Influence of heat exposition on the transition behaviour of the steel 21MnTiB

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Abstract: Owing to operations the construction materials change their properties. The material properties and characteristics are considered as the most important. One of properties is the toughness of the used material. Toughness of steel as one of construction materials is expressively temperature–dependent. This dependence – transition behaviour, can vary in dependence of degradation processes which proceed in the material. This paper concerns the problem of the transition behaviour changes of the steel 21MnTiB in dependence on the heat treatment and heat exposition.

Keywords: steel; impact energy; transition curve

Polymorphism of iron, changes in alloying metals solubility connected with phase transformations and with temperature decrease together with very different values of interstitial and substituting elements diffusivity are the causes of considerable variability of possible phase transformations of these alloys. Heat treatment realizes the positive utilization of phase transformations. In this way it is possible to modify the iron alloys properties in a large extent. On the other hand the steel ageing is the example of the phase transformation undesirable effects (Kettunen & Kuokkala 2003).

The continual precipitation comes in solid solutions (ferrite, austenite, martensite), which become to be oversaturated in the course of changes in temperature. In the case of martensite or retained austenite the nonequilibrium state arises in the course of the martensitic transformation and in the course of tempering the continual precipitation occurs. The nonequilibrium stage can be classified in four basic stages.

The first tempering stage (up to 200°C) is the tetragonal martensite disintegration in the low carbon cubic martensite and the nonequilibrium carbide ε ($Fe_{2,4}C$) with close arranged hexagonal lattice. The coherent carbide ε ($Fe_{2,4}C$), which prefers the precipitation at the martensite boundaries, has the expressive hardening effect, which compensates for the greater part the hardness decrease, which is caused by the decrease of the interstitial martensite, is accompanied by only a mild hardness and strength decrease.

The second tempering stage (about 200 to 300°C) includes the retained austenite disintegration in the bainitic type structure, which looks like the martensite structure heated to up the same temperature. This change is accompanied by the specific volume increase, the heat liberation and the internal stress decrease. The consequence of the retained austenite disintegration is either the reduction of the steel hardness decrease or its increase, but only at the retained austenite high content (Brooks 1979; Budinski 1979).

The third tempering stage (over 300°C) includes especially the cementite creation and contemporary the low carbon martensite disintegration in the ferrite structure. The coherent nucleated cementite precipitates increase gradually with the contemporary dissolving of the ε carbide particles and with the gradually decrease of the carbon content in the matrix. The originally cementite rods configuration get coarse with the increasing tempering temperature. The expressive monotonic hardness and strength decrease and contemporary the ductility and formability increase is the consequence of the above mentioned changes.

The fourth tempering stage (over 500°C) includes at carbon steels the coarsening of cementite particles owing to its consecutive coalestition, spheroidizing, recrystallisation and the ferrite grain coarsening. At low-alloy steels the cementite enriches itself with carbide creating elements. At alloy steels the creation of special carbides of the lattice different from cementite occurs. Precipitation of these carbides is conditioned by diffusion of substituting elements, which create these carbides (Brooks 1979; Hertzberg 1989; Ptáček 1999).

But after tempering the disintegration of the solid solution does not end and it proceeds slower or rapider in dependence on the temperature (Owen & Fawkes 1983).

MATERIAL AND METHODS

For the evaluation of the thermal exposition influence on the transition behaviour the steel 21MnTiB was chosen. The chemical composition is presented in Table 1. Before the heat treatment the steel was of ferritic-pearlitic structure (Figure 1).

