composed of pearlite and ferrite. For compositions containing high Si contents, the matrix phase was ferrite, and the hardness was nearly same throughout the part. They also stated that the tool lives of high Si containing DI is nearly 1.5 times higher than tool live of traditional composition.

They reported that harder pearlite-softer ferrite matrix phase led to interrupted cuts for traditional composition. For compositions containing high Si contents, no interrupted cuts were observed since the matrix phase was composed of only ferrite phase. Furthermore, Dawson and Hollinger [35] presented that increasing pearlite concentration improved milling tool life, while it reduced the tool life in turning operations.

Table 6. The coefficient of friction and wear loss values of traditional and modified EN-GJS-500-7 ductile cast irons.

Composition	Coefficient of friction	Wear loss (mm^3)
Traditional	0.21	0.0181
Modified	0.15	0.0049

Table 7. The tool life of traditional and modified EN-GJS-500-7 ductile cast irons during the turning process.

Composition	Tool life (number of machined specimens)	
	Specimen 1 (ϕ66, L125)	Specimen 2 (ϕ48, L125)
Traditional	113	197.3
Modified	143.5	257.3

4 Conclusion

The microstructural properties and mechanical properties of EN-GJS-500-7 (GGG50) grade DIs having modified chemical compositions are studied in detail, and following conclusions can be drawn:

- EN-GJS-500-7 (GGG50) grade DIs having modified composition are successfully produced without any important casting defects.
- The ferrite amount of modified composition is significantly higher because of the high amount of Si and low amount of pearlite former.
- For modified composition, the microstructures are nearly uniform among the surface and the center regions.
- For modified composition, uniform hardness distribution is observed.
- The tensile properties of both modified and traditional compositions are better than those for present in the standard.
- For modified composition, the yield strength and the ultimate tensile strength is slightly lower than those for traditional composition, while impact energy is a bit higher.
- The ductility of both compositions is similar.
- Modified composition exhibits better wear resistance (less wear loss and lower friction coefficient) compared to traditional composition.
- For the modified composition, the tool life is also strongly longer than traditional composition.

5 Author contribution statements

Author 1: Conceptualization, Investigation, Experiments Author 2: Writing – original draft, Writing – review & editing, Author 2: The development of the idea

6 Ethics committee approval and conflict of interest statement

All authors declare that the present paper is prepared in accordance with ethical standards.

The authors declare that they have no known competing financial interests or personal relationships.

7 References

[1] Pribulová A, Futaš P, Pokusova M. “Influence of charge composition on EN-GJS-500-7 ductile iron properties in foundry operating conditions”. *Materials Science Forum,* 998, 42-47, 2020.

[2] Veljačić Z, Grilec K. “Increasing the Wear Resistance of Marine Diesel Engines Elements Made of Ductile Iron”. *NAŠE MORE: znanstveni časopis za more i pomorstvo,* 68(3), 150-156, 2021.

[3] Pacha-Gołębiowska H, Piekarska W. “Mechanical properties of ductile cast iron relation to the charge elements”. *IOP Conference Series: Materials Science and Engineering,* 1199(1), 012022, 2021.

[4] Gouveia RM, Silva FJ, Paiva OC, Andrade MDF, Pereira LA, Moselli PC, Papis KJ. “Comparing the structure and mechanical properties of welds on ductile cast iron (700 MPa) under different heat treatment conditions”. *Metals*, 8(1), 72, 2018.

[5] Jeshvaghani RA, Shamanian M, Jaberzadeh M. “Enhancement of wear resistance of ductile iron surface alloyed by stellite 6”. *Materials & Design*, 32(4), 2028-2033, 2011.

[6] Iacoviello F, Di Cocco V. “Influence of the graphite elements morphology on the fatigue crack propagation mechanisms in a ferritic ductile cast iron”. *Engineering Fracture Mechanics*, 167, 248-258, 2016.

[7] Sübütay H, Şimşir M, Aydın M, Karaca B. “Effect of chill formation on the mechanical properties and microstructure of grey and nodular cast irons used in automotive industry”. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 22(1), 1-7, 2016.

[8] Aşkun Y, Hasirci H, Şeker U. “Evaluation of machinability of ductile irons alloyed with Ni and Cu in terms of cutting forces and surface quality”. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 9(2), 1-7, 2003.

[9] Dundar S. “Application of austempered ductile iron to rail wheel sets”. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 9(3), 283-287, 2003.

[10] Hütter G, Zybell L, Kuna M. “Micromechanisms of fracture in nodular cast iron: From experimental findings towards modeling strategies–A review”. *Engineering Fracture Mechanics*, 144, 118-141, 2015.

