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Research Article

Effects of Heat Treatment on Graphite Morphology and Impact Resistance in Industrial Grey and Ductile Irons

Tkachenko Igor[1]*, Tkachenko Kostyantyn[2], Miroshnichenko Victoria[3]

[1] *Priazovsky State Technical University, Department of Materials Science, Mariupol, Ukraine*
[2] *Priazovsky State Technical University, Department of Materials Science, Mariupol, Ukraine*
[3] *Priazovsky State Technical University*, *Department of Materials Science*, Mariupol, Ukraine

***Corresponding Author:** Tkachenko Igor[1]* *Priazovsky State Technical University, Department of Materials Science, Mariupol, Ukraine.*

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Abstract:

Based on the results previously obtained for cast alloy structural steels, the influence of isothermal holding at heating or cooling on graphite morphology and impact strength in industrial grey and ductile pearlitic irons were investigated. Some novel microstructure features were revealed in the irons after their optimal heat treatment, namely: ferrite matrix formation instead of pearlitic one in both irons; partial or full solving the original networked graphite plate-like inclusions; branched interfaces of originally spheroid graphite inclusions surrounded by probably nano - structured matrix areas etc. The microstructure features revealed were assumed to be responsible for the obtained unprecedented increase of impact strength up to KCU ≈ 550 kJ/m^2 for each iron grade. The phenomena observed were attributed to a number of the known processes development during the proposed heat treatment, but require additional precise investigations in view of their general importance for metallic materials: composites, deposited, 3-D printed, powder sintered etc.

Keywords: Pearlitic grey and Ductile irons, Heat treatment, Graphite morphology, Impact resistance

Introduction

Extremely low plasticity and especially impact resistance are well known attributes of grey and ductile irons. Practically the only responsible factor in the case is graphite phase morphology which is stabilized by the end of liquid metal crystallization. It is commonly accepted to consider the morphology as an invariant for any kind of the solid cast iron treatment. So, an increase of the irons impact performance by a heat treatment is traditionally considered as undecidable problem. Meantime, similar in many respects problems concerned with undesirable structure component morphologies there are also in many modern cast alloy structural steels. The main consequence they cause is some types of the steel embrittlement. Despite the traditionally poor theoretical and experimental attempts to solve the problems by a heat treatment application, it was revealed recently [1] the high ability of novel heat treating regimes to provide extremely homogeneous

As a particular result, over threefold increase in the impact strength of an industrial cast alloy structural steel is reached. The novel regimes are based on some commonly accepted principles [1,2] concerned with the effects of grain and subgrain boundaries on alloy element diffusivity and new phase nucleation in metallic matrix alloys. General character of the regimes background principles allowed to suppose [1,2] their applicability to solving the analogous performance problems for various metallic alloys with polymorphic matrix phase transformations at heating and cooling.

The aim of the paper is to outline some basic obtained results of the principles application to develop heat treating regimes that provide improving graphite morphology and impact resistance in industrial grey and ductile irons.

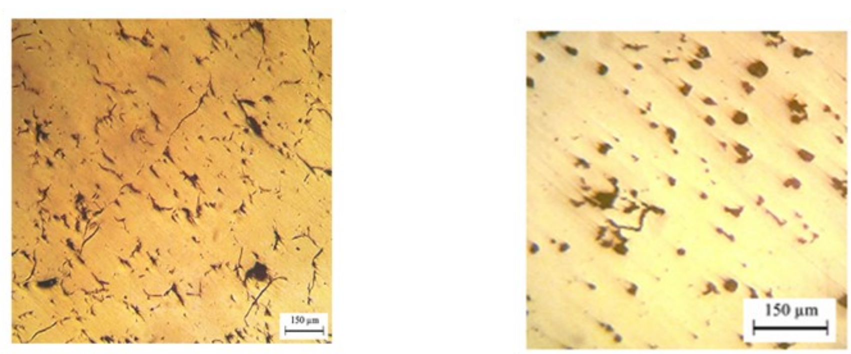
Materials and Methods

Investigations were conducted using industrial pearlite matrix grey and ductile irons of the grades, respectively: EN-GJL-350 and EN-GJS-600-3. Several foundings of each iron grades were used for the researches. The foundings were chosen among industrial ones produced according to the PN-EN-1563:2000 standard by using the conventional industrial technologies of induction melting, ladle treatment and sand mould casting. In such a way, research sample billets of the sizes 40x40x300 mm were obtained. Heat treatment of the billets comprises: austenitizing at T = 800…900 ^{0}C, 50 min with further furnace

isothermal holding at cooling or reheating within the interval 600…900 ^{0}C, 1…9 hours with final calm air cooling. Finally, two metallographic and three standard Mesnager impact test samples were machinery cut from the each billet. The iron sample

