Influence of heat treatment on mechanical properties of steel

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ABSTRACT: This article concerns an influence of heat treatment on strength and toughness of steel. The partial results of tests on steel 12 042 are presented.

Keywords: heat treatment; strength; toughness

Heat treatment of steels consists in the purposeful control of phase and structural changes process by outside conditions regulation with the aim to reach economicaly the required properties of heat-treated parts. The know-how of the kinetics and mechanism of phase and structural changes in the solid state is the basis of heat treatment. It is necessary to join the idea of the concrete part of a definite size and form to the steel of the definite chemical composition. At the parts of the suitable form there is relative easy to realize the thermal changes so that the only one austenite transformation runs through, but at heat treatment of real parts several different transformations can run through at the same time in different places. The heat treatment consists in the carrying-out of the serie of elemental operations using different technologic equipments, which have sometimes the decisive influence. The solid state phase changes of steels are the basis of the heat treatment, but it is not possible to speculate about them separately from a number of problems, which are often of technologic nature (PLUHAŘ 1987).

Different methods of annealing, hardening and tempering are used in a wide range. The precipitation hardening is the less used process, but very important at maraging steels type. The deprecipitation of the supersaturated solution is very important at polymorphic steels, too, e.g. by its negative influence at steel ageing and essentially it is the main process at tempering (HERTZBERG 1989; SCHOTT 1989).

Mostly the improvement of mechanical, physical or technologic properties is the aim of the heat treatment. The mechanical properties, influenced above all by the carbon content, can be changed in the wide range by heat treatment. The difference of mechanical values at different heat treatment state are evoked by the different carbon bond and by the different size of systems, where it is bonded. The structure of periodic alternated ferritic and cementite strips of the lamellar pearlite is the harder the more fine-grained the strips are. By the hardening to the martensite topmost hardness values are reached and their level depends on the carbon content (HERTZBERG 1989).

The internal stress, which can present by the deformations or by the rupture when hardening or after hardening, decreases by the tempering, which accommodates the mechanical properties to the required ones. The change of the tetragonal to the cubic martensite and almost the contemporary transformation of the retained austenite is not accompanied by the substantial hardness lowering. The precipitation of carbides and their consecutive coagulation at the tempering temperatures over 250°C evokes the hardness decrease. With the hardness decrease the yield value decreases, but the plasticity increases. The bilateral proportion of these values can be adapted by the tempering conditions choice. With the increasing tempering temperature decreases the internal stress of hardened parts and increases the impact value, especially between the tempering temperatures 400 to 600°C. The general trend of the impact value increase when the tempering temperature increases show especially at some alloy steels significant deviations owing to the temper brittleness evolution (high- and low-temperature temper brittleness). The toughness decrease comes at the definited for the given steel characteristic zone of the tempering temperatures. This decrease, which can not be always unambiguous demonstrated by the usually used notched-bar impact tests, can be better identified by the transit curves monitoring and by the transition temperature displacement (HERTZBERG 1989; CHOTĚBORSKÝ 2003).

The heat treatment of steel consists in the hardening and the tempering and is called the anisothermal hardening treatment. It is the important method of heat treatment, because it makes possible to acquire the structure with prescribed properties, which values can modify in the wide range. It is very important that by the hardening treatment to the same tensile strength as there is after the normalizing, but the major yield point, the elongation at break and the impact value is reached than after normalizing. With regard to the possible load of the constructi-

