Graphitization transformation acceleration in CK45 steel during heat treatment process

The presence of free carbon (graphite) in the microstructure of steels may play an effective role in improving some of their physical and mechanical properties. Researches performed in the field of the production of such steels are insufficient and in most cases there is a special interest in decreasing the graphitization time period. By selecting high applicable steels such as CK45, the present research tries to make the competition in the production of such steels possible in comparison with similar ones in terms of application by decreasing the graphitization time. In this respect, by choosing various heat treatment cycles, the results indicate that the treatment cycles are designed so that the presence of a reasonable percentage of graphite with proper size and good distribution manner in special conditions are produced in two stages; namely the decomposition processes and the isotherm phase transformation.

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1 Introduction

In terms of microstructure, commercial low-carbon steels usually consist of two phases, namely ferrite and cementite in which the latter is mainly observed as pearlite layers [1, 2].

Cementite is thermodynamically meta-stable as an inter-metallic compound of iron and carbon which is decomposed into free carbon or graphite with ferrite in equilibrium conditions [3-9]. This issue is observable clearly in the solidification of grey and malleable irons. In other words in these cast irons the driving force of the graphitization increases due to the presence of high amounts of carbon and silicon [1-12], so during cooling the melt, graphite particles nucleate inside the melt to become stable.

On the other hand, the addition of carbide stabilizing alloying elements such as manganese and chromium lead to decrease in the driving force of this transformation [13]. In the case of alloying steels containing these elements, graphitization time from the solid state increases up to some hundred hours [14, 15].

From kinetic point of view, graphitization from steels with different initial structure leads to considerable changes in the duration of this transformation. Based on experimental observations [16-19] steels with martensitic or bainitic structure takes the shortest time for graphitization. In addition, cold working the steel leads to decrease in the duration of the graphitization process [20]. For cold-rolled steels, the fracture of carbide particles during the rolling process leads to the formation of the necessary space for the formation of graphite phase during subsequent heat treatment [21].

Despite the positive effect of the graphite phase as one of the best solid lubricant materials on the machining capability and wear resistance of graphitized steels [22], prolonged time of this process in relation to customary commercial steels has made this phase transformation less favorable in industrial criterion and is non-economical. In this respect, He e. a. have studied the formation of the graphite phase in medium carbon steels. According to their researches by alloying these steels with silicon and aluminum the period necessary for the graphitization has been reduced to about 3.5 h [19, 23].

Meanwhile acceleration of this process in commercial medium carbon steels such as CK45 is less studied, so this research tries to study the effect of the application of special controlled heat treatment cycles on the reduction of the graphitization time.

2 Experimental procedures

The steel used in this research is a hypo-eutectoid (CK45) one whose composition is detailed in Table 1. The heat treatment cycles applied to the specimens are depicted in

Table 1: Chemical composition of CK45 steel

Chemical elements, content, wt %					
C	Si	S	P	Mn	Cr
0.46	0.3	0.015	0.014	0.65	0.1

Table 2: Heat treatment cycles applied on CK45 specimens

Specimen	Heat treatment cycles
1	Austenising at 900 °C → water quenching → annealing for 24 h at 650 °C → cooling in furnace
2	Austenising at 950 °C → water quenching → annealing for 24 h at 650 °C → cooling in furnace
3	Heating in carbon container for 5 h at 650 °C → cooling in furnace
4	Heating in carbon container for 5 h at 700 °C → cooling in furnace
5	Heating in carbon container for 6 h at 800 °C → cooling in furnace

Table 2. The martensitic specimens (no. 1 and 2) were produced by holding the initial steel at two different austenite temperatures 900 °C and 950 °C for half an hour and then quenching in water at ambient temperature.

After that the specimens were annealed at 650 °C for 24 h and finally cooled in furnace. The specimens were placed in a container filled with cast iron chips in order to prevent the decarburizing of the specimens during annealing. For producing specimens no. 3 and 4, they were placed in different containers having char powder and barium carbonate (Ba_2CO_3) with 20 wt% Ba_2CO_3 – 80 wt% C after cutting from the initial (as received) steel.

