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Increasing of Utility Properties of Grey Cast Iron Castings with Heat Treatment

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Abstract

Grey cast iron belongs to materials for casting production, which have wide application for different industry branches. Wide spectrum of properties of these materials is given by the structure of base metal matrix, which can be influenced with heat treatment. Processes of annealing can be applied for grey cast iron without problems. During heat treatment processes, where higher cooling rates are used, the thermal and structural strains become important. Usage and conditions of such heat treatment for grey cast iron castings of common production are the subject of evaluation of this article.

Keywords: Grey cast iron, Heat treatment, Hardening capacity, Austenite, Martensite

1. Introduction

Grey cast iron belong to the oldest and most used metal materials for casting production. They have good foundry properties and with continuous improvement of production technology they have achieved also suitable utility properties which have shown with increased of technical level and working reliability of castings. Present knowledge achieved from studies of isothermally improved or anisothermally worked steel and iron shows advantageous strength and plastic characteristics of bainitic structures and also increased wear resistance.

In alloys with suitable chemical composition it is possible to achieve bainitic structure also with conditions of fluent cooling, e.g. in air, using directional cooling or cooling in a mould [1]. From the point of view of practical application this is the easiest way of heat treatment. With anisotropic breakdown of austenite mostly complicated structural mixtures with significant ratio of martensite is created and therefore the final properties of casting are being achieved with following tempering.

In comparison to steel, the relations between properties and structure of cast iron were less examined. Significant turnover was showed in last years, mainly with increased usage of ductile cast iron.

2. Heat Treatment of Graphitic Irons by Refinement

From the point of view of maximal productivity and effectiveness of production it would be best to produce the cast iron castings without the need for heat treatment. Grey cast irons are not very often heat treated. It is due to the fact, that with heat treatment we are not able to change the shape and distribution of graphite (although the graphitization degree is partially being changed), we can influence the basic metal matrix [2]. According to this, we can significantly change the hardness, partially the tensile strength, but due to the shape of graphite we cannot practically influence the low toughness of grey cast iron. Mechanical properties and wear resistance in grey cast iron castings can be significantly increased with hardening followed by tempering – refinement.

After refinement application of grey cast iron casting, important role plays also hardening capacity of cast iron. From the result of some researches it is evident, that for basic types of cast iron the hardening capacity by martensitic hardening is increased with increasing austenitization temperature – with increasing concentration of C in austenite. Mn significantly increases the hardening capacity, influence of Si is less significant. For low-alloyed cast irons is the hardening capacity positively influenced mainly with Mo [3]. Addition of Ni and Cr has lower influence on hardening capacity in comparison to Mn and Mo.

During heating of cast iron over the critical temperature solid solution austenite is created, which is being saturated with C up to 1,2% with increasing temperature (theoretically up to 2,1 %). During slow, balanced cooling, austenite is transformed to ferrite in critical temperature interval, which practically solutes no C.

With fast cooling speeds, e.g. cooling into water or oil, it is possible to suppress the change of austenite to ferrite. As the result of fast cooling between temperatures 100 – 200 °C, the bigger part of austenite is being transformed to needle hardened structure – martenzite – with the same chemical composition, same saturation of C as former austenite. High fragility of martenzitic structure can be changed by tempering – new heating over the Ac1 temperatures. With this, the hardness is decreased, and tensile strength and tensibility is increased in common. Kinetics of austenitic transformation in Fe – C alloys is showed with the use of kinetic diagrams of austenite breakdown ARA or IRA (Fig. 1) (2).

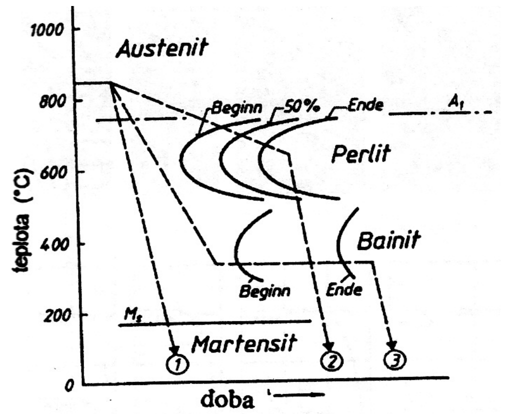

Fig. 1. Diagram of austenite breakdown with different heat treatment 1 – hardening, 2 – perlitization annealing, 3 – isothermal refinement

2.1. Austenitization

Austenitization temperature and holding time should ensure the dissolution and homogenization of C in austenite. The higher is the heating over transformation temperature, the lower period of heating is needed. The speed of dissolution of C from graphite will be higher, when the particles of graphite are small and evenly distributed – which shortens the diffusion tracks of C. The higher is the overheating over the transformation interval of temperatures, the higher hardness after hardening will be. Commonly the overheating temperatures 850 – 950 °C, holding time cca 1 hour/25 mm of wall thickness of casting are advised.

