The ladle treatment of cast steel with alkaline and rare earth metals (AEM and REM) has recently become widespread. In studies which we published earlier [1, 2], it was shown that the treatment of type 20GFBL steels with AEM and REM compounds may lead to a decrease in the total number of sulfides and to their globularization. Both of these factors should increase the cold and fracture resistance of these steels.

In this study, which is a continuation of our previous work [1, 2], the following goals were set: to study the composition of inclusions in steels containing AEM and REM additives, to establish the fracture characteristics of these steels, and also to examine the effect of these modifications on the thermal fatigue resistance.

The investigated 20GFBL steels were treated with silicocalcium (30% Ca), an iron-base strontium containing alloy (35% Sr), silicobarium (25% Ba), and ferrocerium (50% Ce). The chemical composition of the steels and the amount of each additive are given in Table 1. The metal was cast into wobbler test pieces according to State Standard 977-75. Every specimen was cut into four samples which were normalized at 950°C. The x-ray microanalyzer Superprob-733 was used to determine the composition of the sulfides. The REM-200 scanning electron microscope was used to study the fracture surfaces.

Because a standard method and equipment for thermal fatigue testing of steels does not exist, we used an experimental set-up and technique which was developed in [3]. The steel samples in the form of parallelepipeds of size $30 \times 10 \times 3$ mm are held in clamps and are tensile loaded at a constant stress. Heating of the sample occurs for 13 sec, then they are water cooled for 3 sec. After every 250 thermal cycles, the number of thermal fatigue cracks is counted, and their lengths on the side surface of the sample are measured using a MOV-1-1.5 ocular micrometer.

Scanning electron microphotographs of the sulfide inclusions obtained using secondary electrons and various characteristic x-ray emissions during surface scanning of the steels treated with silicocalcium, silicobarium, and ferrocerium (melts 4, 9, and 12 respectively) are given in Fig. 1. It can be seen that in every case the inclusions show a change in composition.

The essential difference which each modifying element has on the composition of the inclusions should be pointed out. In steels, modified by silicocalcium and silicobarium, the sulfides contain, in addition to Ce and alkaline earth elements, a noticeable amount of Mn. Consequently, when AEM are added to the steel, the Mn in the sulfides is partially displaced by these elements. This will increase both the precipitation temperature and the thermodynamic stability of the sulfides. The degree of Mn displacement will be determined by the amount of the modifier added. When the steels are treated with ferrocerium, the sulfides which form contain very little Mn, i.e., the nature of the sulfide changes. As established in [1, 2], this factor can evidently explain the more significant effect ferrocerium has on the globularization, uniform distribution, and contamination index of the inclusions and, consequently, on the mechanical properties of the steels in comparison to steels modified by AEM.

We investigated the fracture surface of impact samples of normalized steel 20GFBL after impact bending tests at temperatures from +20 to -60°C. The macrofractures had a semibrittle and brittle character.

Investigation of the fractures using a scanning electron microscope (Fig. 2) showed
that for samples from all the melts the ductile fracture regions (small dimples [4]) had the typical ductile fracture relief (Fig. 2a). A difference in the areas of brittle fracture was not observed. In these fracture areas, all of the investigated steels showed transgranular cleavage with the characteristic "river markings" and slight traces of cavity rupture (Fig. 2b). The transition zone from brittle regions of transcrystalline cleavage to ductile regions of dimple rupturing is shown in Fig. 2c. In the plastic fracture region two types of microcavities can be seen: large ones with inclusions at the bottom and small ones not larger than 1-1.5 μm without inclusions. In the regions undergoing transgranular cleavage nonmetallic inclusions are rarely seen. Analysis of the size and shape of the inclusions shows that they are sulfides. In steels without any modifying additions, the sulfides are needlelike, have grains and edges, and often crack during fracture (Fig. 3a), whereas in steels, treated with AEM and REM, they are nearly spherical and remain intact (Fig. 3b).

The fraction of microcavities in the microfractograms of impact fracture specimens noticeably increases when the steels are modified by REM and AEM. This agrees with the more fibrous nature of the macrofracture surface of the modified steels at all of the testing temperatures (Fig. 4). Only in samples taken from melt 12 (0.3% ferrocerium) is there seen a significant decrease in the amount of fibers. This is evidently associated with the so-called overmodification effect (increased contamination of the steel with inclusions).

The energy requirement for completely ductile fracture was evaluated through the impact strength of samples with fatigue cracks. For steels of all the compositions studied, such fracture is observed at +100°C. The values $\alpha_{\text{f}}$ obtained are given in Table 2. It is evident that all of the additives lead to an increase in the required energy. The optimum amount of each additive for increasing the value of $\alpha_{\text{f}}$ was also established. Thus, for silicocalcium, silicobarium, and iron-base strontium the amount was 0.3% and for ferrocerium it was 0.2%. For increased amounts of the additives a decrease in the fracture energy was observed which is associated with the overmodification effect.

We have evaluated the possibility of using steel 20GFBd doped with alkaline and rare earth elements in accessory metallurgical equipment. For the given group of castings the most important property is thermal fatigue resistance [5].

During thermal cycling, just as during mechanical fatigue testing, inclusions act as stress concentrators. Also, in the case of thermal fatigue, the stress rises due to the action of the thermal gradients acting over the cross-section. The less the number of inclusions in the steel and the closer their shape is to a sphere, then the less danger of them acting as stress concentrators.

Since upon addition of the optimum amount of REM and AEM in cast steel, the number of sulfide inclusions decreases and the remainder become more spherical, one would expect an increased resistance of such steels to the nucleation and growth of thermal fatigue cracks.