After closing the lids of the containers, specimens no. 3 and 4 were held for 5 h at 650 °C and 700 °C respectively and finally cooled in furnace. Specimen no. 5 was produced by holding the initial steel in a carbon bed with 20 wt % Ba_2CO_3 – 80 wt% C and then heating at 800 °C for 6 h and finally cooling in furnace.

In order to prepare the optical micrographs, all of the specimens were cut and then were etched by 2% nital after the surface preparation by using sand paper and polishing. In addition, optical micrographs were taken from the centers of the specimens. For preparing SEM graphs and EDX point analysis, the Scanning Electron Microscope model 1450 VP made by Zeis of Germany belonging to the Central Laboratory of Ferdowsi University of Mashhad was used.

3 Results and discussion

The optical microscopic structure of CK45 steel is shown in Figure 1. As considered, the structure of the steel before performing any heat treatment consists of ferrite and pearlite. The heat treatment cycles were performed on the parts according to Table 2 in order to investigate the graphitization process and the role of different structures on the rate of this phase transformation in the steel.

Although martensitic structure is known as one of the most suitable structures for graphitization [14, 19], for martensitic specimens no. 1 and 2, there are only fine particles of spherical cementite in a ferrite matrix after annealing for 24 h (Figures 2 and 3). It should be emphasized that ferrite grains are finer than the initial steel due to the annealing of the martensitic structure (Figure 1).

Despite the researches performed in acceleration of graphitization process at 600 to 700 °C [5], there is no sensible graphitization for specimens no. 3 and 4 (Figures 4 and 5). It is found by comparing Figures 4 and 5 with Figure 1 that the distances between cementite layers within pearlite in specimens no. 3 and 4 are increased compared to the initial steel and these layers are broken into smaller parts after fragmentation because of holding the steel in the spherodizing range.

By investigating Figure 6 which shows the structure of specimen no. 5, it seems that more graphite particles are formed in this structure. In other words by the formation of the austenite phase in 800 °C and slow cooling of the part in the furnace, the necessary conditions for the formation and growth of graphite particles in this specimen are produced.

The EDX analysis performed on the particles existing in this specimen show the presence of graphite phase in this specimen (Figure 7). The weaker intensity of carbon peak in

