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Production of Spherical Cementite within Bainitic Matrix Microstructures in High Carbon Powder Metallurgy Steels

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Abstract**—**The hardness-microstructure relationships of spherical cementite in bainitic matrix obtained by a different heat treatment cycles carried out to high carbon powder metallurgy (P/M) steel were investigated. For this purpose, 1.5 wt.% natural graphite powder admixed in atomized iron powders and the mixed powders were compacted under 700 MPa at room temperature and then sintered at 1150 °C under a protective argon gas atmosphere. The densities of the green and sintered samples were measured via the Archimedes method. A density of 7.4 g/cm^3 was obtained after sintering and a density of 94% was achieved. The sintered specimens having primary cementite plus lamellar pearlitic structures were fully quenched from 950 °C temperature and then over-tempered at 705 °C temperature for 60 minutes to produce spherical-fine cementite particles in the ferritic matrix. After by this treatment, these samples annealed at 735 °C temperature for 3 minutes were austempered at 300 °C salt bath for a period of 1 to 5 hours. As a result of this process, it could be able to produced spherical cementite particle in the bainitic matrix. This microstructure was designed to improve wear and toughness of P/M steels. The microstructures were characterized and analyzed by SEM and micro and macro hardness.

Keywords**—**Powder metallurgy steel, heat treatment, bainite, spherical cementite.

I. Introduction

ALLOY steels, commonly known as plain carbon steels, have vital proposals for a wide range of industrial applications, including automotive parts. The reason for this is lower costs than the alloyed steels. For some applications, however, their use is limited due to their low mechanical strength [1]. Porosity is commonly seen in materials produced by conventional powder metallurgy. However, it is well known that the pores adversely affect the mechanical properties because they cause a notch effect. Numerous properties of PM materials especially such as ductility, tensile strength, impact and fatigue are directly related to their pores, alloy elements and microstructure [2], [3]. Many low alloy PM steels cannot be used as sintered. For this reason, the heat treatments are applied after the sintering to strengthen the PM steels. It is necessary to produce hard phases in a microstructure to increase wear resistance. To do this, the most common heat treatment applied to PM carbon steels is quenching + tempering [4]. In the steels with an initial microstructure as primary ferrite-pearlite or primary cementite-pearlite, it takes a long time considerably to spheroidize cementite. Additionally, over-tempering of steels with an initial martensitic microstructure provides the precipitation of spherical cementite particles [5]. Spheroidized cementite particles can improve the strength, ductility and toughness of high carbon steels. More homogeneous dispersed spherical cementite in the fine ferrite grains brings excellent formability [6]. The spheroidizing process of cementite has been investigated by many researchers [7]-[9]. A unique microstructure is formed between the austenite perlite and martensite transformation temperatures from eutectoid transformation temperatures. The structure that occurred at these intermediate temperatures was first seen by optical microscope by Davenport and Bain [10]. This structure, which is very different from perlite and martensite, is called "bainite" by his colleagues in honor of Edgar C. Bain. Even though the development of CFB steels is still in progress, few applications have been found, i.e. rails [11]-[13] and armours [14], but there are few other application possibilities, which are investigated by researchers (i.e. railway wheels [15], ball bearings [16], [17] and elements for the automotive industry [18]. At a given hardness, the lower bainite has higher toughness and ductility than the tempered martensite, of which the conventional quenched and tempered specimen is inferior to the marquenched and tempered specimen. Additionally, the ultimate tensile strengths of the two structures are around equal, but the yield strength of tempered martensite exceeds that of lower bainite. The fracture surface of lower bainite exhibits transgranular cleavage and that of tempered martensite reveals intergranular failure due to the occurrence of Tempered martensite embrittlement [19]. In general, the mechanical properties of a particular material are closely related to the microstructure and heat treatment process. Research on the effects on the mechanical properties of microstructures or heat treatment parameters has a significant engineering value [20]. Steel materials having SCBM microstructures of the invention are intended to have high hardness due to spherical hard cementite phases and also to have high strength and hardness due to bainitic microstructure.

II. Experimental Studies

In experimental work, chemical composition of mean size less than 60 μm obtained from sinter-metal to produce high-carbon powdered metal steel. Water atomized ATOMET 1001

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pure iron powders given in Table I were added with 1.5% by weight of graphite as carbon source. The prepared mixture powders were shaped according to ASTM-G99 standard by single axis pressing at a room temperature of 700 MPa and these samples were sintered in an argon gas atmosphere controlled furnace at 1150 °C to produce powder metal samples at a density of 7.4 g.cm $^{-3}$.

