A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 58 2013 Issue 3
DOI: 10.2478/amm-2013-0077

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WEAR RESISTANCE OF GRAPHITIZED STEELS

ODPORNOŚĆ GRAFITYZOWANEJ STALI NA ZUŻYCIE ŚCIERNE

Heat-treated graphitized steels with different carbon, silicon and copper contents have been the object of study. The influence of the composition on the structure and wear resistance (weight loss of the specimen) of graphitized steels (after hardening and tempering) under the conditions of metal to metal dry sliding friction with the use of Amsler-type friction machines, has been investigated in this work.

Research results have shown that the main factors affecting wear resistance of graphitized steels have been not only their metal base hardness, but the quantity, shape and distribution of graphite inclusions uniformity in the structure of such steels as well. A regression dependence of the quantity of specimen's weight loss on carbon, silicon and copper content has been obtained in the work.

The highest wear resistance was pertained by the steel having the following content: 1.60…1.70%C; 2.20…2.30%Si; 0.80…0.90%Cu; 0.60…0.70%Mn; 0.15…0.18%Cr; 0.22…0.25%Al; up to 0.015%S and 0.024%P.

Keywords: Graphitized Steel, Graphite Inclusions, Wear Resistance

Przedmiotem badań była grafityzowana stal (po obróbce cieplnej) o zróżnicowanej zawartości węgla, krzemu oraz miedzi. W pracy przedstawiono wyniki badań wpływu składu chemicznego grafityzowanej stali, po hartowaniu i odpuszczaniu, na jej strukturę i zużycie ścierne (zmniejszenie masy próbki) w warunkach suchego tarcia "metal-metal" na maszynie typu Amslera. Wyniki badań świadczą o tym, że odporność na zużycie ścierne zależy nie tylko od twardości osnowy metalowej, lecz także od ilości, kształtu i jednorodności wydzieleń grafitu oraz rozkładu przestrzennego wtrąceń w strukturze stali tego typu. Otrzymano zależności regresyjne wartości ubytku masy próbek w funkcji zawartości węgla, krzemu i miedzi. Największą odpornością na zużycie ścierne wyróżniają się stale o następującym składzie chemicznym: 1,60…1,70% C, 2,20…2,30% Si, 0,80…0,90% Cu, 0,60…0,70% Mn, 0,15…0,18% Cr, 0,22…0,25% Al, do 0,015% S i 0,024% P.

1. Introduction

Graphitized steels in which carbon is partly found in the form of a graphite phase are widely used as anti-friction materials [1-4]. Due to inclusions of graphite which serves as a natural lubricant such steels have low tendency to adhesion, good running-in ability, heat conductivity and stability of properties during thermal cycling. This allows applying of them for cold stamping dies, drawing tools, separators of rolling bearings and bushings of plain bearings, worm wheels, etc.

According to [5], the most known grades of anti-friction graphitized steels ЭИ293 and ЭИ336 can appropriately replace such anti-friction materials as brass ЛС59-1, duralumin Д16 and others for parts operating under conditions of reciprocally sliding surfaces. For example, using of the graphitized steel ЭИ366 instead of steel Х12М has provided durability increase of cutting down dies by 1.5 times [5, 6].

The influence of carbon, silicon and copper on the wear resistance of graphitized steels has been the object of research in this work. The specified elements have been selected from the following considerations. Metal base hardness, quantity and graphite inclusions form in the structure are known to be among the main factors which determine the wear resistance of graphitized iron-carbon alloys under the conditions of dry friction-sliding (metal to metal). These factors are influenced mainly by carbon as a natural source of carbides and graphite in the structure, as well as silicon as the strongest graphitizer. Copper influence on the wear resistance of graphitized steels is not studied sufficiently. Positive influence of copper on wear resistance of cast irons is known [7-9]. It is shown in the works that copper not only increases mechanical properties of cast irons, but also favorably influences their heat conductivity and heat resistance. This is important for such articles as brake blocks, separators of speed bearings, ingot moulds, etc.

2. Experiment planning

In order to investigate the influence of graphitized steel's content on its wear resistance the method of experiment's planning has been used. Carbon, silicon and copper content have been used as independent variables, and the specimen's weight

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loss Δm under conditions of wearing during dry friction metal to metal – as dependent variables. A full factor experiment of the second order 2^3 (Table 1) containing eight basic experiments as well as experiments at a "star" and zero levels has been realized in this work. The calculated chemical content for each experimental variant is shown in Table 2.

