EFFECT OF DEFORMATION TEMPERATURE AND HEAT TREATMENT ON THE STRUCTURE AND PROPERTIES OF HIGH-MANGANESE STEEL

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The investigation was conducted on test pieces obtained by free forging (forging reduction ratio 1.5 to 5) of ingots. The steel (1.15% C, 12% Mn, 0.6% Si, 0.013% S, 0.075% P) was melted in a basic induction furnace.

Before forging, the ingots were heated to 1150°C and held at this temperature 3-5 h, depending on the cross section. The final forging temperature was 800-850°C for all test pieces.

The forgings were subjected to four different heat treatments: I) cooling in air after forging; II) cooling in water after forging; III) heated to 1050-1080°C for 1 h directly after forging, with cooling in water; IV) cooling in air after forging, followed by heating at 1050°C for 3 h and cooling in water.

Abrasive wear tests were made in the MI-1M machine. The wear tests were made with rollers 50 mm in diameter, one of them (the sample) machined from the forged test piece and the other (the standard) from the ingot subjected to the standard heat treatment. The load on the rollers was 50 kg, slippage was 10%, the number of revolutions was 70,000, and the abrasive medium was an emulsion of zirconium oxide in water.

The wear resistance was determined from the ratio of the absolute weight loss of the test piece $\Delta m_t$ and the standard $\Delta m_s$.

Even after relatively small deformation (forging reduction ratio 1.5) the mechanical properties of the steel increase by an average of 10% after all heat treatments (Fig. 1). The improvement of the mechanical properties is greatest with a forging reduction ratio of 2.5-3.0, the mechanical properties remaining unchanged with further increase of the forging reduction ratio.

A high strength was obtained after heat treatments II-IV, and the greatest increase of the yield strength occurred with a forging reduction ratio of 2.5-3.0 (about 40%) after cooling from the forging temperature in water and in air. The ductility and impact strength varied in the same manner.

The fairly high yield strength after treatments I and II is due to the fine-grained structure of the steel after deformation, the presence of a large number of slip lines and twins, and also carbide precipitates in the austenite grain boundaries and within the grains. The reduction of the mechanical properties with a forging reduction ratio larger than 3.0 in samples from series I and II is due to the decrease of the final forging temperature, which causes the formation of a stressed structure with a large number of carbide precipitates.
Fig. 2. Variation of grain size with forging reduction ratio and type of heat treatment (given on the curves).

Fig. 3. Variation of wear with final forging temperature (forging reduction ratio 2.5): ---) Abrasive wear; ----) impact-abrasive wear.

Samples annealed at 1050°C (III and IV) have an elevated ductility and impact strength.

From the variation of the grain size with the forging reduction ratio at different heat treatment temperatures it was found that grain refining is greatest with a forging reduction ratio of 2.5-3. The grain size was smallest for samples of series I and II due to negligible recrystallization.

As the result of recrystallization during heat treatments III and IV, the grain boundaries formed during deformation disappear and the old grain boundaries are reestablished. With holding for 1 h at 1050°C this process does not have time to be completed, as the result of which the austenite grains differ in size.

The wear resistance was highest for samples of series II and somewhat lower for samples of series I (Fig. 1). The wear resistance was lower for samples annealed at 1050°C.

The impact-abrasive wear resistance was determined on forged crusher plates of the same steel (forging reduction ratio 2.5) subjected to heat treatment II. The wear was measured after crushing 2100 kg of screened grit (hardness 14-16 on Protod'yakonov's scale). The initial forging temperature was 1200°C and the final forging temperature was varied (60° intervals) from 1100 to 650°C (the temperature was measured with a thermocouple attached to a blank). The samples were cooled in running water after forging.

The abrasive wear decreases with reduction of the final forging temperature to 800-850°C (Fig. 3), and remains unchanged at lower temperatures. This results from the change in the structure of the deformed steel; with decreasing final forging temperatures the number of twins and slip lines increases, while the number and distribution of carbide precipitates change. At a temperature above 800-850°C the carbide phase is precipitated in the form of finely dispersed inclusions primarily in slip planes, and in the grain boundaries at lower temperatures.

Reducing the final forging temperature to 850°C has almost no effect on the impact-abrasive wear resistance, which increases at 800°C. The lower wear resistance after a final forging temperature below 850°C is evidently due to the "overhardening" in the surface layers of the metal, characterized by a stressed structure. Also, with decreasing final forging temperatures the number of carbide precipitates in the grain boundaries increases, which lowers the wear resistance of the steel. It can be seen in Fig. 4 that with a