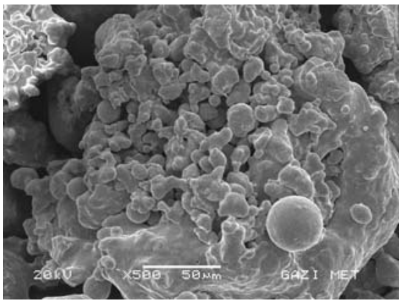


Fig. 1 SEM microstructures of the ATOMET 1001 pure iron powders

TABLE I
CHEMICAL COMPOSITION OF WATER ATOMIZE ATOMET 1001 IRON POWDER

Composition	C	Mn	S	Fe
Atomet 1001	0.004	0.18	0.01	99.4+

The sintered samples were coded with S- followed by sample M- having the martensitic microstructure obtained from this sample, sample FBM having the full bainitic microstructure, sample "FMSC" having the ferritic matrix spherical cementite microstructure obtained by tempering the martensite sample, and finally the sample FMSC having Ac1 The samples with spherical cementite microstructure in bainitic matrix obtained by partial austenitization at 735 °C followed by rapid quenching at 300 °C for 1-2 and 5 hours were coded as SCBM-1 and SCBM-2, SCBM-5 respectively.

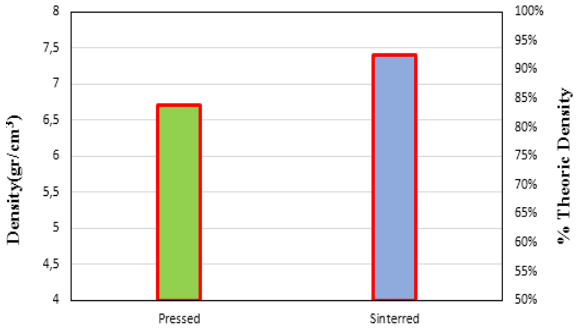


Fig. 2 Density values and condensation rates of samples after pressing and sintering

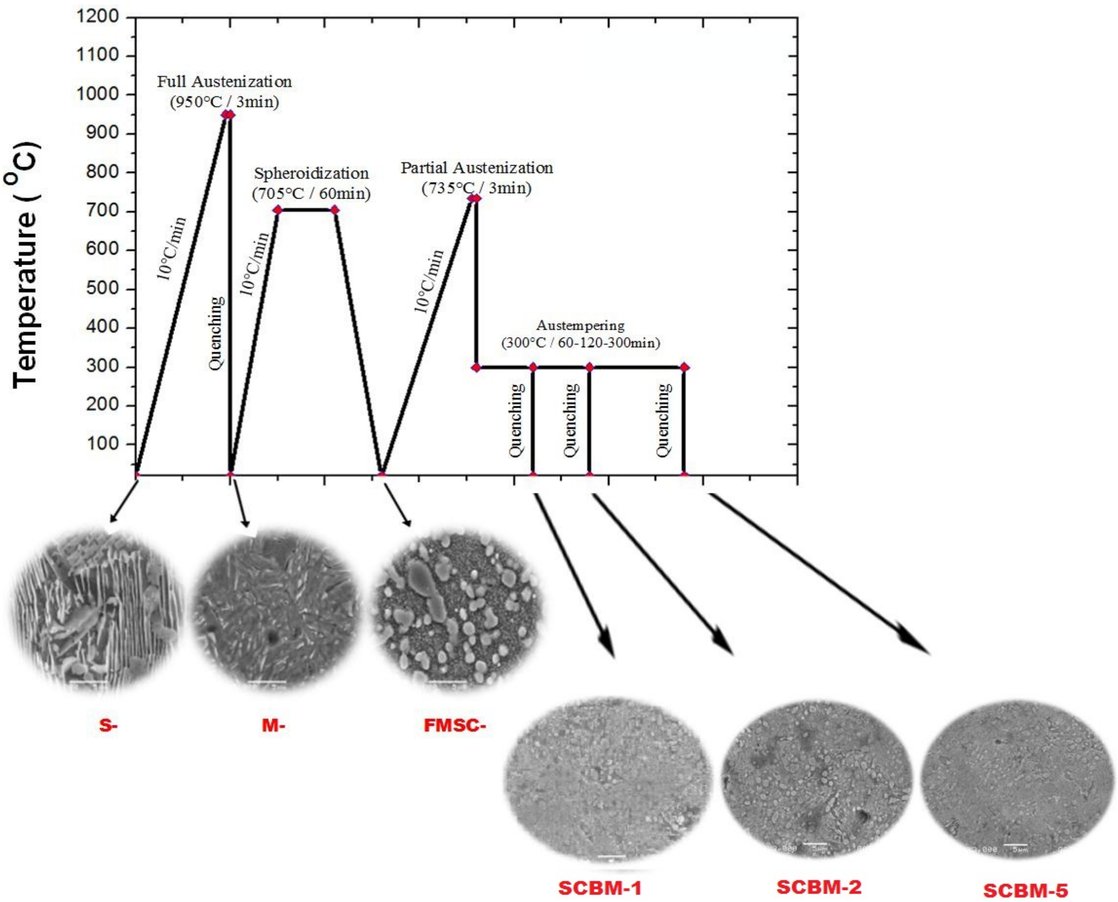
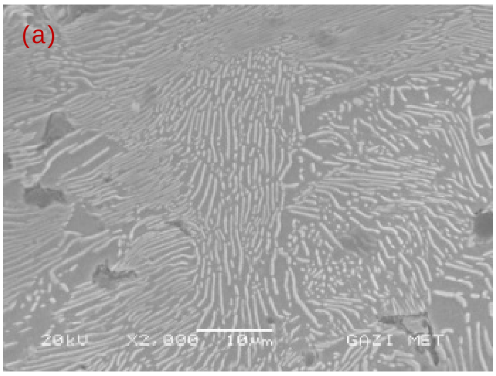


