In the present work we have investigated various types of thermomechanical treatment (TMT) to determine the effect of deformation on the mechanical properties of steel. The composition (%) and the critical points were as follows: 0.50 C, 1.55 Cr, 4.0 Ni, 0.31 Mo, 0.27 Mn, 0.25 Si; \(M_s\) 250°C, \(A_{cr}\) 730°C, \(A_{cs}\) 810°C.

The steel was cast into 150 x 150 x 300 mm ingots and forged into 45 mm squares. The forgings were annealed at 1200°C/10 hrs. The work was started with determining the strength level that can be developed by using ordinary heat treatment. For this purpose, specimens were oil quenched from 900°C and then tempered at various temperatures. The mechanical properties of the steel, depending on tempering treatment, are shown in Figure 1.

Specimens 20 x 30 x 65 mm in size were then upset on a 100-ton hydraulic press at 900 or 550°C, followed by quenching some of them in oil and holding the others isothermally in molten lead at 320°C/2 hrs. Those intended for deformation at 550°C were transferred from the heating furnace (900°C) into a tin bath at 550°C. The high stability of the undercooled austenite excluded the possibility of \(\alpha\) formation during cooling. The deformation lasted about 10 to 15 secs but, due to insufficient preheating of the ram, it occurred within the 900–500 and 550–500°C ranges. Impact and tensile specimens (10 x 10 mm section and 5 mm dia, respectively) were finished by grinding. Prior to testing they were tempered at 100°C.

Deformation at 900°C. a) Oil quenching after deformation. The \(\sigma_b\), \(\sigma_s\), \(\delta\) and \(\psi\) data are given in Figure 2 for various reductions. Upsetting at the austenitizing temperature of 900°C followed by an oil quench, Figure 2, I, systematically increased the tensile strength with increasing reduction. The maximum strength was developed at 50% compression.

After a 25% upset, \(\sigma_s\) decreased from 175 to 165 kg/sq.mm whereas it again increased reaching 190 kg/sq.mm at 50%.

The fall of \(\sigma_s\) after 10–30% reduction can be explained by an increased amount of retained austenite which reached a maximum at low deformations (abt. 25%), Figure 3. This also explains the much better ductility after 12% straining. Nevertheless, after 50% reduction not only the strength properties but also the ductility increased (\(\delta = 22\%\) instead of 9%, \(\delta = 9\%\) instead of 6%). The impact toughness improved somewhat after a 50% reduction whereas it remained approximately constant at 4 kgm/sq.cm.

b) Martempering after deformation. Isothermal quenching at 320°C after straining at 900°C considerably reduced ductility, Figure 2, II. After 20% upsetting, the reduction of area fell from 42 to 9%, the elongation from 10 to 0% and the impact toughness from 4 to 2 kgm/sq.cm. The tensile and yield strengths increased but did not reach the level obtained by oil quenching. The overall level of strength and ductility was much below the oil quenched condition. The amount of retained austenite varied in the same manner as in oil quenching, i.e., it increased with small deformations but decreased with heavy ones.

Deformation at 550°C. a) Oil quenching after straining. The effects of the degree of upsetting of the undercooled austenite at 550°C on the mechanical properties were followed up to 35% strain. The tensile strength increased in proportion to the reduction, Figure 2, III. However, the reduction of area and elongation decreased after small deformations (15-17%) but then they increased again and at
Thermomechanical Treatment of Steel and its Effect on the Mechanical Properties

Fig. 2. Effect of reduction on mechanical properties during TMT:
I and II — deformed at 900°C; III and IV — deformed at 550°C; I and III — oil quenched after straining; II and IV — held at 320°C/2 hrs after upsetting.

35% were above the value of the quenched but undeformed condition. The yield strength and impact toughness changed in a similar manner as after a high-temperature deformation.

b) Marquenching after deformation. After such a treatment (900 + 550 + 320°C/2 hrs) all the mechanical properties fell with increasing deformation, Figure 2, IV. The reason for this effect was not clear and it calls for further study.

Hence, depending on the type of TMT, the resulting properties of the steel differed considerably. The Table on the next pages sums up the data for quenched and TMT treated specimens using six different procedures.

The table shows that 90% deformation at 900°C followed by oil quenching improved the strength as well as the ductility. Other treatments resulting in martensite formation (oil quench) also gave higher mechanical properties than ordinary quenching and tempering while the bainite resulting from isothermal hardening gave, after TMT, properties inferior to those of ordinary heat treatment.