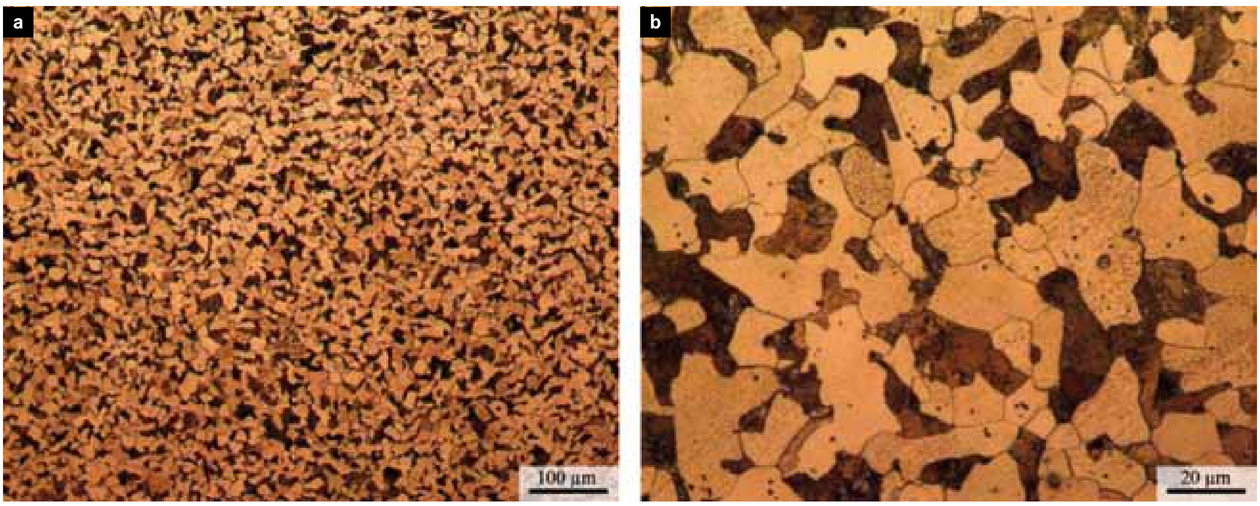

Figure 1: a) Microstructure of as received steel consists of ferrite and pearlite; b) the same structure with more magnification

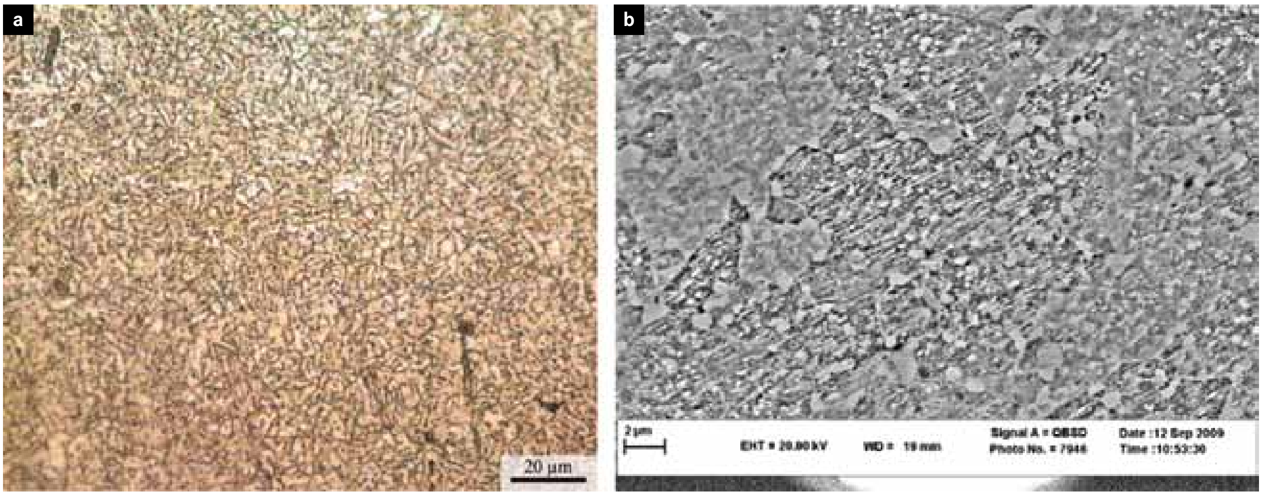

Figure 2: a) Microstructure of steel after annealing martensitic structure for 24 h at 650 °C (related to specimen no. 1); b) SEM micrograph from the same structure

