Preliminary thermomechanical treatment (PTMT) has come into wider use in recent years.

In PTMT, steel with a ferrite-carbide structure is subjected to cold working with a specific degree of reduction and then heat treated, the conditions of the heat treatment ensuring retention of the fine structure resulting from deformation.

Postdeformation heating must ensure the redistribution of dislocations with formation of stable polygonized boundaries and also the precipitation of finely dispersed hardening carbides that stabilize these boundaries during subsequent recrystallization.

In the power industry, steel 12KhlMF (GOST 10802-64) is widely used for steam superheater tubing. The standard heat treatment (SHT) for this steel consists of normalizing at 950–980°C for 20 min and tempering at 720°C for 1 h. This results in a ferritic-pearlitic structure (Fig. 1a).

Transmission electron microscopic examination of steel 12KhlMF after cold working with subsequent normalizing at 950°C showed that the recrystallization process is completed simultaneously with completion of \( \alpha \rightarrow \gamma \rightarrow \alpha \) recrystallization. The structure of recrystallized ferrite grains is shown in Fig. 2a, where dispersed vanadium carbides can be seen (heating to 950°C is insufficient for complete solution of the carbides).

Figure 3 (a, b) shows the fine structure of ferritic and pearlitic grains in steel 12KhlMF after SHT (structure of feeder tubes in power plant).

At 720°C there is intensive decomposition of the solid solution with formation of special carbides: VC, M\(_{23}\)C\(_6\), M\(_7\)C\(_3\) (according to data from electron diffraction analysis of replicas with extracted particles).

The main field of the ferrite grain has a low dislocation density (see Fig. 3a). One should note that around the carbides there are zones with a contrast differing from that of the ferrite matrix. Probably this region of ferrite is impoverished in the alloying elements forming the carbides.

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Moscow Institute of Steel and Alloys, Eastern Branch of the Thermotechnical Institute. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 12, pp. 21-23, December, 1969.
In pearlitic zones there is noticeable coalescence and partial spheroidizing of the carbides of the cementite type (see Fig. 3b).

Long-term strength tests of samples after SHT showed that the time to failure averages 500 h at a testing temperature of 570°C and stress of 18 kg/mm².

To increase the long-term resistance of steam superheater tubing we tested two variations of PTMT*:

a) cold rolling + intermediate heating to 400°C + normalizing at 950-980°C + tempering at 720°C for 1 h;
b) the same as (a) except for intermediate heating at 500°C. Figure 4a shows dislocation arrays in steel 12Kh1MF after cold working.

Intermediate heating of the cold-rolled steel to 400°C did not lead to substantial changes in the dislocation arrays; after normalization this unstable structure disappeared and the base metal was recrystallized (see Fig. 2b). Tempering at 720°C led to the same changes as in SHT. The time to failure in the long-term strength tests averaged 500 h, as after SHT.

* In all cases we used standard cold-rolled tubing from the Nikopol Southern Tubing Plant subjected to the standard reduction (ε ∼ 60%).