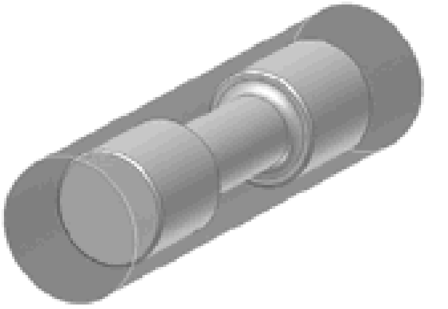


Fig. 1. The sampling method for the tensile test

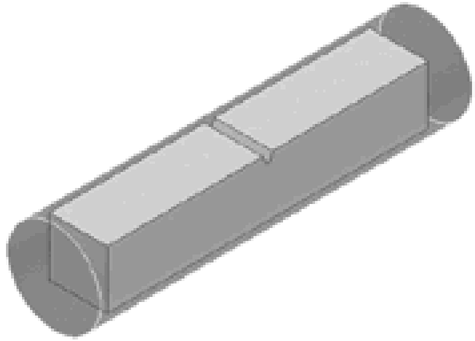


Fig. 2. The sampling method for the Charpy notched-bar impact test

onal parts the yield point is determining. At construction steels this circumstance is very important. Using the hardening treatment the increase of the yield point, the elongation at break and the impact value can be reached at the same time in comparison of the same steel values after the normalizing. This improvement of the steel quality is based on the martensite transformation to annealed ferritic-cementitic structures (sorbite). If the mechanic values increase by the hardening treatment should be reached in the whole cross section, after the hardening the martensite must be in the whole cross section. The part, which was not through-hardened in the whole cross section, does not contain the martensite structure in the centre and therefore the yield point and the impact strength values are in the centre minor than the values of the surface areas (HERTZBERG 1989; SEDLÁČEK 1985).

The absolute strength value or yield point value of hardened steel tempered to the determinated temperature depends above all on the carbon content. The alloying elements influence is above all in the cross section, which can be through-hardened and therefore these mechanic values can be reached in the part centre. Very effective and at the same time the inexpensive way of the hardenability increase is to add very little amount of some elements in the low-alloy steels. Above all the very little addition of boron (0.001–0.005%) improves very the steel through-hardening till to the medium carbon content, but the through-hardening of major carbon content is influenced very little. The hypereutectoid steel is influenced not at all. The boron addition in steels is effective only in case when oxygen and nitrogen are rigidly bonded. Therefore before the boron addition or immediately after Al, Ti, Zr are added for the necessary deoxidation and denitration (PLUHAŘ 1987).

MATERIAL AND METHODS

The steel 12 042 is used for the high-strength bolts production. The major hardenability is secured by the boron micro-alloying. The important screw property is the uniform structure in the whole cross section. For that steel properties determination and its brittle failure behaviour the starting material for the sample production was the semi-product in form of rods of 15.8 mm diameter, made from the wire of 18 mm diameter by drawing. The chemical composition of tested steels is presented in Table 1, the material withdrawal for samples production is shown in Figs. 1 and 2.

RESULTS AND DISCUSSION

The sample structure without heat treatment is shown in Fig. 1. Its tensile strength is 510 MPa, yield strength 400 MPa. The strength values of heat treated samples are shown in Fig. 3, where the structure after tempering temperature of 200°C is in Fig. 4b, after 300°C in Fig. 4c and after 400°C in Fig. 4d.

The toughness evaluation was made by one of most used tests, the Charpy notched-bar impact test. The energy (KV, KU) absorbed by the test sample of definited dimensions at its testing using pendulum impact testing machine, is the toughness measure. This energy depends both on the crack start and propagation, and on the sample shape and dimension. Mostly this test is used for the material quality evaluation (material cards, delivery conditions etc.), where the absorbed energy value is specified.

At the determination of absorbed energy – temperature dependence we get so-called transit curve. It shows the way how the part fails at definite temperature. In the I range there are the brittle fractures, which need very little energy, on the contrary in the range III the tough fractures. The II range, where both types occur, is called "transite" range.

From the absorbed energy – temperature dependence we determine the transite temperature in various ways, namely:

1. as the minimal energy 27 J, marked as K_{27J},
2. the $Kv_{max}/2$ value,
3. or as the value corresponding the 50% part of the brittle and tough fracture.