Fig. 3 Schematic heat treatment cycle graphics of SCBM samples

To reveal the microstructures in all the samples, exemplary metallographic processes were applied, and they were etched with 2% Nital solution. In imaging of microstructure, JEOL JSM-6060LV Scanning Electron Microscope (SEM) was used selecting secondary electron imaging mode. Vickers hardness measurements of the samples were determined by using a 1-kg load in Shimadzu HV-1 hardness device, and the HV2 mean values were found by taking a hardness value from at least five different points for each sample.

III. Experimental Results and Discussion

High-carbon powder metallurgy steel production, considered for the production of bainitic matrix spherical cemented microstructures, has been carried out. For this purpose, the microstructure of the sintered specimen is given in Fig. 4 (a). As seen from the microstructure, primary cementite and perlite lamellas are expected in the sample after sintering. It is also seen that the pores from the most important problems of production with powder metallurgy are present in the structure even in a small number. When spectral analysis of sintered samples subjected to all heat treatments was performed, it was determined that the ratio of approximately combined carbon was 1.49% by weight. In the FMSC and SCBM samples, a quenched full martensitic microstructure was produced in order to produce spherical cementite particles. The martensitic microstructure obtained after quenching at 950 °C is plate type morphology due to the high carbon content it contains, as seen in Fig. 4 (b). Fig. 4 (c) shows the microstructure of the lower bainite obtained by austenitizing the sample of "FBM" at 950 ° C and cooling it to 300 °C at isothermal annealing at neutral temperature. Fig. 4 (d) shows the microstructure of the FMSC sample, in which the martensite sample was spheronized for 60 min in an Ar-protected atmosphere furnace. Spherical cementites with ferritic matrix precipitated after a 60 minutes spheroidization heat treatment.