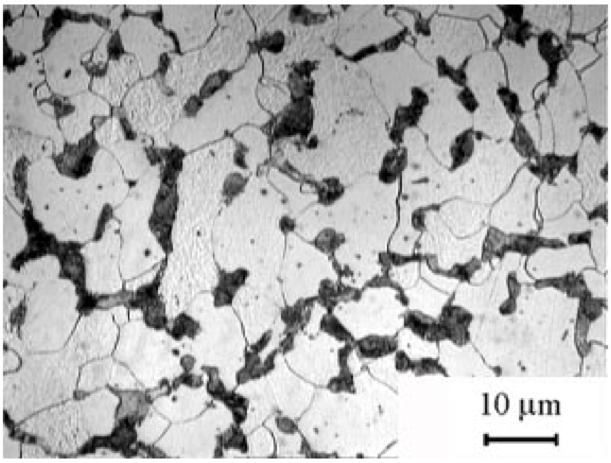

Figure 1. Ferritic-pearlitic structure, fine-grained laminated to transition pearlite

The steel 21MnTiB was heat treated using the standard process to various strengths (hardened from 880°C into oil, aftercooling in water, tempering at 200°C (Figure 2), 300°C (Figure 3), 400°C (Figure 4).

After the heat treatment the relations between strength point and tempering temperature and between yield point and tempering temperature were determined, as it is presented in Figure 5.

The transition behaviour of the steel 21MnTiB was determined using the Charpy notched – bar impact test (ČSN EN 10 045-1) and the standard specimens in the range of temperature which fully

Table 1. Chemical composition of 21MnTiB steel (weight percentage)

C	Mn	Si	B	Cu	Ti	Al	P
0.2	0.89	0.09	0.005	0.057	0.015	0.03	0.015

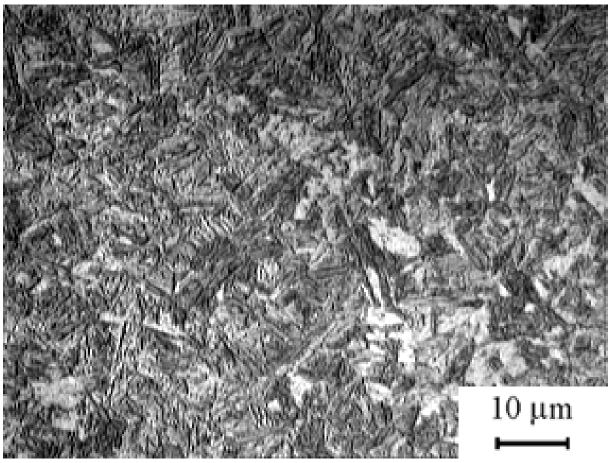

Figure 2. Tempered martensite very fine retained austenite with

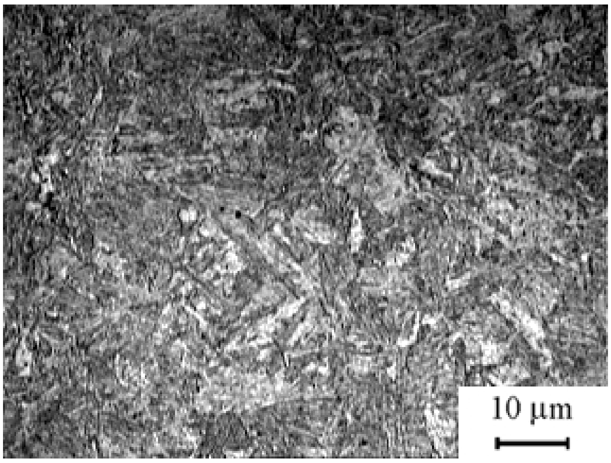

Figure 3. Sorbitic structure oriented according to primary martensite needles

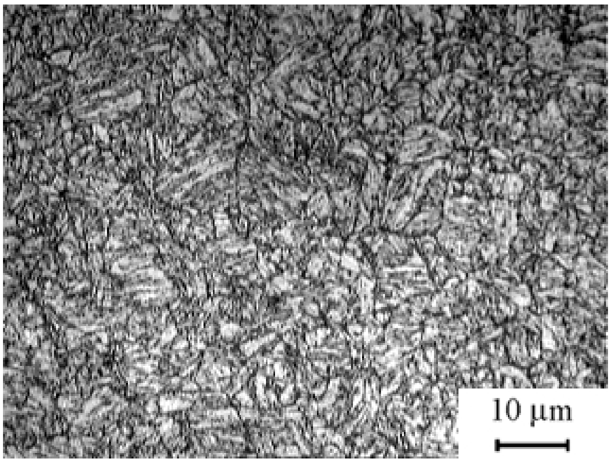

Figure 4. Perfectly tempered sorbitic structure

includes the transition range. The impact energy values determined when testing, related to the test temperature, were plotted by a suitable curve using the least-squares method (Chotěborský 2005).

