

Prospective use of Graphitized Steels in Mechanical Engineering

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Abstract. Graphitized steel in some cases, due to its intermediate position in composition and properties between low-carbon steel and cast iron, can provide the necessary combination of properties of structural material. They are successfully replace ductile iron, carbon and low-alloy steel in the manufacture of critical parts of machines and mechanisms.

Keywords: *graphitized steels, alloying elements, mechanical engineering.*

I. INTRODUCTION

Graphitized steel are usually hypereutectoid alloys in which a part or all of the carbon in the form of graphite inclusions. Due to inclusion of graphite, which serves as a lubricant and increases the thermal conductivity of steels which are used as wear-resistant materials (stamp for cold stamping, drawing tools, beater, balls and armor lining plates of coal mills, shot blasters casing and blade, sandblasters nozzles, etc.) as well as for the manufacture of parts operating in the temperature cycling loads (casting molds, ingot molds, glass-forming tool, furnace equipment parts, etc.). Taking into account the good damping capacity, low sensitivity to stress concentrators and a relatively high mechanical properties of graphitized steel, they are successfully replace ductile iron, carbon and low-alloy steel in the manufacture of critical parts of machines and mechanisms.

II. RESEARCH METHODOLOGY

According to [1], major alloying elements in graphitized steels are: carbon (1,2-1,6%), silicon (0,75-2,5%) and manganese (0,2-1,2%). Also nickel, molybdenum, copper, aluminum and titanium find application [2, 3]. Steels of the above composition have good casting properties: high fluidity, low linear

shrinkage and low tendency to form hot and cold cracks. Heat treatment of steels normally consists of two stages: annealing at 850-950°C for the decay of secondary cementite and graphite phase formation and annealing at 700-780°C for forming the structure of the metal base. As a result of appropriate technological methods (ladle inoculation, increased content of silicon and other) could achieve a complete graphitization of excess eutectoid carbon and obtaining a structure of pearlite graphite without the use of heat treatment.

As noted above, the graphite inclusions give graphitized steel anti-friction properties, increase their damping capacity and reduce sensitivity to stress concentrators. On the other hand, increasing amounts of graphite phase, strength and ductility indicators are reduced. In paper [4] estimated influence of the graphite phase at the mechanical properties of the alloys with increasing carbon content. Between the amount of graphite and the strength of the alloys were observed linear dependence: increasing amount of carbon from 0.48 to 4.02% and, accordingly, the amount of graphite inclusions from 2.1 to 12.3 vol. % led to a decrease of tensile strength from 652 MPa to 168 MPa at room temperature; from 511 MPa to 152 MPa and from 155 MPa to 48 MPa at temperatures of 500°C and 700°C respectively. The hardness was decreased from HB220 to HB121 (Fig. 1).

The amount of graphite phase had a significant influence on the wear rate in terms of friction of metal on metal with slippage under load 50N: with increasing the amount of carbon and decreasing the distance between inclusions of graphite wear rate decreased. At the location of the graphite phase in the form of dendritic colonies, when the distance between the inclusions is practically reduced to a minimum, the wear rate was minimal due to

the lubricating effect of the graphite. With increasing carbon content of more than 2.5% was observed the decrease of wear resistance, due to embrittlement and chipping of metal near large inclusions of graphite.

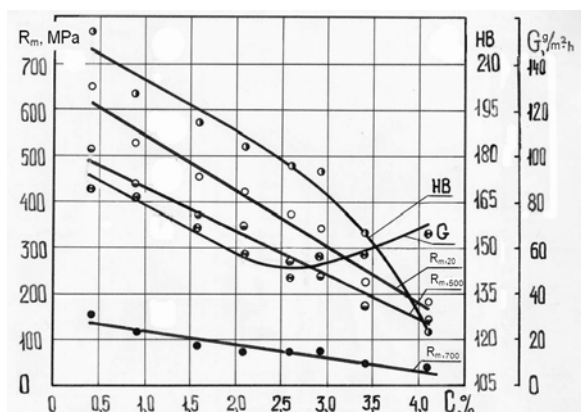


Fig. 1. Influence of carbon on tensile strength R_m at 20°C, 500°C and 700°C, on hardness HB and durability G of iron-carbon alloys

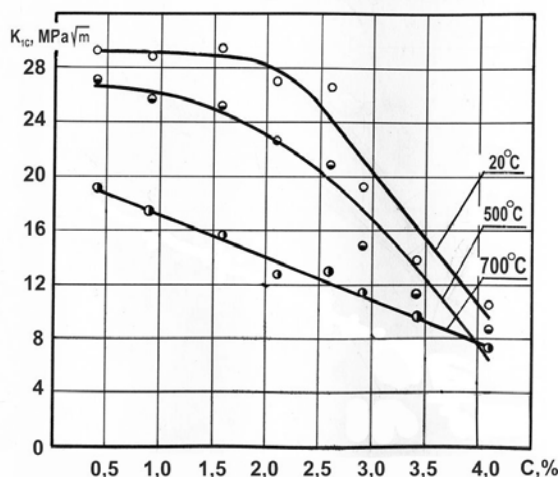


Fig. 2. The influence of carbon on fracture toughness K_{IC} of iron-carbon alloys at 20, 500 and 700°C

Somewhat different results were obtained when testing for the crack resistance (Fig. 2). With increasing carbon content up to 1.51% fracture toughness K_{IC} at a temperature of 20°C remained unchanged, at 500°C - declined slightly; higher concentrations of carbon leads to a sharp reduction of this indicator. At a test temperature of 700°C was a linear inverse relationship between the carbon content and K_{IC} .