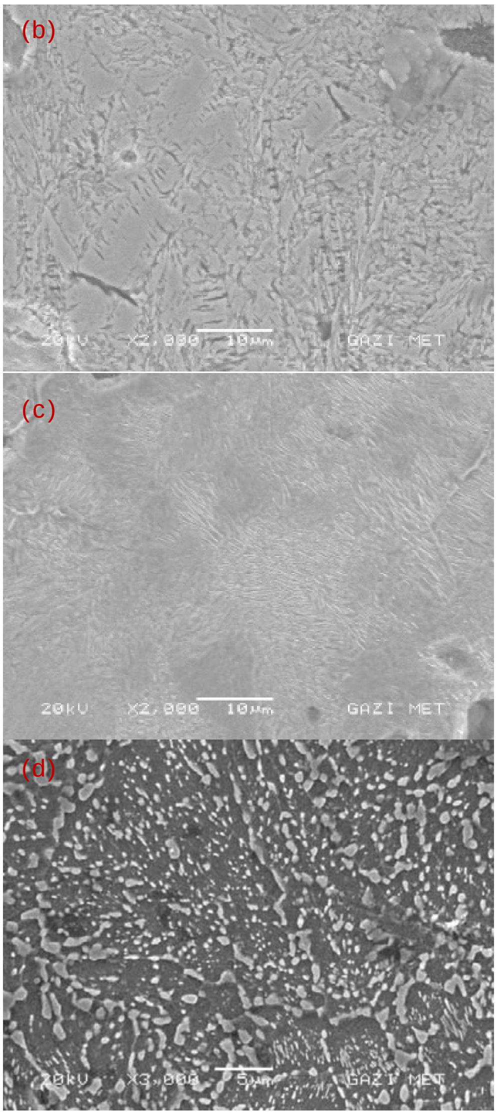


Fig. 4 SEM microstructure images of (a) S-, (b) M-, (c) FBM- and (d) FMSC- samples

Fig. 5 shows the microstructures of the SCBM-1, SCBM-2 and SCBM-5 samples, respectively. For the first time in these samples, bainitic matrix spherical cementite particles were produced. The purpose of this microstructure design developing the toughness and of bainitic especially with the combination of spherical cementitites improving wear resistance, to produce powder metallurgy parts with superior properties. As stated in the experimental works in these samples, the production of bainitic matrix spherical cementites was achieved by different heat treatment cycles. In all SCBM microstructures, the cementite particle size is about 1 µm. With the increase of the austempering time, it is seen that the spherical cementites become larger and more prominent. As a result of a 5 hours austempering heat treatment, it can be said that the bainitic areas also become clearer.

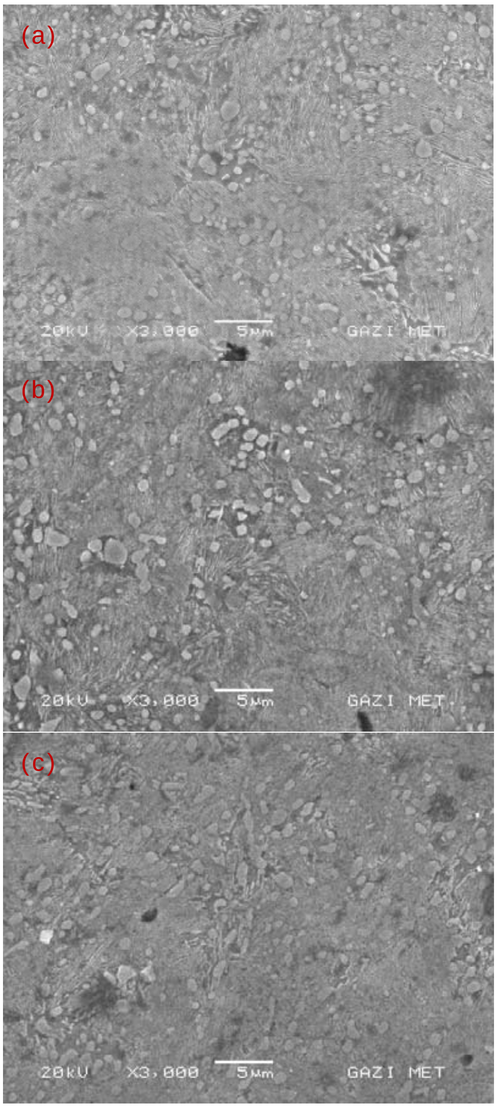


Fig. 5 SEM microstructure images of (a) SCBM-1, (b) SCBM-2, (c) SCBM-5 samples

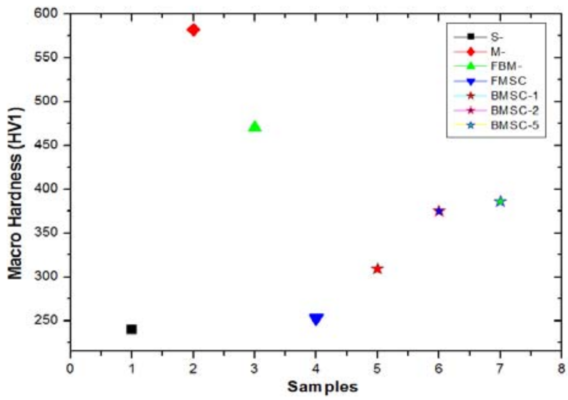


Fig. 6 Hardness graphic of S, M, FBM, FMSC, BMSC-1, BMSC-2 and BMSC-5 samples

Fig. 6 shows the macro hardness of the samples. As expected, the macro hardness values of the S- samples in the sintered conditions are lower than the heat treated samples. Because of the pores of the natural properties of the powder metal materials, the FBM and M-samples have the highest hardness, although the hardness is lower than the ingot alloys. The hardness values of the BMSC samples are somewhat lower than the FMSC higher FBM sample. The increase in the austempering time in the BMSC samples showed that the macro hardness values increased. The highest hardness value was determined as 386 HV1 on the BMSC-5 sample.