Results & Discussions

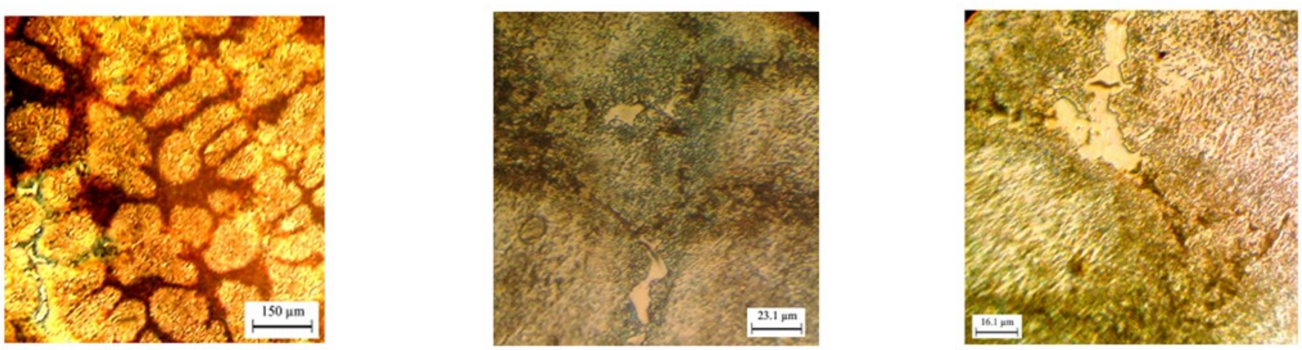
According to the commonly accepted approach, morphology of the original graphite inclusions within the used pearlitic irons in just crystallized conditions was investigated metallographically without etching (see Fig.1). Relatively thin and short platelike graphite inclusions forming the broken network is observed in the microstructure (Fig.1a) of the grey iron. The corresponding impact strength was: KCU ≈ 65 kJ/m^2. As it follows from Fig.1b, the ductile iron microstructure comprises relatively small spheroidal graphite particles with smooth interfaces. It provided the increased impact strength: KCU ≈ 120 kJ/m^2. As it follows from Fig.1b, the ductile iron microstructure comprises relatively small spheroidal graphite particles with smooth interfaces. It provided the increased impact strength: KCU ≈ 120 kJ/m^2.



(a) **(b)**

Fig.1. Microstructures of the investigated grey (a) and ductile (b) irons in as cast condition (without etching). ×100

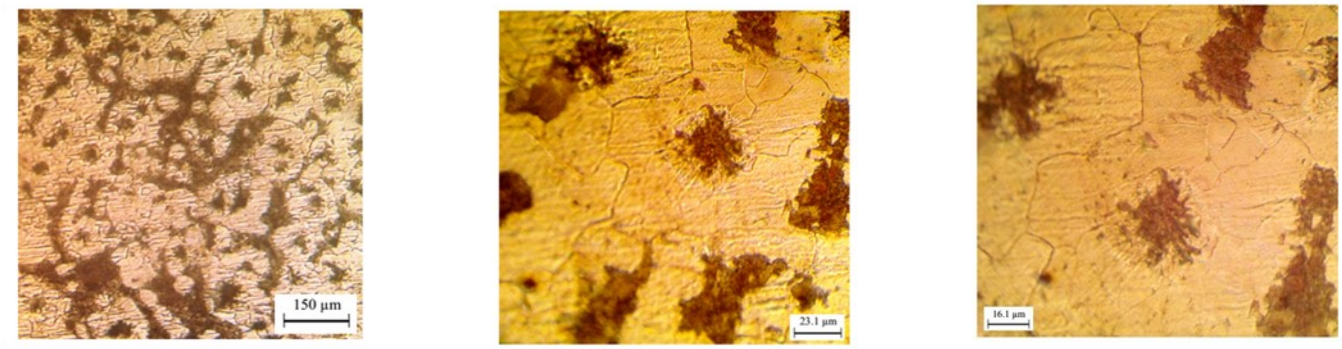
Microstructures of the researched irons after the optimal [2] developed heat treating are shown in Fig. 2 and 3 in the etched condition. In the case of the grey cast iron (see Fig. 2) two main specific microstructure features should be outlined. The first one concerns the formerly pearlitic grey iron matrix. As it seen from Fig. 2b,c after the heat treatment it may be described as consisting of two components: ferrite background and ultra-dispersed graphite particles the arrangement of which is similar to the original cementite plates. Besides the spatial density of the particles is higher in vicinities of the original graphite inclusions still conserving the network arrangement. The other microstructure feature of the heat treated iron is existence of equiaxed or weakly elongated areas, with probably fully ferritic structure (see Fig.2a,b), which are involved into the existing network. Such areas separate groups of the original graphite inclusions still forming the network, but having become very curved and less in sizes (see Fig.2c) after the heat treatment. The phenomena observed should be attributed [3,4] to the following processes consecutive development: - new, ultra-fine grains of the daughter matrix phase nucleation on the interfaces and dislocation sub-boundaries; - partial or full solving the original graphite inclusions together with decomposition of the pearlite matrix cementite by carbon diffusion on intra or inter - phase. boundaries; - new ultra - fine graphite particles precipitation on the matrix subgrain and grain boundaries. All above changes of the grey iron microstructure provide increase of its impact strength up to KCU $\approx$ 520 kJ/m^2.