Table 1. Chemical composition of tested steel

Content of elements	%C	%Si	%Mn	%Cr	%Al	%Cu	%B	%V
12 042	0.35	0.22	0.63	0.094	0.014	0.081	0.004	0.010

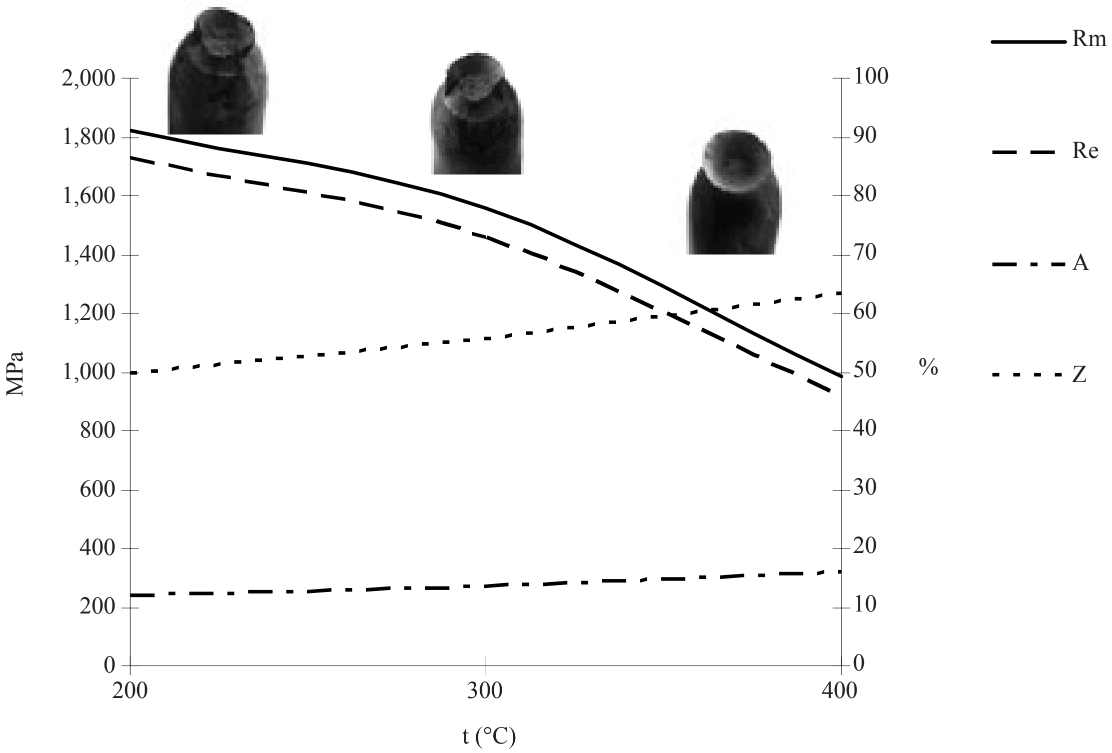
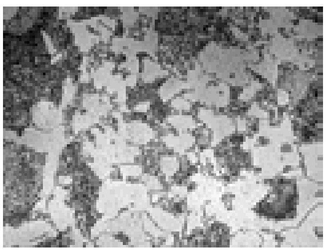


Fig. 3. The tempering diagram of the steel 12 042

The transite temperatures of heat untreated 12 042 steels are relative high (over 20°C) and the use in this state is impossible at the dynamic stress. At static stress the whole dependence shifts to lower temperatures, because it depends not only on the structure and the grain size but mainly on the strain mode and rate.

The steel 12 042 heat treated (Fig. 4d) by tempering to superior strength shows the transite temperature in Fig. 5. Above –40°C temperature only tough fractures occur, the risk of the brittle fracture does not occur. The toughness of in this way heat treated steel increases with increasing temperature, but the tensile strength and the yield point decrease. At the martensitic or tempered-martensitic structure the curve has no transite range, but the impact energy values KV increase with increasing temperature practically linear. At the value decrease of yield strength owing to the tempering temperatures (see Fig. 3) the KV values and the curves course at the tempering temperatures 200°C and 300°C differs only imperceptible, e.g. the KV values difference at °C temperature is approximately 5 J.