Overall, the results presented above show that the graphitized unalloyed steels in strength, hardness, fracture toughness and wear resistance is approximately twice higher than those of gray iron and ductile.

III. RESEARCH RESULTS AND DISCUSSION

Further increase of the mechanical and service properties of graphitized steels can be achieved by alloying. In paper [2] investigated the effect of doping of Mn, Cr, Ni and Mo on the structure and mechanical properties of graphitized steels modified with aluminum. For this purpose in 120-pound induction furnace with a basic lining steel with base chemical composition was smelted: 1.38...1.40%C; 0.85...0.90%Si; 0.26...0.28%Al; 0.029...0.031%P; 0.022...0.027%S. Alloying elements were changed in the ranges shown in the table 1. The liquid metal was poured into the dry sand-clay molds. The resulting casting were subjected to graphitized annealing at 850°C for three hours, followed by annealing nodularisation, providing $\alpha \leftrightarrow \gamma$ conversion. As shown by metallographic analysis, in all variants of steels the inclusion of graphite were in the form of small (10 ... 40 μm) evenly distributed spherical precipitates and vermicular form (Fig. 3 a), when the metallic matrix was almost entirely represented by a granular perlite (Fig. 3 b). With increasing content of alloying elements monotonically increases strength, hardness and yield strength, while decreasing elongation (Table 1).

TABLE 1. THE CONTENT OF ALLOYING ELEMENTS IN THE COMPOSITION OF THE GRAPHITIZED STEEL AND MECHANICAL PROPERTIES

Variant of steel	Amount of alloying elements				Mechanical properties				
	Mn, %	Cr, %	Ni, %	Mo, %	R_m , MPa	$R_{0.2}$, MPa	δ , %	HB	K_{IC} , MPa · $\sqrt{\text{m}}$
1	0,80	—	—	—	418	288	8,3	195	33,9
2	0,80	0,30	—	—	582	334	7,6	197	38,3
3	0,80	0,30	1,2	—	697	348	7,5	217	40,6
4	1,80	0,30	1,2	—	775	433	5,0	241	39,8
5	1,80	0,30	1,2	0,32	917	479	4,5	255	36,6
6	1,80	0,60	1,2	0,32	920	525	3,0	255	34,7

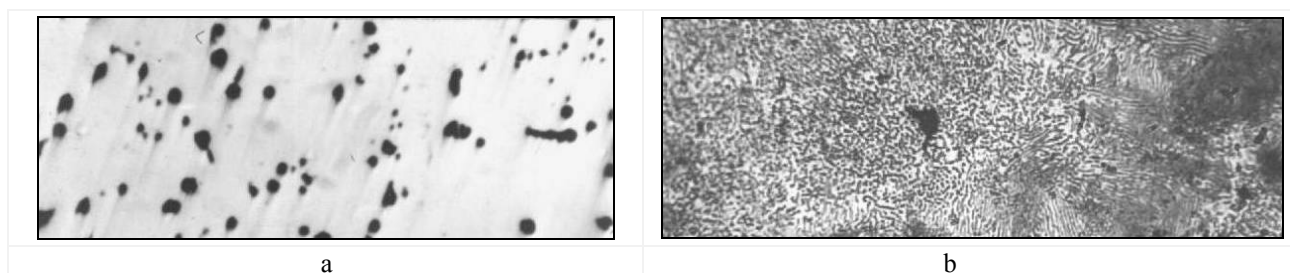


Fig. 3. The typical structure of the steel after heat treatment (a – not etched $\times 100$; b – etched $\times 500$)

This change of the properties can be explained by solid solution hardening of the metal matrix with alloying elements. The critical stress intensity factor was changed from $33,9 \text{ MPa} \cdot \sqrt{\text{m}}$ to $40,6 \text{ MPa} \cdot \sqrt{\text{m}}$ and had a maximum value for steel of 3rd variant, complex alloyed 0,8%Mn; 0,3%Cr and 1,2%Ni.

Thus, alloying with manganese, chromium, Nickel and molybdenum improves the mechanical properties of graphitized steel in solid solution hardening. It is established that graphitized steel with composition: 1,38...1,40%C; 0,85...0,90%Si; 0,7...0,8%Mn; 0,25...0,3%Cr; 1,0...1,2%Ni; 0,25...0,28%Al; 0,029...0,031%P; 0,022...0,027%S after graphitizing and subsequent annealing nodularisation had a stress intensity factor $K_{IC}=40...45 \text{ MPa} \cdot \sqrt{\text{m}}$, which is almost 1.5 times higher than characteristics in ferrite-pearlite ductile iron.

IV. SUMMARY

The results show that the graphitized steel in some cases, due to its intermediate position in composition and properties between low-carbon steel and cast iron, can provide the necessary combination of properties of structural material, for example, the thermal conductivity and strength for metal forms, resistance to wear - for parts operating under conditions of dry friction and, consequently, to improve the reliability and durability of machine parts of metallurgical and mechanical engineering industry.

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