TABLE 1

Central compositional plan of the full factor experiment 2^3

Variation interval and factors of levels		Studied factors		
		X_1 (C, %)	X_2 (Si, %)	X_3 (Cu, %)
Zero level: $X_0 = 0$		1.2	1.6	2.0
Variation interval	1.0	0.4	0.6	1.2
	1.682	0.7	1.0	2.0
Lower level: X = – 1.0		0.8	1.0	0.8
Upper level: X = + 1.0		1.6	2.2	3.2
Star points	X = –1.682	0.5	0.6	0
	X = 1.682	1.9	2.6	4.0

TABLE 2

Calculated chemical content and properties of graphitized steels

Experiment number	Calculated chemical content, mass. %			Average weight loss of the specimen after testing for 90 min Δm, g
	C	Si	Cu	0.6924
1	0.8	1.0	0.8	0.8887
2	1.6	1.0	0.8	0.3921
3	0.8	2.2	0.8	0.3423
4	1.6	2.2	0.8	1.0213
5	0.8	1.0	3.2	1.8116
6	1.6	1.0	3.2	1.0329
7	0.8	2.2	3.2	1.2762
8	1.6	2.2	3.2	0.9892
9	0.5	1.6	2.0	1.6732
10	1.9	1.6	2,0	0.6596
11	1.2	0.6	2.0	0.3875
12	1.2	2.6	2,0	0.8494
13	1.2	1.6	0	1.3456
14	1.2	1.6	4.0	0.7346
15	1.2	1.6	2.0	0.6924

The experimental alloys have been smelted in the 60 kg induction furnace with basic lining. Carbon, silicon and copper contents in these alloys have been varied according to the plan, the content of other elements was as follows: 0.60...0.70% Mn; 0.15...0.18% Cr; 0.22...0.25% Al and up to 0.015% S and 0.024% P. Required carbon concentrations have been obtained by means of carbonization of the liquid alloy with cast iron Л5 in the furnace. Required silicon and copper concentrations have been obtained by means of the addition of ferrosilicium ФС65 and electric-technical copper М1 into the furnace. After that the smelt has been modified with silicocalcium, ferrosilicium and aluminium in the ladle. The liquid metal has been poured into dry sand moulds which provided obtaining of ingots with the cross section of rectangular and round shape.

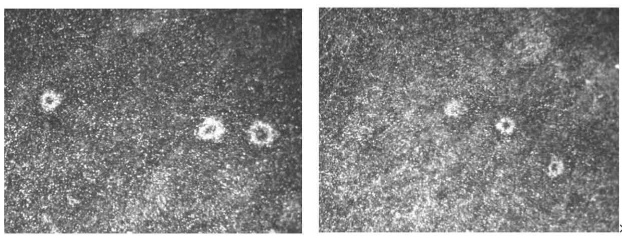
Results of the metallographic analysis of the obtained alloys in the cast state (not heat treated) have shown heterogeneity of microstructures depending mainly on carbon and silicon content.

The structure of steel containing 0.48% C consisted of a ferrite-pearlite metallic base with insignificant quantity of uniformly distributed point graphite inclusions. The increase of carbon content up to 0.78% facilitated the increase of graphite quantity to 3% of volume; herewith the metallic matrix was almost entirely represented by a large-lamellar pearlite phase. With the increase of carbon content up to 1.54% C the graphite phase quantity in steels increased to 5% of volume. The main distinction of structure of steel with the highest carbon concentration (1.95%) was formation of lamellar inclusions of graphite in the ferrite-pearlite metallic base. At this time the graphite phase quantity in this steel reached 8% of volume.

Predisposition of steels to graphitization in the foundry mould has been greatly influenced by silicon. At its lowest content of 0.62% secondary cementite was found in the steel's structure together with graphite inclusions. Increasing of silicon content up to 1.07% in the steel containing 1.54% C also didn't eliminate the formation of excessive iron carbide. Secondary cementite was not found in the structures of other variants of experimental steels, containing 1.65% Si and more. The structure of steel with the highest silicon content of 2.55% (1.26% C) was characterized by the ferrite-pearlite metallic base and large uniformly distributed globular graphite inclusions.