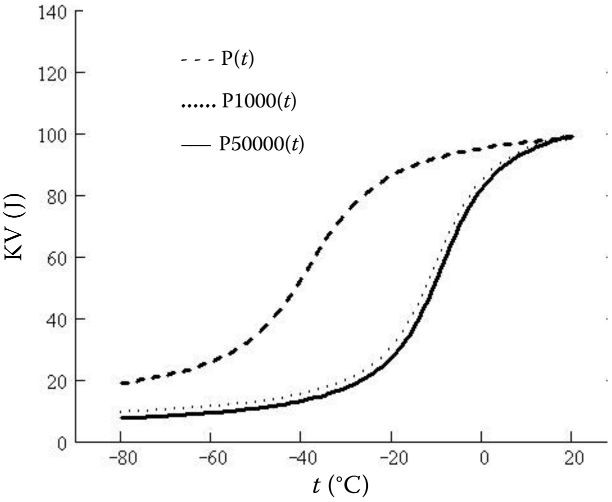

Figure 6. Transition curves of the steel 21MnTiB tempered at 200°C, P(*t*) – without ageing and at ageing temperature 100°C, P1000(*t*) – ageing time 1000 h, P5000(*t*) – ageing time 5000 h

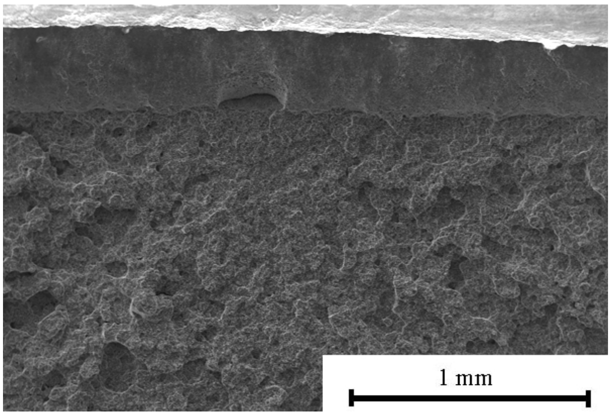

Figure 8. Local view of the fracture surface from Figure 7

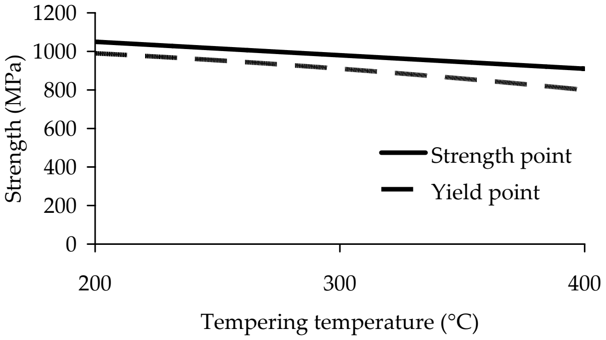

Figure 5. Tempering diagram of steel 21MnTiB

RESULTS

The measured curves of the steel 21MnTiB, improved by heat to the high strength (tempering temperature 200°C), are presented in Figure 6.

