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Research Article

THE TRANSFORMATION OF CK45 STEEL TO THE DUAL PHASE GRAPHITE STEEL AND THE STUDY OF ITS MICROSTRUCTURE

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ABSTRACT
The aim of this study was to produce dual phase graphite steel by the samples of CK45 steel under graphitization heat treatment in two stages of a) heating in 750 ^{0} C / 8h - 950 ^{0} C / 2h and then b) in ice quenching water reheating in 710 ^{0} C for 12 hours and then cooling in the furnace. The samples were graphitized partially austenitized in 735 ^{0} C in Different times. The cross section of the sample was studied by optical microscope and SEM and the hardness test was done on samples. According to the obtained results, during the first cycle about the 1/3 percent of surface graphitized spheres were created by 10 µm, during the second cycle the amount of graphite increased by 2.9 percent. Anneal created due to the critical phase between dual Bainite-Ferrite Structures, the amount of Ferrite is decreased by the increase of anneal time but the hardness of samples does not change.

Keywords: *Graphitization, Dual-Phase, the CK45 Hypereutectoid Steel, Microstructure*

INTRODUCTION

Steels' properties are affected by forming phases of their microstructure. Heat treatment includes the conventional methods of controlling microstructure and consequently achieving the desired properties to suit the application. For example, by applying a suitable heat treatment we can achieve a fully martensitic structure, high hardness steel, or a fully ferritic steel structure with high flexibility. Most commonly used steels in industry have tempered ferrite-pearlite or martensite structure. Steels with ferrite-pearlite structures have good flexibility, but their tensile strength and abrasion resistance is low in comparison to martensitic steels.

Instead, martensitic steels have little flexibility, are hardly machined and shaping them with permanent deformation is almost impossible. In some cases, it is necessary to use steel which has more strength than ferrite-pearlite steels and to have proper flexibility.

Access to such steel will be possible by creating dual phase structure consisting of soft ferrite or austenite phase and a solid phase such as martensite or bainite. Although, other phases like spherical cementite may be present in the microstructure of these steels, but due to the different role of soft and hard steels, these steels are commonly known as dual phase steel.

The production of these steels as well as their mechanical properties has been studied extensively by various researchers. For example, Rasuli *et al.,* studied the tensile properties of dual phase steel produced by inter critical annealing process and concluded that in the same volume fraction of martensite phase, samples with higher carbon content have high tensile and yield strength. Samples with high martensite phase have more work hardening rate which increases steel strength (Leslie, 1980; Gau and Thomas, 1982; Rashid, 1979; [4]).

Decomposition of cementite's hard phase (Fe_3C) in steel to reach the mixture of soft phase graphite and ferrite as well as to achieve steel with high self-lubrication and cutting power is another example of changing microstructure with proper heat treatment. Graphite is one of the best-known solid lubricants that its presence in the final structure of ferrous alloys is a factor to improve abrasion resistance, machining and self-lubrication. Although, high self-lubrication and cutting capabilities can be achieved through adding elements such as sulfur and lead to the chemical composition of steel, but the presence of elements such as sulfur and lead has an adverse environmental effect and the strict environmental

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regulations have created serious challenges in the use of lead and sulfur-containing steels. Therefore, the process of graphitization heat treatment is an effective method to achieve good cutting steels or high self-lubrication capabilities. Examples of such steels are used in the production of mill rolls. In the mill rolls having self-lubrication property to reduce the friction between rolls and work piece as well as the wear of rolls is of great importance. Graphite steels are used not only in the construction of mill rolls, but also they can be used in automotive industry as an alternative to steels containing sulfur and lead (Pierson, 1993; Takashi and Toshiyuki, 2004).