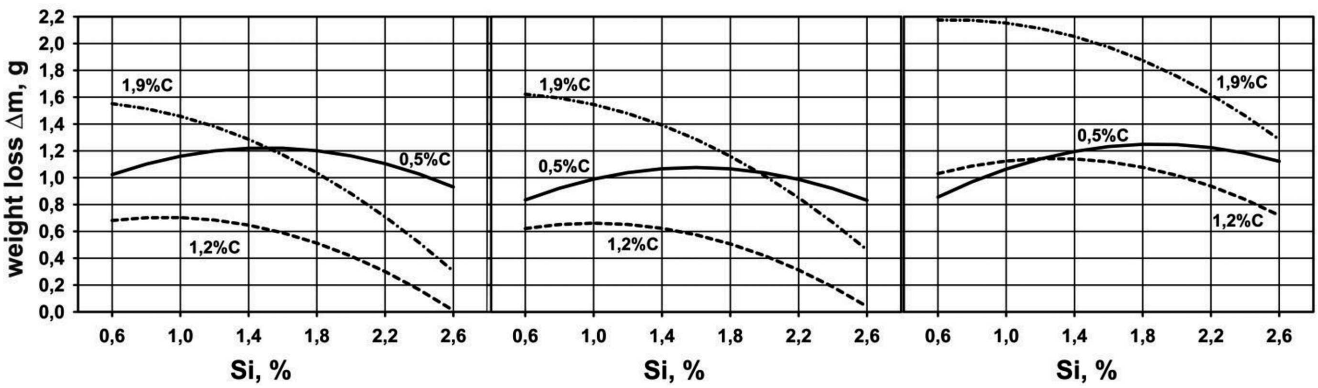
Changing of copper content from 0.02 to 3.95% has not sufficiently influenced the structure of metallic base of steels in cast state – small-lamellar pearlite has been detected in the structure. However, clusters of graphite inclusions in form of chains have been observed in steels with 3.17% Cu and more.

In order to increase the hardness and wear resistance of experimental steels the obtained castings have been quenched at 860°C with oil cooling and subsequent low-temperature tempering at 200°C for two hours. After heat treatment the metallic base of steels consisted of tempered martensite with fine-disperse ε-carbides (Fig. 1).



×800

Fig. 1. Metallic base and graphite inclusions in the structure of steels after quenching with low-temperature tempering



a b c

Fig. 2. Carbon, silicon and copper influence on the weight loss of steel: a – at 0% Cu; b – 0.8% Cu; c – 3.2% Cu

3. Investigation results

Wear resistance tests under conditions of dry friction-sliding metal to metal have been carried out with the use of МИ-1 friction machine (disk to disk) [10] according to the following parameters: diameters of the test specimen and counterbody – 40 mm; counterbody material – steel 40X (quenching, low-temperature tempering); load on the friction pair – 500 N; rotational speed of the counterbody – 615 rot./min; rotational speed of the specimen – 400 rot./min; linear speed of the specimen's slip in relation to the counterbody – 27 m/min. Wear resistance of the material has been assessed according to the weight loss of the specimens Δm determined after 90 min. testing by means of weighing on the scales with accuracy of 0.0002 g (Table 2). Processing of the results by means of regression analysis allowed to obtain an equation displaying the dependence of the specimen's weight loss Δm on carbon, silicon and copper content:

$$\Delta m = 1.5344 - 2.3447C + 0.9388Si - 0.4464Cu - 0.4129CSi + 0.231CCu + 0.0561SiCu + 1.2375C^2 - 0.2433Si^2 + 0.0765Cu^2; \quad r = 0.85$$

Graphical analysis of the obtained regression dependences has been performed with the purpose of determining the content which would provide the least weight loss Δm (Fig. 2). Herewith the graphs have been plotted for three copper content values: 0%; 0.8% and 3.2%. Carbon content corresponded to three values (lower, zero and upper levels), silicon content varied in the ranges investigated in this work.

4. Conclusions

Graphical dependences analysis has shown that with the increase of carbon content in steels from 0.5 to 1.2% Δm decreases as a result of increasing of metallic base hardness (tempered martensite is more oversaturated with carbon), as well as increasing of graphite phase quantity, which performs a function of a lubricant and prevents from dripping and scorings. Increasing of carbon content up to 1.9% rather decreased the wear resistance. This may be explained by the change of graphite inclusions form from compact to lamellar. Such graphite form has been a stronger stress concentrator and facilitated the experimental specimen's particles breakaway during friction sliding.

Results of graphical dependences analysis have also shown that silicon, in general, increased the wear resistance (decreased Δm) on the account of metallic base hardness increase by means of its solid-solution strengthening; and also on the account of the graphitizing action of this element, promoting the increase of graphite phase quantity.

The most optimal silicon content was 2.2...2.4%. Its further increase resulting from the decrease of mechanical properties has been unacceptable. According to the results of the experiment copper content increase up to 0.8% increased the steels' wear resistance in consequence of solid-solution and disperse strengthening of the metallic base (see Fig. 2 a, b). However, the increase of copper content in steels to 3.2% with carbon content of more than 1.2% lead to the increase of Δm as a result of negative influence on the graphite inclusions form, which corresponds to the data [11].

Generally, the results of the conducted research allowed to optimize and suggest the wear resistant graphitized steel content, which possesses a combination of high service properties after quenching and low-temperature tempering: 1.1...1.3% C; 2.2...2.4% Si; 0.7...0.9% Cu; 0.60...0.70% Mn; 0.22...0.25% Al.

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This article was first presented at the VI International Conference "DEVELOPMENT TRENDS IN MECHANIZATION OF FOUNDRY PROCESSES", Inwałd, 5-7.09.2013

Received: 20 January 2013.