Using heat treatment of this steel we reach both the strength properties and at the same time the transite temperature decrease compared to the heat untreated state. All arguments are for the use of this steel in the heat treated state and the suitability of this steel for heat treatment is evident.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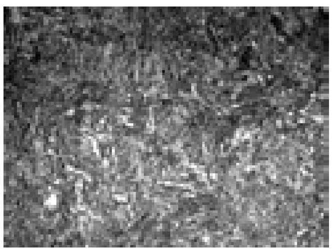
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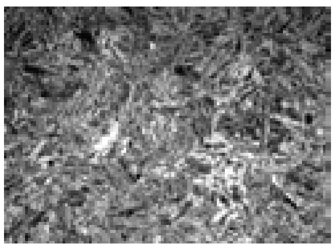
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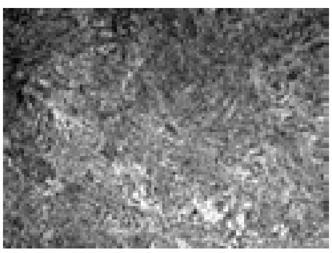
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Fig. 4a. Ferritic-pearlitic structure, partial spheroidized pearlite

Fig. 4b. Partial tempered martensite

Fig. 4c. Tempered martensite with partial cancelled acicular structure

Fig. 4d. Sorbite without free ferrite ferritic-pearlitic structure

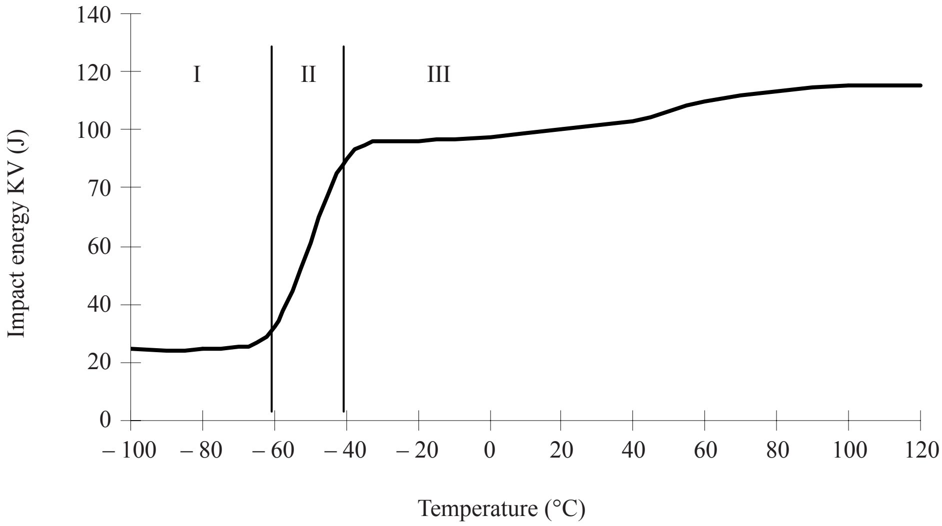

Fig. 5. The impact energy – temperature dependence of 12 042 steel heat treated to the superior strength

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Received for publication August 9, 2004
Accepted after corrections October 29, 2004

Vliv tepelného zpracování na mechanické vlastnosti oceli

ABSTRAKT: Příspěvek se věnuje tepelnému zpracování ocelí, vlivu tepelného zpracování na pevnost a houževnatost ocelí. V příspěvku jsou prezentovány dílčí výsledky zkoušek oceli 12 042.

Klíčová slova: tepelné zpracování; pevnost; houževnatost

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