TECHNICAL INFORMATION

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EFFECT OF THE PEARLITE STRUCTURE OF STRUCTURAL STEEL ON ITS MACHINABILITY

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Factors affecting the machinability of automatic steels containing sulfur and lead, namely, the microstructure of the pearlite and the content of sulfur and lead additives, are investigated. It is shown that satisfactory machinability of lightly loaded parts can be provided under certain cutting conditions by producing an optimum morphology for the pearlite in the steel and increasing the sulfur concentration without adding lead.

For steels of the pearlitic class with a medium carbon concentration (40, 40G, 40Kh, etc.) satisfactory machinability (turning, drilling) of parts in large-scale production can be attained in the case of a lamellar pearlite morphology in a hypopearlitic structure [1, 2]. It has been shown in [1] that only a low degree of carbide spheroidization (10 – 15%) is admissible in softening recrystallization annealing of sized steel 40Kh processed on automatic turning machines.

Unfortunately, the structural factor is often ignored by metallurgical plants that produce steels to be machined. Before sizing, the rolled stock is often subjected to a lengthy incomplete or subcritical annealing, and several incomplete intermediate and final recrystallization annealings of the sized steel are conducted in furnaces with lengthy heat treatment regimes; this gives a microstructure with predominantly granular pearlite, which worsens the machinability of the steel.

The introduction of lead alone [3] or lead in combination with sulfur [4] improves markedly the machinability of the metal. However, an elevated sulfur concentration (for example, 0.08 – 0.015% in steel AS45G2) restricts the application range of such steels just to lightly loaded parts with minimum requirements on their mechanical properties. For example, for steel AS45G2 as supplied $\sigma_{0.2}$ should be ≥ 450 N/mm^2, δ should be $\geq 6\%$, and the hardness should be ≤ 229 *HB*.

The introduction of lead into the composition requires special measures in melting because of the toxic emission of lead [5]. Due to the difficulties in realizing these measures and the strict ecological requirements the production of lead-containing automatic steels has been reduced considerably in recent years, which affects the machining process negatively.

This stimulates research on the effect of the microstructure of this class of steel on the machinability. The possibility of eliminating lead from the composition of such steels is mostly associated with fuller use of the lamellar morphology of pearlite.

We conducted our experiments[2] at the Moscow Plant of Tractor Equipment, which is experiencing a lack of automatic lead-containing steels.

A 264-mm-long spindle that is a part of the electrical equipment of an automobile (Fig. 1) is produced at this plant from sized automatic lead- and sulfur-containing rod steel 13 mm in diameter. After a mechanical treatment that consists mainly of noncentered grinding, the part is subjected to the following complex machining: (1) depositing grooves onto the end part at a speed of 700 rpm and a feed of 0.01 mm/rev, (2) broaching the tail part through a matrix with the formation of a gear profile. The mechanical properties of a ready spindle correspond to the requirements of the domestic standard for automatic sized steel as supplied.

[2] With the participation of G. A. Bykov.

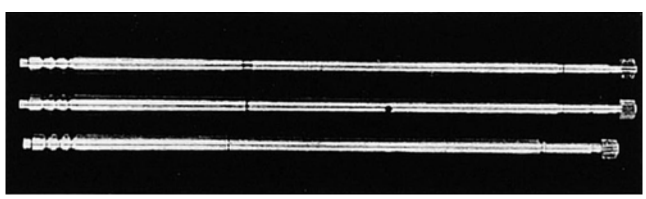

Fig. 1. Overall view of spindles of steel 40 (*1*), imported steel AS45G2 (*2*) and the lead-free substitute (*3*).

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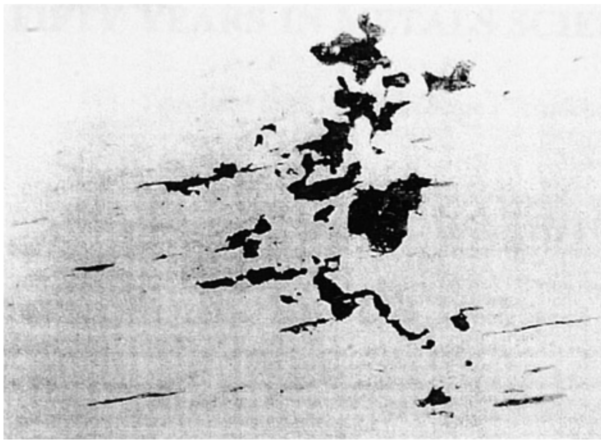


Fig. 2. Nonmetallic inclusions (sulfides) in imported steel AS45G2 (× 400).