×100 (a) **×650 (b)** **×930 (c)**

Fig.2. Microstructures of the investigated grey iron after the proposed optimal heat treatment (4 % nital etching)

Microstructure of the ductile iron after the etching in the optimal heat treated condition is shown in Fig.3. At first it should be noted ferrite microstructure of the former pearlitic iron matrix. Meantime, ferrite grains of unusual type together with typical ones are observed. The grains of the novel type have no polyhedral but rather ellipsoid form and arranged directly on or in close vicinities of the boundaries of typical polyhedral ferrite grains (see Fig. 3a). Additionally, extended dark areas containing several closely arranged original graphite inclusions exist. Besides, separate graphite inclusions of the equiaxed (in average) and branched awkward shapes, surrounded by the dark areas of the similar forms are also observed at small magnifications (see Fig.3a). At the higher ones (see Fig.3b,c), mainly branched shapes of the formerly spheroid graphite inclusions are revealed. In turn, the areas surrounding such inclusions have complex, non-identified by the optical metallography structural states with the marks of radial symmetry.



×100 **(a)** **×650** **(b)** **×930** **(c)**

Fig.3. Microstructures of the investigated ductile iron after the proposed optimal heat treatment (4 % nital etching)

The observed phenomena may be explained [3,4] by the mechanism analogous to the above grey iron case: new ultra-fine daughter matrix phase grains formation, at first on the mostly curved "graphite-matrix" interfaces and dislocation sub-boundaries; further intensive redistribution of carbon and other chemical elements by the grain boundary diffusion; the pearlitic cementite decomposition and the original graphite inclusions solving; new ultra-fine graphite particles precipitation inside of the matrix phase areas surrounding the remaining initial graphite inclusions. The resultant impact strength of the ductile optimally heat treated iron is KCU » 550 kJ/m^2.

Evidently that the proposed above mechanisms of the phenomena revealed need to be additionally investigated for possible updating basic principles of the Material Science, renewal existing heat treatment industrial technologies and finally to promote targeted metallurgy renaissance [5]. Meanwhile, wide range of the current industrial applications for the developed cast irons heat treating regimes may be proposed right now: lightening and lifelength increasing for the most of modern cast iron products; the unalloyed cast irons application instead of some cast alloy steels; waste reduction in metallurgy due to the cast iron product quality and reliability improvements etc.

Conclusion:

1. Based on the previously obtained theoretical and experimental results, the effects of isothermal holding at heating or cooling on the morphology of graphite phase and impact strength in industrial grey and ductile pearlitic irons were investigated.
2. Full decomposition of the pearlite matrix cementite; partial or full solving the original networked graphite plate like inclusions; formation of uniformly distributed fine graphite particles within the whole ferrite matrix are observed in optimally heat treated pearlitic grey cast iron.
3. Formation of ferrite matrix instead of the pearlitic one, partial solving the original graphite spheroid inclusions with forming branched interfaces and surrounding matrix areas having probably nano-size microstructures are the main results of the ductile iron optimal heat treatment.
4. Unprecedented increase of the impact resistance up to KCU ≈ 550 kJ/m2 is reached for both the optimally heat treated industrial grey and ductile irons that nearly twice exceeds the levels obtained in the conventional cast alloy steels
5. The phenomena observed were attributed to a number of the known processes development during the proposed optimal heat treatment: daughter matrix phase ultra-fine grains nucleation primarily on the curved "graphite-matrix" interfaces and dislocation sub-boundaries; intensive redistribution of carbon and other chemical elements by the grain boundary diffusion; the pearlitic cementite decomposition and the original graphite inclusions solving; new ultra-fine graphite particles uniform precipitation within a matrix phase.
6. Further precise and deep investigations are necessary to specify details and mechanisms of the phenomena revealed to promote further Material Science and Engineering development.
7. Wide range of industrial applications of the developed heat treating regimes is currently available without an additional funding.

References:

[1] I. Tkachenko, K. Tkachenko and V. Miroshnichenko, Formation of identical fine grained microstructures with high impact resistance in as cast and as hot rolled conventional low alloy structural steels, in: Contributed Papers from Materials Science & Technology 2018. Paper presented at MS&T18, Columbus, Ohio, 2018, pp. 1542-1548.

[2] I. Tkachenko, K. Tkachenko and V. Miroshnichenko, Some features of the heterogeneous diffusive nucleation and their use to form new type microstructures and eliminate chemical nonuniformities in bulk industrial product made of alloy structural steels, Ukraine Svidotstvo № 68323 dated 25.10.2016. Application №68903 dated 25.08.2016. (2016)

[3] I. Tkachenko, K. Tkachenko, Some features of the austenite formation during alloy structural steel heating, Visnik of Priazovsky State Technical University, 12 (2002) 25-27

[4] I. Tkachenko, M. Uniyat, Influence of heat treatment on spatial distribution of chemical elements in weldable microalloyed steels, Metal Physics and Novel Technologies, 37 (2015) 531-537.

[5] D. Jarvis, ed., Metallurgy Europe - A Renaissance Programme for 2012-2022, Science Position Paper MatSEEC, 2012

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