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References

[1] Ashrafizadeh F., Influence of plasma and gas nitriding on fatigue resistance of plain carbon (Ck45) steel, Surf. Coat. Technol. 174, 1196.1200, (2003).
[2] Wu, M., Tsao, L., Shu, G., Lin, B.: Mater. Sci. Eng. A, 538, 2012, p. 135. Doi :10.1016/j. Msea. 2011.12.113.
[3] Wu, M. W., Tsao, L. C., Chang, S. Y.: Mater. Sci. Eng. A, 565, 2013, p. 196. doi:10.1016/j.msea.2012.12.032.
[4] S. Tekeli, A. Güral. Dry sliding wear behaviour of heat treated iron based powder metallurgy steels with 0.3% Graphite + 2% Ni additions. Materials and Design 28 (2007) 1923–1927.
[5] Altuntaş, O.: Investigation of Spheroidization Heat Treatment Effects on Microstructure and Impact Toughness Properties of High Carbon Powder Metal Steels. (Master Thesis). Ankara, Gazi University Institute of Science and Technology 2013.
[6] Wang, B., Liu, Z. Y., Zhou, X. G., Wang, G. D.: Journal of Iron and Steel Research, 20, 2013, p. 25. doi:10.1016/S1006-706X(13)60107-7.
[7] Wu, T., Wang, M. Z., Gao, Y. W., Li, X. P., Zhao, Y. C., Zou, Q.: Journal of Iron and Steel Research, 19, 2012, p. 60. doi:10.1016/S1006-706X(12)60140-X.
[8] Lv, Z. Q., Wanga, B., Wang, Z. H., Sun, S. H., Fu, W. T.: Mater. Sci. Eng. A, 574, 2013, p. 143. doi:10.1016/j.msea.2013.02.059.
[9] Yi, H. L., Hou, Z. Y., Xu, Y. B., Wu, D., Wang, G. D.: Scripta Materialia, 67, 2012, p. 645. doi:10.1016/j.scriptamat.2012.07.020.
[10] Krauss, G. Steels: Processing, Structure, and Performance, ASM International, (2005).
[11] H. Bhadeshia, New bainitic steels by design, Displac. Phase Transform. Appl. Mater. Eng. (1998)69–78.
[12] C. Pitt, Wear and microstructure relationships in carbide-free bainitic rail steels, (Ph. D. thesis), University of Cambridge, 1999.
[13] X. Feng, F. Zhang, J. Kang, Sliding wear and low cycle fatigue properties of new carbide free bainitic rail steel, Mater. Sci. Technol. 30 (12) (2014) 1410–1418, http://dx.doi.org/10.1179/1743284713Y.0000000474.
[14] S. Bakshi, P. Shipway, H. Bhadeshia, Three-body abrasive wear of fine pearlite, nanostructured bainite and martensite, Wear 308 (2013) 46–53, http://dx.doi.org/10.1179 / 1743284713Y.0000000474.
[15] M. Zhang, H. Gu, Fracture toughness of nanostructured railway wheels, Eng. Fract. Mech.75 (18) (2008) 5113–5121, http://dx.doi.org/10.1016/j.engfracmech.2008.07.007.
[16] M. Sherif, P. Rivera-Diaz-del Castillo, H. Bhadeshia, H. Huang, S teel alloy WO 2013149657 A1, 2013.
[17] P. Rivera-Diaz-delCastillo, B. Szost, R. Vegter, H. Bhadeshia, Bearing steel WO 2014121836 A1,2014.
[18] C. Garcia-Mateo, F. Caballero, Advanced high strength bainitic steels, Compr. Mater. Process.1 (2014)165–190.
[19] Tu, Meng-Yin, et al. "Comparison of microstructure and mechanical behavior of lower bainite and tempered martensite in JIS SK5 steel." Materials Chemistry and Physics 107.2-3 (2008): 418-425.
[20] Sawa M, Rigney DA. Sliding behavior of dual-phase steels in vacuum and air. Wear 1987;119:369–90.