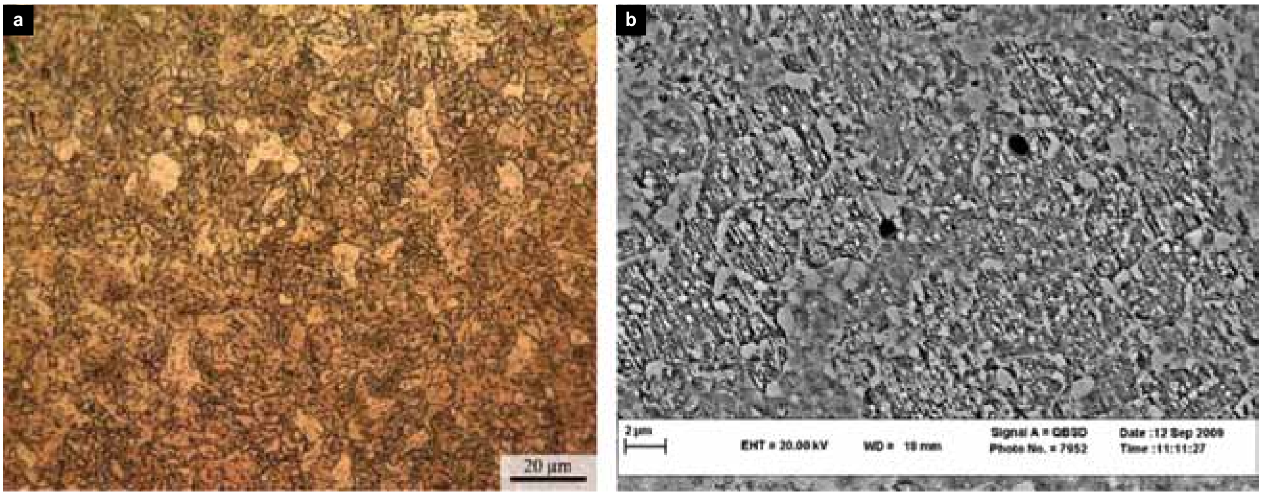

Figure 3: a) Microstructure of steel after annealing martensitic structure for 24 h at 650 °C (related to specimen no. 2); b) SEM micrograph from the same structure

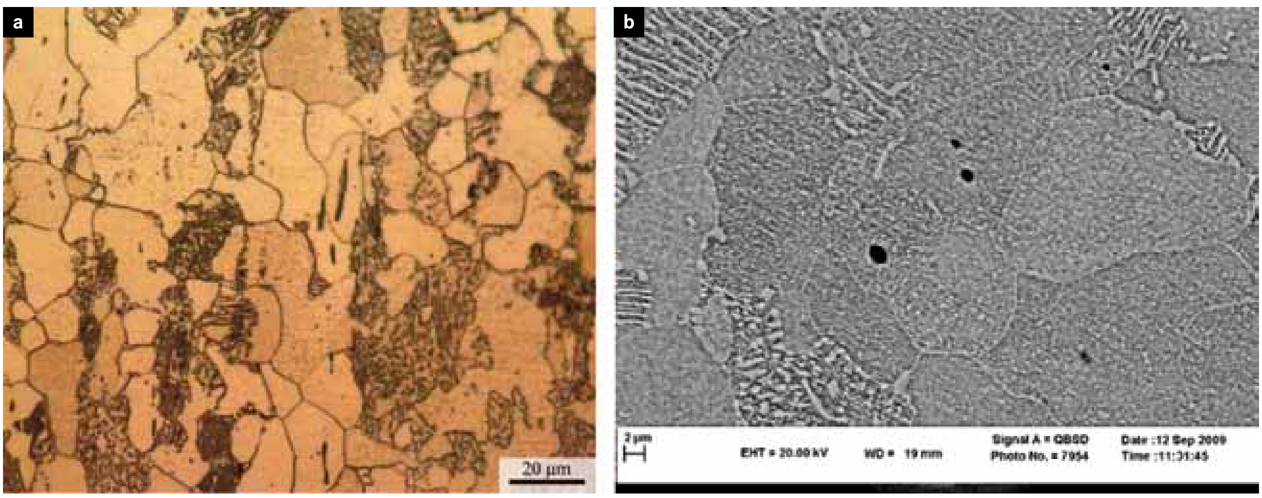

Figure 4: a) Microstructure of steel after annealing for 5 h at 650 °C (related to specimen no. 3); b) SEM micrograph from the same structure