[11] Kolukisa S. "The effect of the welding temperature on the weldability in diffusion welding of martensitic (AISI 420) stainless steel with ductile (spheroidal graphite-nodular) cast iron". *Journal of Materials Processing Technology*, 186(1-3), 33-36, 2007.
[12] Stawarz M. "Comprehensive quality assessment of ductile iron". *Eksploatacja i Niezawodność – Maintenance and Reliability,* 2(22), 55-58, 2004.
[13] Rojek J, Hyrcza-Michalska M, Bokota A, Piekarska W. "Determination of mechanical properties of the weld zone in tailor-welded blanks". *Archives of Civil and Mechanical Engineering*, 12, 156-162, 2012.
[14] Collini L, Pirondi A, Bianchi R, Cova M, Milella PP. "Influence of casting defects on fatigue crack initiation and fatigue limit of ductile cast iron". *Procedia Engineering*, 10, 2898-2903, 2011.
[15] Ferro P, Lazzarin P, Berto F. "Fatigue properties of ductile cast iron containing chunky graphite". *Materials Science and Engineering: A*, 554, 122-128, 2012.
[16] Collini L, Pirondi A. "Fatigue crack growth analysis in porous ductile cast iron microstructure". *International Journal of Fatigue*, 62, 258-265, 2014.
[17] Iacoviello F, Di Cocco V. "Degenerated graphite nodules influence on fatigue crack paths in a ferritic ductile cast iron" *Frattura ed Integrità Strutturale*, 34, 416-414, 2014.
[18] Stets W, Löblich H, Gassner G, Schumacher P. "Solution strengthened ferritic ductile cast iron properties, production and application". *International Journal of Metalcasting*, 8, 35-40, 2014.
[19] EN 1563 Standard, "Founding - Spheroidal graphite cast irons", 2018.
[20] de La Torre U, Loizaga A, Lacaze J, Sertucha J. "As cast high silicon ductile irons with optimized mechanical properties and remarkable fatigue properties". *Materials Science and Technology*, 30(12), 1425-1431, 2014.
[21] Yürektürk Y, Baydoğan M. "Effect of aluminizing and austempering processes on structural, mechanical and wear properties of a SSF ductile iron". *Materials Research Express*, 6(1), 016550, 2018.
[22] Borsato T, Ferro P, Berto F, Carollo C. "Effect of solidification time on microstructural, mechanical and fatigue properties of solution strengthened ferritic ductile iron". *Metals*, 9(1), 24, 2018.
[23] Hartung C, Logan R, Plowman A, Wilkinson D, Hoel EG, Ott E. "Research on solution strengthened ferritic ductile iron (SSFDI) structure and properties using different treatment and inoculation materials". *International Journal of Metalcasting*, 14(4), 1195-1209, 2020.
[24] Weiβ P, Brachmann J, Bührig-Polaczek A, Fischer SF. "Influence of nickel and cobalt on microstructure of silicon solution strengthened ductile iron". *Materials Science and Technology*, 31(12), 1479-1485, 2015.
[25] Erturk SÖ, Ozel A. "Investigation on the production of solution strengthened ductile iron part grade 500-14". *Bayburt Üniversitesi Fen Bilimleri Dergisi*, 3(1), 41-45, 2020.
[26] Weiß P, Riebisch M, Bührig-Polaczek A. "Mechanical properties and impact toughness of nickel and aluminum alloyed high silicon ductile iron". *Materials Science Forum*, 925, 304-310, 2018.
[27] Riebisch M, Sönke HG, Pustal B, Bührig-Polaczek A. "Influence of carbide-promoting elements on the pearlite content and the tensile properties of high silicon SSDI ductile iron". *International Journal of Metalcasting*, 12, 106-112, 2018.
[28] Keleş A, Cengiz R, Yildirim M. "Effect of Alloying Elements and Technological Parameters of Austempering on the Structure and Mechanical Properties of Ductile Cast Iron (ADI)". *Metal Science and Heat Treatment*, 65, 191–199, 2023.
[29] Menk W. "A New High Strength High Ductile Nodular Iron". *Materials Science Forum,* 925, 235-230, 2018.
[30] Kandemir AS, Gecu R. "Influence of vanadium content and cooling rate on the characteristics of vanadium-alloyed spheroidal graphite cast irons". *Journal of Alloys and Compounds*, 934, 168017, 2023.
[31] Aydın E. Mechanical, Machinability, High Temperature Wear, Corrosion and Tribocorrosion Behavior of Alloyed EN-GJS-500-7 Quality Spheroidal Graphite Ductile Iron. PhD Thesis, Bilecik Şeyh Edebali University, Bilecik, Turkey, 2023.
[32] Bjsrkegren LE, Hamberg K. "Ductile iron with better machinability compared to conventional grades". *Foundryman*, December, 386-391, 1998.
[33] Afseoren M, Ersoz TT, Yildirim M. "Comparison of Warm and Cold Forging with Friction Welding for Inner Constant Velocity Joints (CVJs)". *Transactions of the Indian Institute of Metals,* 77(11), 3341-3352, 2024.
[34] Yürektürk Y. Effect of Austempering and Aluminizing Processes on Properties of High Silicon Spheroidal Graphite Ductile Irons. PhD Thesis, İstanbul Technical University, İstanbul, Turkey, 2023.
[35] Dawson S, Hollinger I. "The Effect of Metallurgical Variables on the Machinability of Compacted Graphite Iron". *Sintercast,* Sintercast2014, 1-23, 2014.