2.2. Hardening

The aim of rapid cooling of austenite which is stabile only under the high temperature is to achieve, that austenite will be partially or completely transformed to hardened structure – martenzite. To achieve the martenzitic structure in non-alloyed cast iron, the high speed of cooling according to ARA diagram must be achieved with cooling under the temperature 200 °C in period shorter than 20 seconds. Cast iron, particulary grey cast iron, should not be so rapidly cooled due to their susceptability to tearing. The addition of alloying elements, e.g. Cu or Ni could significantly decrease the critical cooling speed[4]. As cooling medium for cast iron the oil is used, which does not take off the heat from casting so intensively. It is good to move with the casting in the bath and with temperature 150 °C take it off and temper it.

2.3. Tempering

The heating of material to the temperatures between 150 – 650 °C, but under the lower transformation temperature A11. Holding time 1 hour on the wall thickness 25 mm is sufficient. Character of tempered structures is changed from bainite to sorbite. Tempering temperatures between 100 – 200 °C influence the hardness of hardened cast iron very low, but strength is increased a little bit. Therefore, the tempering up to 200 °C is suitable for achieving of good wear resistance. To achieve the maximum strength it is suitable for non-alloyed grey cast iron to choose tempering temperatures 300 – 370 °C, for alloyed grey cast iron 400 – 500 °C [5].

2.4. Refining of non-alloyed grey cast iron

In order to discover the structure changes and parameters of utility properties of non-alloyed grey cast iron on castings of common production with wall thickness up to 50 mm, the samples from material STN 422415, 422420 and 422425 were heat treated – hardening followed by tempering. The structures and mechanical properties in casted state and after refining were compared. Chemical composition and middle values of mechanical properties were checked on sample castings in casted state (20 °C) and after tempering (to 250, 350 and 450 °C) are shown in Tab. 1 and 2.

Table 1.
Chemical composition of grey cast iron

Mat.	C %	Si %	Mn %	P %	S %	Se %	T_{odl} °C	Structure
EN-GJL-150	3,55	2,21	0,34	0,15	0,091	1,01	1330	F90P10
EN-GJL-200	3,39	2,11	0,48	0,10	0,087	0,95	1340	F45P55
EN-GJL-250	3,26	1,92	0,37	0,12	0,077	0,90	1340	F10P90

Process of heat treatment was set as follows:
Austenitization: 920 °C , holding time 2 hours
Hardening: water
Tempering: 250 – 350 – 450 °C, holding time 2 hours
Cooling: slow in the oven

Table 2.
Mechanical properties and tempering temperatures of grey cast iron

Mat.	Rm[MPa]	A5[%]	HB	T[°C]
422415	201,3	3,53	184	20
	195	1,36	359	250
	207	1,03	325	350
	218	2,1	309	450
422420	253,6	3,43	207	20
	213,7	0,97	420	250
	255	1,97	404	350
	335	2,03	329	450
422425	274	3,27	213	20
	246,7	1,37	420	250
	313,7	1,33	383	350
	314	1,8	321	450

Microstructures of samples for casted state and given tempering temperatures are showed on Fig. 2 to 6.