Most of the early research was on the production of graphite steels by the use of high carbon steels (% C> 0.8%). In recent years, the transformation of medium-carbon steels such as CK45 to graphite steel is also taken into consideration. For example, Kiani *et al.*, studied the effect of annealing temperature on graphitization in CK45 steel and concluded that through a two-stage heat treatment process, CK45 graphite steels can be achieved. According to their reports, by the reduction of temperature in the second stage of heat treatment, the number of graphite per unit area increases and the size of graphite spheres decrease. Old observations showed that the basic marten site and Bainite structure in comparison to ferrite-pearlite structure require shorter time for graphitization and cold work and cause a reduction in graphitization process (Neri *et al.*, 1998; Rounaghi and Kiani-Rashi, 2011; Rashid, 1387; Austin and Fetzer, 1945).

In Graphite steels that have been studied so far, in most cases the field structure has been ferrite or pearlite. These phases are soft and are weak in wear and scratch. Therefore, although the presence of graphite reduces the friction coefficient and thus due to reduction of friction shear force can reduce wear rate, but the presence of soft ferrite and pearlite phases can neutralize the positive effect of graphite self-lubrication.

Also, during steel deformation, applied stresses are easily transformed to graphite through soft phase and can lead to their fragmentation; thus discrete areas are created that play a crack role. Interface between graphite and these soft phases can be a good place for cracks germination, especially under periodic stresses. Furthermore, where there is a need to high strength, ferrite and ferrite-pearlite microstructures cannot be useful.

A solution to prevent the negative effects of soft ferrite phase is to construct a dual phase structure. The presence of hard martensite or Bainite phase through the increase of resistance in abrasion can have a synergistic effect on improving abrasion resistance and lead to higher abrasion resistance. By creating dual phase graphite steels with hard eyes we can prevent the transfer of stress and strain to graphite spheres, since in such cases hard phase is formed as a ring around graphite spheres, which prevents the transfer of stress.

In ductile cast irons the conditions of dual phase structures with hard and soft eye were examined. But during the search of academic resources other than the results reported by KianiRashid *et al.*, concerning CK100 hypereutectoid steel (Rounaghi and Kiani-Rashi, 2011), another report was not found about dual phase steels especially dual phase hypereutectoid graphite steels. This study was done to determine the heat treatment conditions resulted in the creation of dual phase graphite structure in CK45 hypereutectoid steel. In this paper, the results of micro structural examinations of CK45 graphite steels are presented after different cycles of heat treatment.

Research

At first, the cylindrical samples with thickness of 3 mm were prepared by cutting a steel rod with diameter of 20 mm. the used steel was CK45 and its chemical composition was determined through emission spectrometry method in accordance with ASTM E- 415-08 (Table 1).

Table 1: Chemical composition of steel used in the present study (wt%)

Element	C	Si	Mn	P	S	Cu	Fe
Standard	0.42Min 0.5Max	0.35	0.5Min 0.8Max	0.035	0.035	0.15	Base
Present study	0.44	0.20	0.80	0.022	<0.002	-	Base

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Graphitization heat treatment and then heat treatment of creating dual phase structure were applied on steel samples biphasic. In graphitization treatment, firstly samples were heated to a temperature of 950 °C and were kept for 2 hours at this temperature in order to obtain a fully austenitic structure. Then samples were transferred to the furnace with 750 °Cand were kept for h 8.

Then the samples were quenched in water (Cycle A). Quenched samples were reheated up to 710 °C and maintained for h 12 at this temperature and then were cooled at furnace till room temperature (Cycle B). After this thermal cycle, samples' microstructure included coarse graphite spheres in ferritic field with the small amount of coarse peralite.

To change the underlying structure of graphitized samples of ferrite to dual ferritic- martensiteic structure and determine the effect of heating on the creation of such structure, the samples were heated in 735°C at three different time points of 15, 30 and 60 minutes and then rapidly were quenched in water.

After heat treatment cycles, the samples were cut in the direction perpendicular to the thickness. Then the cross-section microstructure of samples was examined by optical and scanning electron microscope after sanding, polishing and etching. To detect the phases, HTML color was used according to guides of reference (Kovase, 1987). Also, Vickers hardness test was performed on sample.