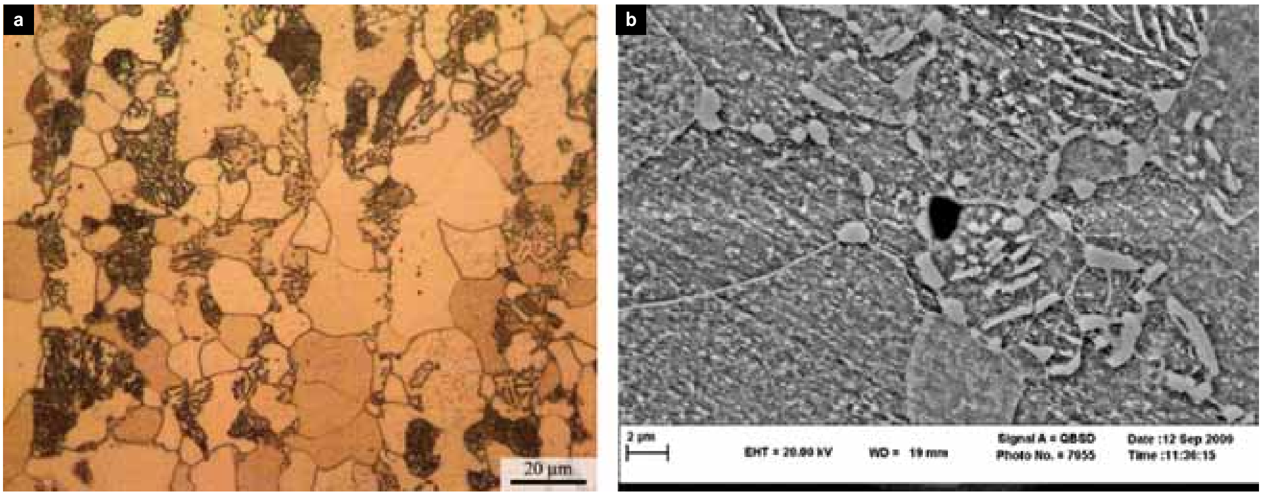

Figure 5: a) Microstructure of steel after annealing for 5 h at 700 °C (related to specimen no. 4); b) SEM micrograph from the same structure

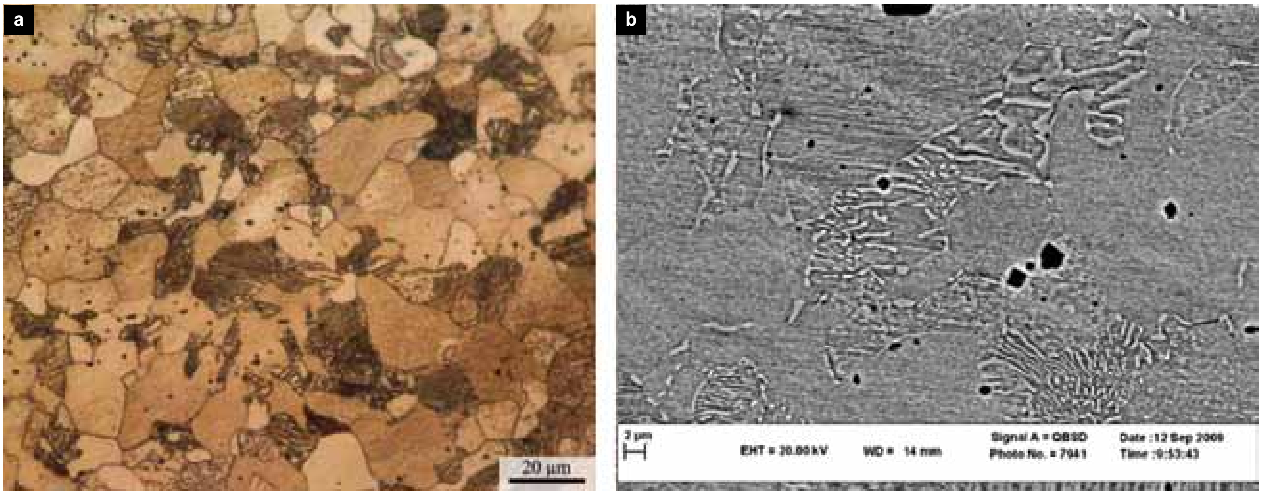

Figure 6: a) Microstructure of steel consists of graphite particle, after cooling from 800 °C in furnace (related to specimen no. 5); b) SEM micrograph from the same structure