TABLE 1

Steel	Concentration of elements, %			
	C	Mn	S	Pb
AS45G2	0.40 – 0.48	1.35 – 1.65	0.08 – 0.13	0.15 – 0.30
Of type AS45G2 (imported)	0.46	1.97	0.49	0.29
AS35G2	0.32 – 0.39	1.35 – 1.65	0.08 – 0.13	0.15 – 0.30
40	0.39	0.63	—	—
Substitute steel	0.36	1.43	0.23	—

The spindle has traditionally been produced from domestic or imported automatic steel AS45G2 (see Table 1) that contains an elevated amount of sulfur and a lead additive. The steel with a lead additive has been chosen to meet the requirements imposed on the turning and broaching processes under conditions of line production; it provided a high endurance of cutters of high-speed steel and a good quality of the gear profile on the tail. The elevated sulfur content improved the machinability without complications because the requirements on the mechanical properties of the spindle were quite low.

When the shipments of steel AS45G2 were stopped, the plant had serious complications with the machinability of the spindles and other parts. Specialists of the Bardin Central Institute of Ferrous Metallurgy studied under plant conditions the possibility of replacing the leaded steel. They made an attempt to compensate for the absence of lead by producing an optimum morphology of pearlite in the structure of sized steel by appropriate heat treatment and some modifications of the sizing process. A difficulty was that it was not known what structure was optimum for successful broaching.

Imported steel of the AS45G2 type employed in the plant that was used for similar parts was studied in order to determine its distinctive features (see Table 1). The steel possessed good machinability. It contained an unusually (for domestic industry) high content of sulfur (0.49% instead of the 0.08 – 0.13% required by the national standard) and manganese,

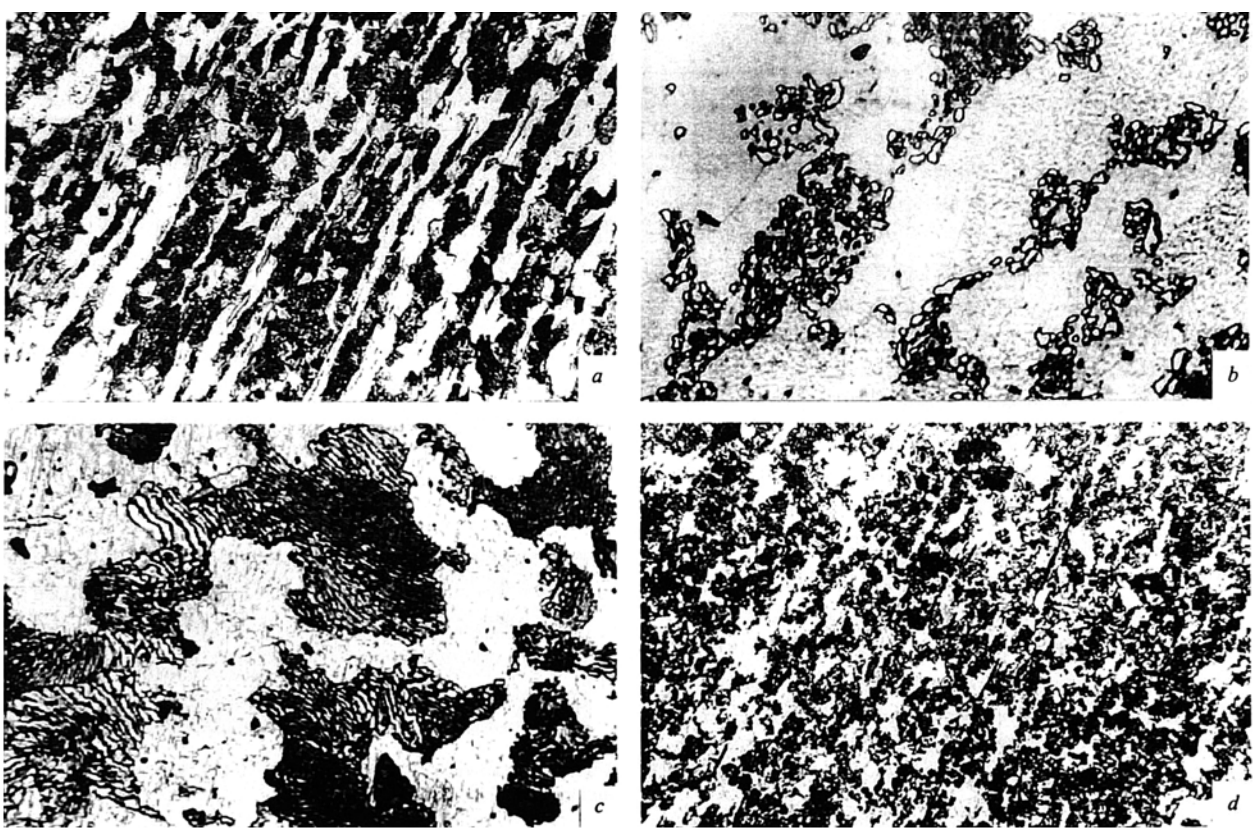


Fig. 3. Microstructure of imported steel AS45G2 (*a*), steels AS35G2 (*b*), 40 (*c*), and the substitute steel (*d*): *a*, *b*, *d*) × 400; *c*) × 1000.

which caused the formation of coarse sulfides[3] in the structure (Fig. 2).