Figure 7. Fracture surface appearance of the specimen tempered at 200°C after the test at −65°C

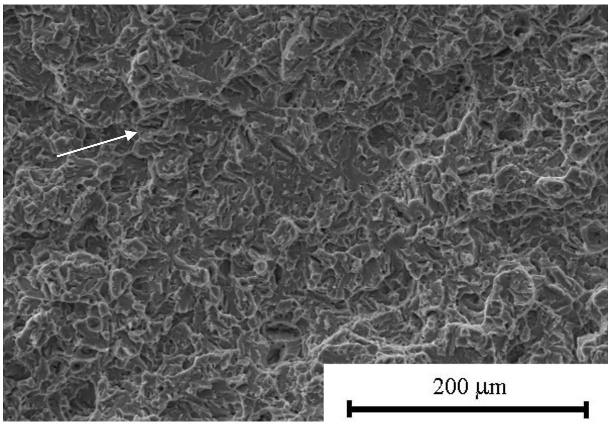

Figure 9. Local view of the fracture surface from Figure 8, the crowfoot points to the place of the cleavage fracture initiation

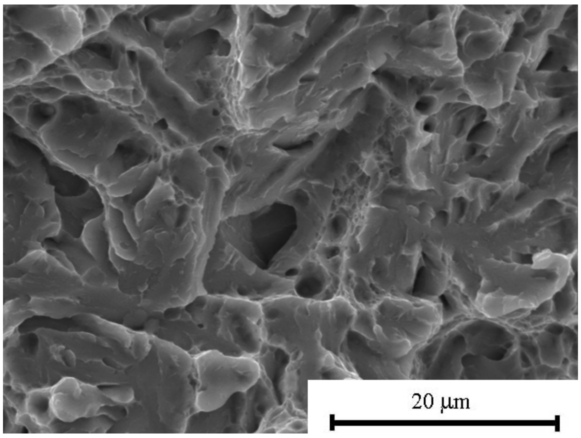

Figure 10. Local view of the fracture surface from Figure 9, the place of initiation

Under the transition range the brittle failures occur, as it is shown in Figure 7 (item of this fracture is shown in Figures 8–11). Over the transition temperature were ductile fractures, as it is shown in Figure 11.

The measured transite curves of the improved steel 21MnTiB (tempering temperature 300°C) are presented in Figure 12.

The measured transition curves of the improved steel 21MnTiB (tempering temperature 400°C) are presented in Figure 13.

At the specimens tempered at 400°C it was found that the primary sorbitic structure crumbled owing to the heat exposition, as it is shown in Figure 14.

By disintegration of the primary structure the change of the fracture surface appearance can be explained. At specimens without the heat exposition only brittle or tough fractures appear (Figure 15), but

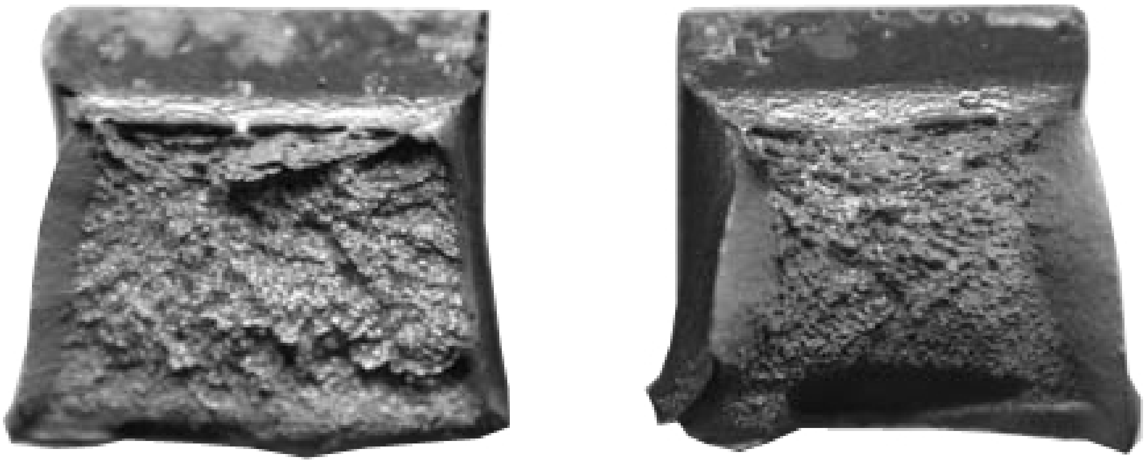

Figure 11. Fracture surface appearance of the steel 21MnTiB tempered at 200°C without the heat exposition at the test temperature (from left to right) –40°C and 20°C.