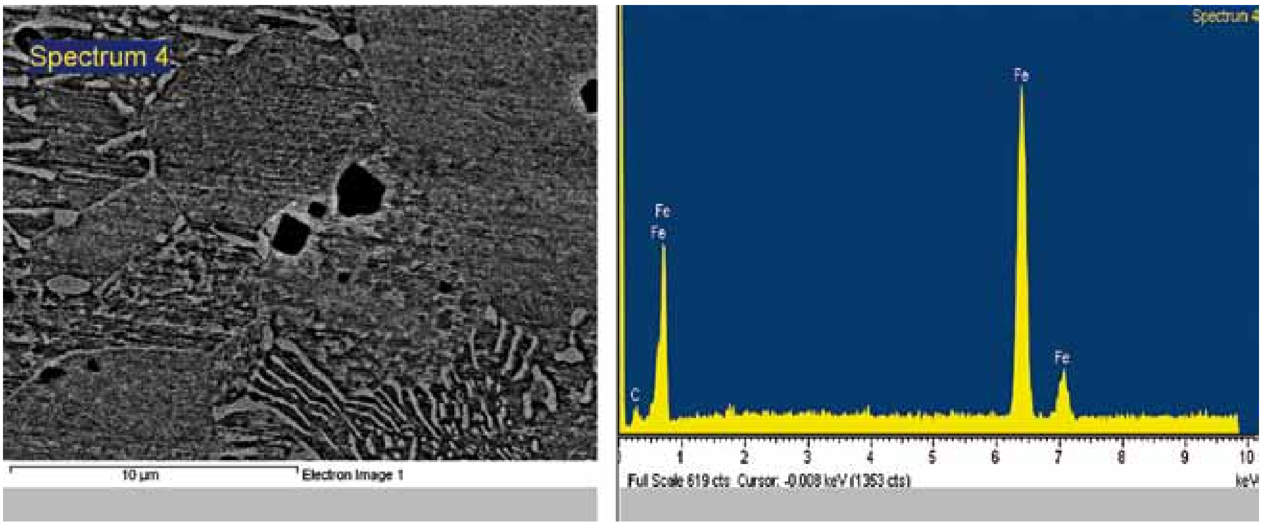

Figure 7: EDX analysis related to specimen no. 5

the diffraction pattern is due to the dispatching of a large part of graphite particles during polishing in which only a negligible part of it is left in the hole affecting the diffraction pattern. Besides this phenomenon, there are other observations for graphitization from austenite phase in hyper-eutectoid steels which confirm the formation of graphite in the matrices of these steels during slow cooling from the austenising temperature [7].

It has generally been accepted since about 60 years ago that during the solidification of cast iron, graphite is formed directly from the melt and so it does not lead to the decomposition of pre-formed carbides or super-saturated austenite. In any case it should be mentioned that under special conditions, graphite may form via such mechanisms which are proved in the graphitization of malleable cast irons and high-carbon steels.

The result of the collection of these experiments is the accessibility to a special kind of steel with a reasonable percent of graphite or free carbon. The important point is the possibility of graphitization in steels by controlling the proper heat treatment process. The low carbon percent in such alloys is the main cause of the limitation of graphitization formation and serious changes in its microstructure. In practice most of these transformations occur at 800 °C in the austenising heat treatment while forming the austenite.

4 Conclusions

Graphitization from the initial martensitic structure is not possible in customary short periods of heat treatment in commercial steels.

During annealing the initial steel at 600 to 700 ˚C, the spherodizing process proceeds graphitization in the initial stages due to being held in the spherodizing range.

The results show that during the slow cooling of the steel from 800 °C, the necessary conditions for nucleation and diffusion of carbon into austenite and the formation of graphite particles are satisfied.

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