RESULTS AND DISCUSSION

Figure 1 shows the Optical microscopy images of samples after (a) and (b) cycles of graphitization. As can be seen the structure of samples contains graphite spheres in both (a) and (b). In (a), graphite sphere with dimensions of 15-7 Mm (mean size of 10 Mm) and density (number per square millimeter) of about190 mm^{-2} can be seen. The amount of graphite is about 6.1 percent.

In structure of samples after (b) cycle, coarse graphite spheres with mean size of 32 Mm were observed along smaller graphite spheres with mean size of 6 Mm. In fact, there is a binary distribution in terms of graphite spheres size. The density of coarse graphite spheres was 22 mm^{-2} and that of smaller graphite spheres was 470 mm^{-2}.

The amount of graphite is about 9.2 percent. This shows that the practices of cycle (b) after cycle (a) increase the amount of graphite in the structure.

During this cycle, supersaturated martensite frees its carbon and some of this carbon adheres to the available graphite and makes the graphite particles larger. Part of it was used in the creation of new nodes. Optical microscope images after the second cycle of graphitization (Figure 2) shows the underlying structure containing ferrite and Perlite phase.

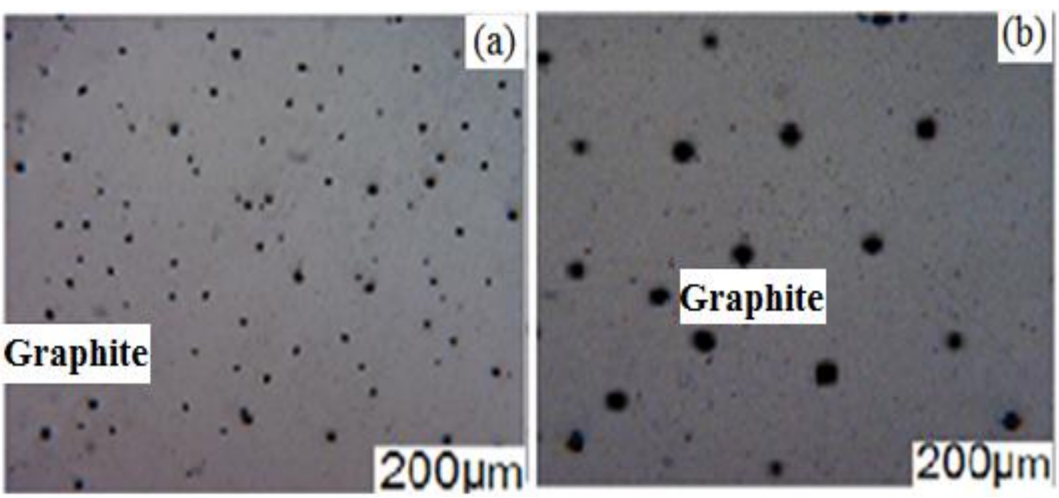

Figure 1: OM micrographs of sample cross section after, a) primary graphitization cycle, b) secondary graphitization cycle

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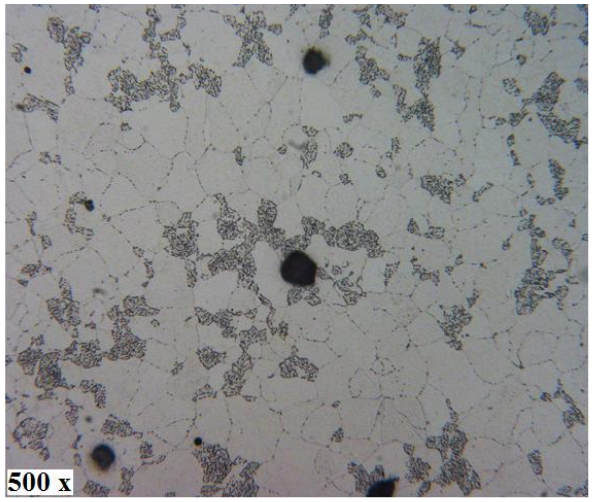

Figure 2: Optical microscope image of the sample after the second cycle of graphitization in etched graphite