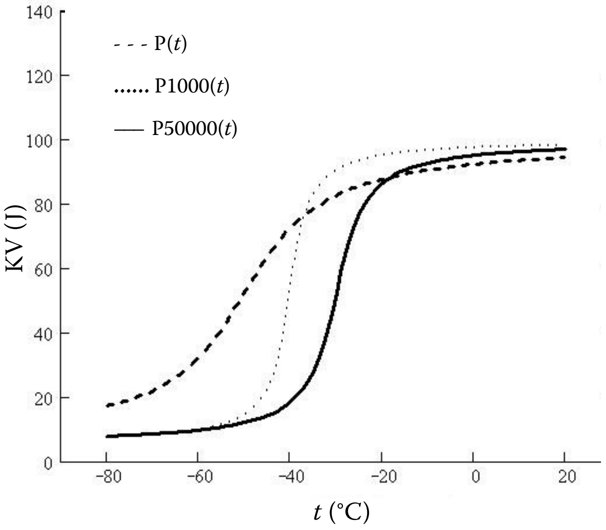

Figure 12. Transition curves of the steel 21MnTiB tempered at 300°C, P(*t*) – without ageing and at ageing temperature 100°C, P1000(*t*) – ageing time 1000 h, P5000(*t*) – ageing time 5000 h

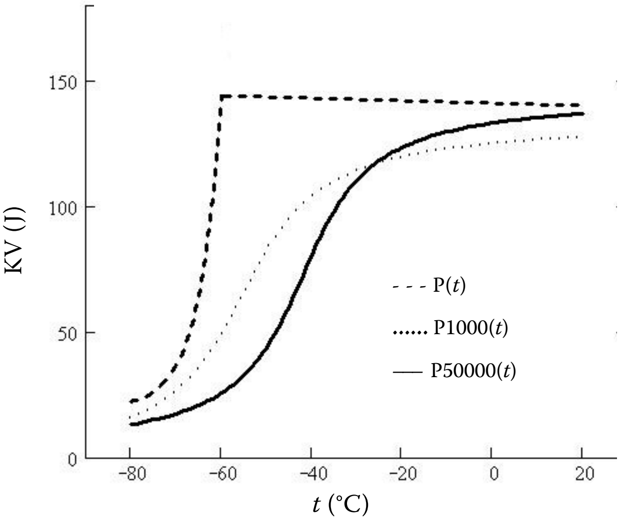

Figure 13. Transite curves of the steel 21MnTiB tempered at 400°C, P(*t*) – without ageing and at ageing temperature 100°C, P1000(*t*) – ageing time 1000 h, P5000(*t*) – ageing time 5000 h