The microstructure of this steel consists of ferrite + lamellar pearlite with grains of size No. 8 oriented along the direction of rolling (Fig. 3*a*); the hardness is 230 *HB*. It can be seen that the supplier used lead additives in combination with other factors that improve the machinability of steel of this type, namely, a maximum content of sulfur and a lamellar pearlite structure.

We also studied the machinability of steel AS35G2 used in the plant for some parts (see Table 1) and supplied by a domestic metallurgical plant. The microstructure of this steel (Fig. 3*b*) contained granular pearlite inadmissible for hypoeutectoud nonautomatic steels. However, the presence of sulfur and lead compensated for the negative effect of this pearlite morphology, and the use of this steel in the production of spindles caused no difficulties.

This seems to explain why monograph [4], devoted to the effect of various additives in steel on its machinability, did not consider the special features of the ferrite-pearlite structure and especially the pearlite morphology.

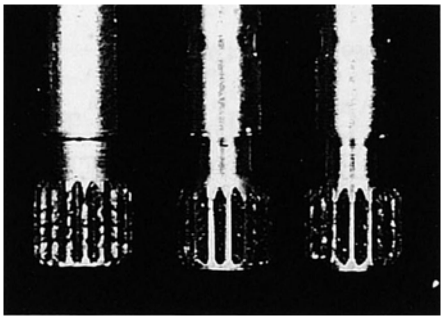
For comparison we studied under plant conditions the machinability of preforms (specimens) of sized steel 40. This steel did not contain lead or sulfur (except for impurities) but its microstructure was optimum for machining (ferrite + lamellar pearlite) (Fig. 3*c*). The machinability of this steel in sizing ($v = 700$ rpm, $S = 0.01$ mm/rev) was satisfactory, but broaching caused some defects, namely, spalling of the gear teeth surfaces (Fig. 4).

We also studied specimens of sized steel 40 with a structure containing ferrite and granular pearlite. With this microstructure the turning process was disrupted completely; the chips were continuous, which is inadmissible for automatic machines, and in some cases the cutters broke.

Results of preliminary tests have shown that the broaching is the critical operation for steel 40 with lamellar pearlite. We assumed that introduction of sulfur into this steel would eliminate the described complications in broaching and would make it applicable for the production of spindles instead of leaded steel.

In this connection the experimental plant of the Bardin Institute and the "Serp i Molot" plant manufactured a small batch of such steel. It was melted in an induction furnace using calcium-containing alloying sets for deoxidization. The chemical composition of the steel is presented in Table 1. After cutting off the discard head and fettling, the ingots were heated and forged into preforms with a square cross section. Then the preforms were heated and rolled into rods 16 mm in diameter on a duo mill in order to prepare them for sizing. The structure of the rolled stock consisted of ferrite + lamellar pearlite.

Under industrial conditions the rolled rods were sized into preforms 13 mm in diameter. The traditional sizing technology was corrected in order to reduce spheroidization of the lamellar pearlite to a minimum.



1 *2* *3*

Fig. 4. Gear profiles of heads of spindles (× 3) made of steels 40 (*1*), AS45G2 (*2*), and the substitute steel (*3*) (in *1* spalls that formed in broaching the teeth can be observed).

For this purpose the sizing process was reduced to a single (final) softening recrystallization annealing; the difference in the diameters of the initial rolled stock and the final sized preforms was reduced to a minimum.

In order to decrease spheroidization in recrystallization annealing the latter was conducted in a high-frequency current installation at 600°C with a 3-min hold.

As a result the microstructure of the sized steel was represented by ferrite + lamellar pearlite with a small degree of spheroidization (Fig. 3*d*).

The mechanical properties of the steel met the requirements presented above.

The obtained sized steel (a small pilot batch) was tested on a technological line of large-scale spindle production. Mechanical and other kinds of treatment of the substitute steel were conducted without complications over the entire technological line; the efficiency of turning did not decrease, the endurance of the cutting tools of high-speed steel did not change compared to the processing of the imported leaded steel, the quality of the teeth in broaching was satisfactory, and the endurance of the tools in broaching did not decrease. The results of the comparative tests of the lead-free steel were evaluated by the plant as positive.

REFERENCES

1. Yu. M. Brunzel', B. A. Moiseev, F. G. Tarasova, et al., "Heat treatment of steel 40Kh to improve its machinability," *Stal'*, No. 5, 50 – 53 (1980).
2. Yu. M. Brunzel', V. F. Vasil'ev, and I. M. Fomin, "Effect of the heat-treatment regime of structural steel on the endurance of tools used for drilling and cutting," *Stal'*, No. 3, 68 – 71 (1993).
3. A. P. Gulyaev, S. K. Il'inskii, and A. P. Sanina, "Leaded steels," *Tyazh. Mashinostr.*, No. 5 (1941).
4. Ya. E. Gol'dshtein and A. Ya. Zaslavskii, *Structural Steels with Enhanced Machinability* [in Russian], Metallurgiya, Moscow (1977).
5. M. A. Tylkin, *Reference Book for Heat Treatment Specialists* [in Russian], Metallurgiya, Moscow (1981).

[3] The nonmetallic inclusions were studied by G. G. Gulei.