Tests of thermomechanical treatment (TMT) with deformation by stamping have revealed several difficulties [1] due mainly to the uneven distribution of deformation through the section of the piece. This does not occur during stamping of flat parts of small section with relatively simple shapes. In such cases TMT ensures consistently high mechanical properties and leads to substantial savings.

An example of such parts is the knife of harvesting machines, which is the basic operating part of the cutting apparatus. The knives (Fig. 1) are plates of trapezoidal shape with sharpened lateral edges, with the shape of a one-sided wedge in the normal section. Interacting with their counterparts (on the principle of shears), the knives seize and cut the stems of plants.

Mass-produced knives have a short service life due to the fact that cutting edges with the necessary hardness to ensure high wear resistance do not have the combination of strength and ductility required. Existing methods of increasing the service life of knives consist mainly of hardening the cutting edges by application of coatings – chromizing, thermal diffusion coatings, et al. However, such hardening is effective only for knives with smooth cutting edges [2]. Attempts to apply hard coatings on the teeth of serrated knives have been unsuccessful due to chipping of the hardened layer and even entire teeth along with the hardened layer.

The necessity of increasing the service life of knives is due to the long time required to replace these parts in the field, which involves considerable material losses. The quality of knives and thus the efficiency in operation of harvesting machines can be improved by HTMT (high-temperature thermomechanical treatment). HTMT of knives made of steel U9 increases the ductility [3], making it possible to improve substantially the combination of mechanical properties with a change in the final tempering temperature.

For tests of knives a semicommercial automatic production line was developed for HTMT (Fig. 2) and also instruments and testing apparatus making it possible to determine the quality of such parts with hardening under optimal conditions [4]. The automatic production line operates as follows: The knife blanks 7 from the magazine 8 (position A) are transferred by the slide bar 9 into the feeder with a spring clip 10 located in the zone of the inductor 11 (position B). The feeder is designed to take the blanks from the magazine in a precisely controlled position and hold them in this position during all movements. After the blank is heated to a given temperature the feeder moves along the carriage 12 into the area of the punch 4 (position C), where the blank along with the carriage and the feeder moves into the die (position D), the press 5 is actuated, and the cutting edges of the knife are formed, followed by immediate cooling of the piece by the metal in the die. The part remains in the die, while the feeder 10 returns to the original position. To ensure the necessary cooling time the press is held in the closed position by means of a clamping device after the slide bar is lifted. When the next heated blank arrives the die is opened and the first part is ejected onto the table (position E). Thus, the loading, heating, and transfer time of the next part, i.e., almost the entire cycle, is used for cooling the part in the die. The output of the line is 600 knives per hour.

This production line makes it possible to obtain large experimental batches of knives to study the effect of the basic parameters of HTMT on the properties of the teeth and cutting edges. In these experiments we varied the austenitizing temperature (deformation temperature), deformation, and cooling and tempering conditions. It was found that changing the heating temperature within the limits investigated (800-920°C) has almost no effect on the properties of the knives, which is of great importance in applications of HTMT in production. Any temperature within these limits is permissible [5].

The results of investigations of the effect of deformation and tempering temperature on the mechanical properties of the teeth and cutting edges of the knives agree with the data obtained in a study of steel U9 with
Fig. 1. Cutterbar of harvesting machine. 1) Knife; 2) counterpart.

Fig. 2. Schematic diagram of semicommercial production line for HTMT of knives (plan view). 1) Automatic feeder; 2) reinforcing lever; 3) clamping device; 4) die; 5) press; 6) high-frequency generator; 7) knife; 8) magazine; 9) slide bar; 10) feeder; 11) inductor; 12) carriage.

After HTMT and low-temperature tempering the ductility increases considerably (Fig. 3). Bending of the cutting edges is observed with HTMT after tempering at 130°, but only after tempering at 300° with the control treatment (OTO). Because of this, the maximum strength with HTMT is obtained at low tempering temperatures, while the increase in strength after tempering at 130-250° amounts to 90-120%. The optimal deformation during HTMT of knives is 30-35% (Fig. 4), which is characteristic of high-carbon steels. With increasing deformation the strength decreases, as was found in [3].

SEM fractographs of samples from the cutting edges of knives (Fig. 5) show that intercrystalline fracture occupies the major portion of the fracture after standard quenching (Fig. 5a). It should be noted that such fracture predominates even after tempering at 300° (Fig. 5b). After HTMT the character of the fracture changes sharply — no areas of grain boundary fracture are observed and the fracture is transcrystalline and "quasi-brittle" with traces of considerable plastic deformation (Fig. 5c, d). This type of fracture requires a substantially larger expenditure of energy, which was also established in fracture toughness tests of samples (and individual teeth).