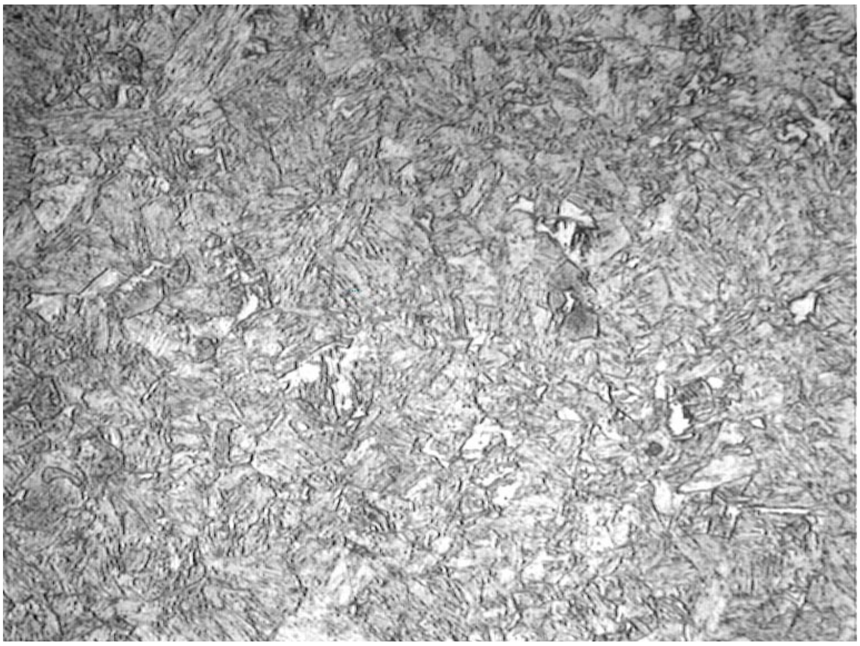

Figure 14. Appearance of the primary sorbitic structure after the 5000 h exposition of 100°C for 5000 h; except the sorbite the ferrite appears

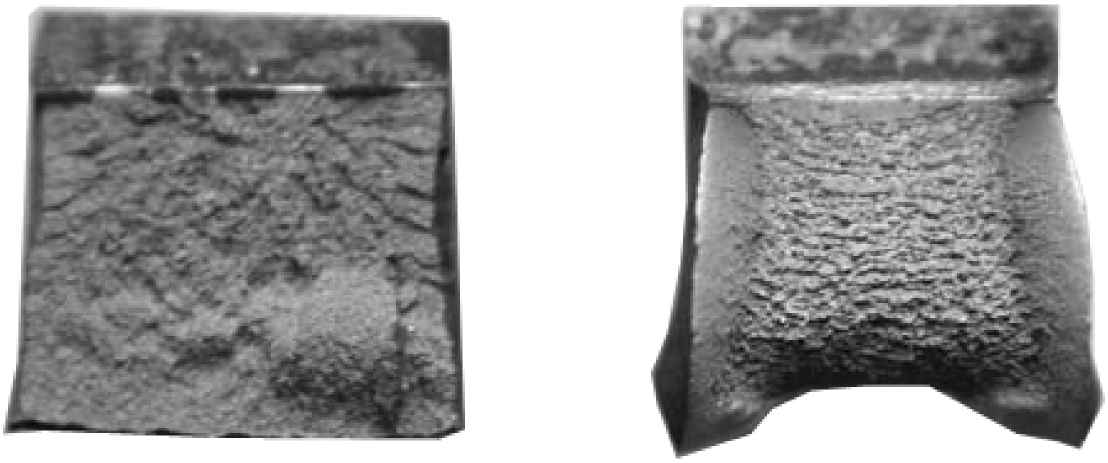

Figure 15. Appearance of the fracture surface of the steel 21MnTiB tempered at 400°C without the heat exposition at the test temperature (from left to right) –80°C and –60°C

Figure 16. Fracture surface appearance of the steel 21MnTiB tempered at 200°C after the heat exposition of 100°C for 5000 h; test temperature –40°C

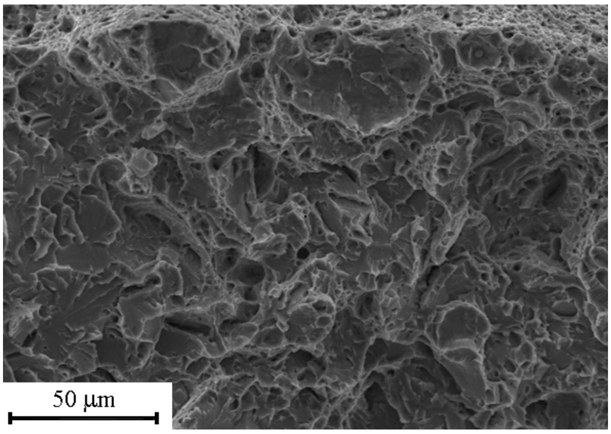

Figure 17. Of the fracture surface from Figure 16 local view; test temperature –40°C