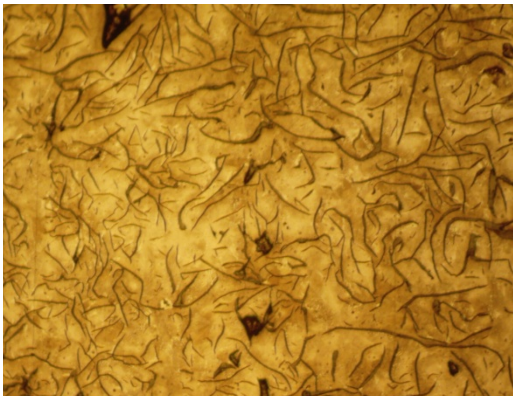

Fig. 2. Microstructure EN-GJL-250 in casted state; Nital 2%; mag. 100x

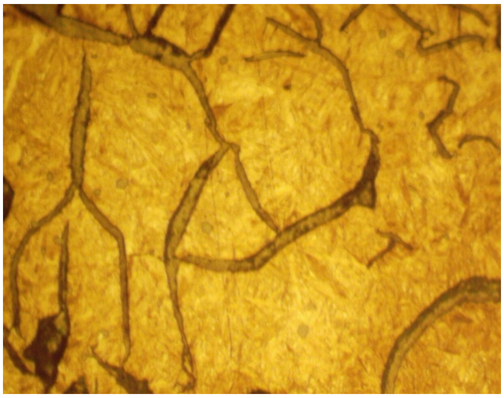

Fig. 3. Microstructure EN-GJL-250 after hardening in water; Nital 2%; mag. 400x

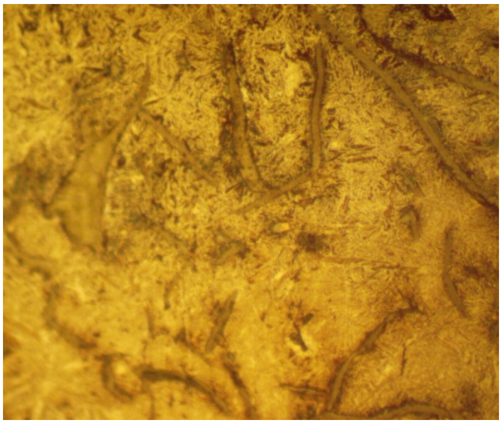

Fig. 4. Microstructure EN-GJL-250 after tempering to 450 °C; Nital 2%; mag. 400x

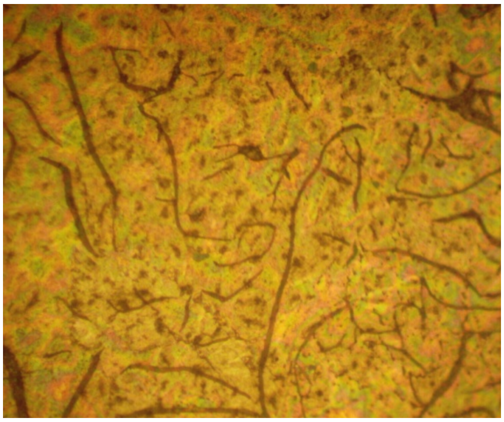

Fig. 5. Microstructure EN-GJL-250 after tempering to 350 °C; Nital 2%; mag. 400x

Fig. 6. Microstructure EN-GJL-250 after tempering to 250 °C; Nital 2%; mag. 400x

Dependencies of mechanical properties on tempering temperature and in casted state are showed on Fig. 7 to 9.

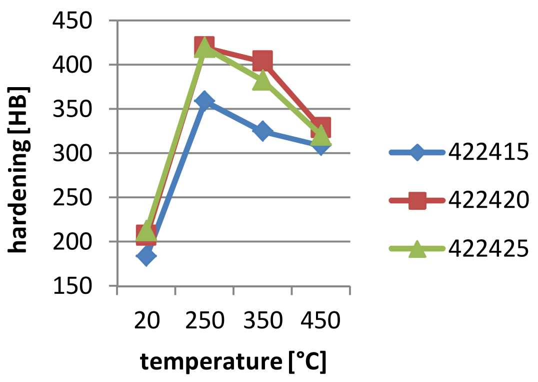

Fig. 7. Dependence of hardness on tempering temperature

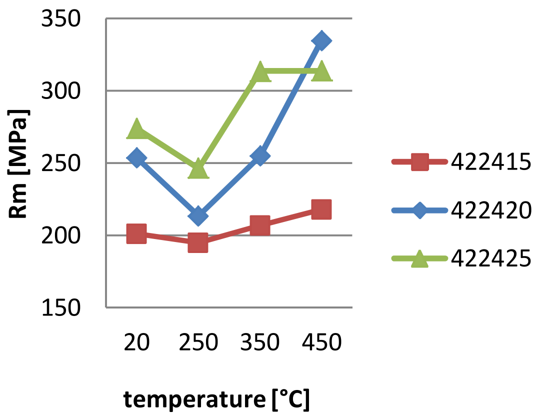

Fig. 8. Dependence of strength on tempering temperature

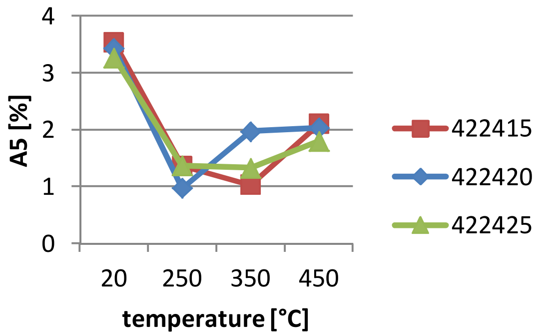

Fig. 9. Dependence of tensibility on tempering temperature

3. Evaluation

During heating and holding of grey cast iron on temperature 920 °C comes to the transformation of perlitic – ferritic matrix to austenite and with rapid cooling of the samples into water was created hardened needle martenzitic structure (from austenitic structure). By tempering of this structures on temperatures 250, 350 and 450 °C the change of mechanical characteristics against the casted state was achieved.

By tempering to 250 °C in the area of creation of lower bainite, soft, thick plates of bainitic ferrite are created which are separated with residual austenite and carbidic phase. This structure has increased hardness and partial lower strength and tensibility than in casted state.

By increasing of tempering temperature to 350 °C, partial decrease of hardness and increase of strength in comparison to casted state was achieved. The tensibility was slightly increased. Structure is created by bainite and residual austenite.

With following increase of tempering temperature to 450 °C, the hardness was again slightly decreased, strength and tensibility have slightly increased. These values correspond with the shape and character of upper bainite created by bainitic ferrite and partially excluded carbides.

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