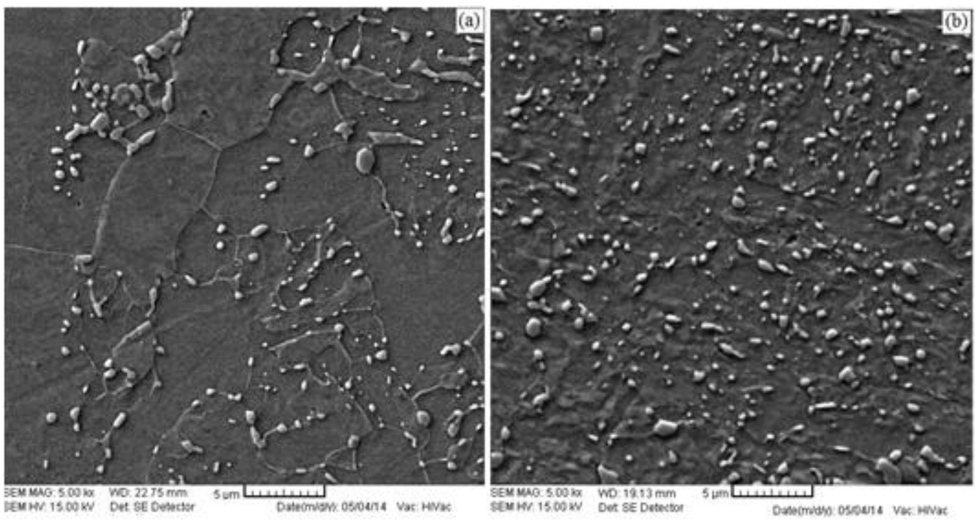

Figure 3: SEM images of dual phased graphite samples in735 ^{o}Cat a) 15 b) 60 minutes

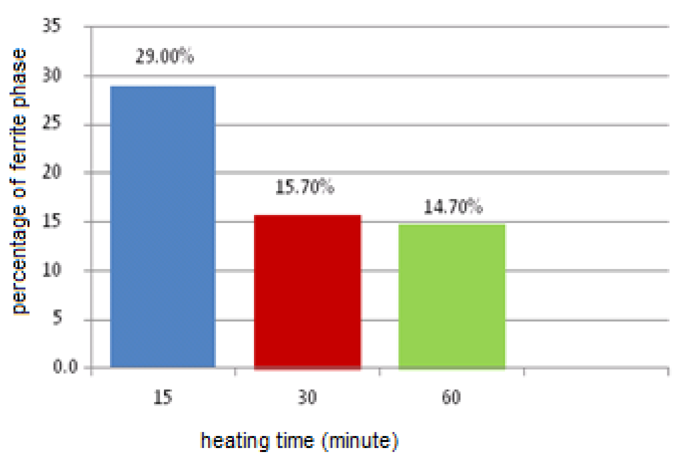

Figure 4: Effect of heating time at 735 °Con the percentage of ferrite phase in dual phased graphite samples

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In Figure 3 SEM images of dual phased graphite samples by heating at 735 °C for 15 min and 60 minutes are presented. It was expected to obtain ferritic- martensiteic structure by quenching samples in water, but the HTML color of samples' cross section indicated the creation of ferritic and bainitic phases. The reason for this is the reduction of samples hardness due to graphitization and the cross of cooling diagram from bainitic area during quenching. Figure 4 shows that by the increase of heating time, the amount of ferrite phase is reduced and the amount of bainite phase is added. However, according to the results of hardness test, the hardness of samples after dual phase operation is about 185 Vickers and the austenitization time has not impacted it much.

Conclusions

1.Two-stage heat treatment graphitization in comparison to single -stage heat treatment graphitization increases the amount of graphite.

2.Two-stage heat treatment graphitization caused the creation of graphite spheres by dual distribution i.e. the presence of coarse graphite along with fine graphite.

3. Inter critical annealing process of graphitized steel in 735 ℃changes the underlying ferritic structure to dual phase ferritic-bainitic structure.

4. By the increase of annealing time between inter critical graphitized steel in 735 ℃, the amount of hard phase increases but doesn't impact hardness.

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