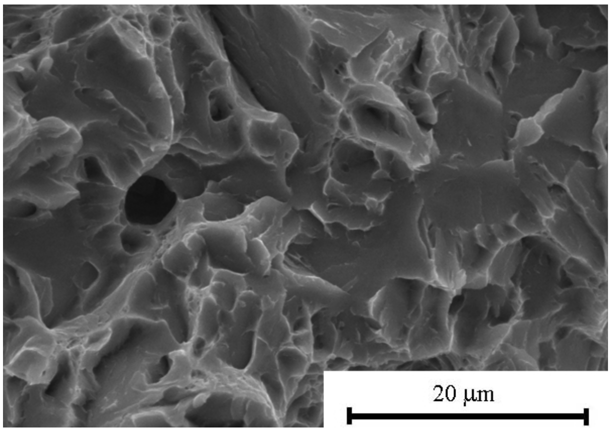

Figure 18. Local view of the fracture surface from Figure 17

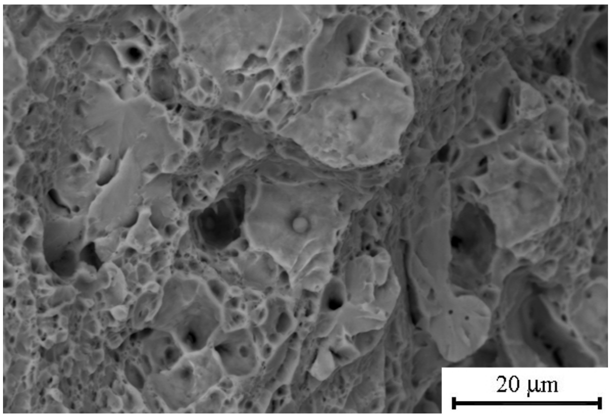

Figure 19. Local view from Figure 16 on the ductile fracture surface (Figure 16); complex carbide in the pit of the ductile failure

owing to sorbite disintegration the classic transition zone with the semibrittle fracture occurrence begins to appear. The semibrittle fracture is shown in Figure 16 (item of this fracture is shown in Figures 17 and 18).

CONCLUSION

Owing to the heat exposition the change of the steel 21MnTiB transition behaviour (as it is shown in Figure 6) is above all induced by the retained austenite disintegration of the primary structure (Figure 2). When we trace the transition temperature change as the inflexion point of the transition curve (Figure 20) we come to the conclusion that owing to the heat exposition the transition temperature increases from original –38°C to –10°C after the time of 5000 hours. It means that the transition temperature increases of 28°C compared to the original value after the heat treatment.

When we heat treated this steel and the resultant structure was as it is presented in Figure 3, in the course of the heat exposition not only the retained austenite disintegration occurs, but the tempered martensite disintegration occurs, too. Owing to these processes the transition temperature increased from the primary –50°C to –30°C after 5000 hours. With the tempered martensite disintegration the mean value of impact energy of tough ruptured specimens increased, too.

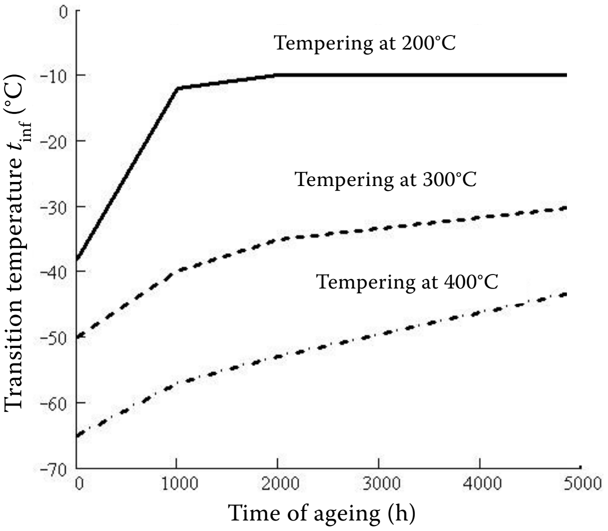

Figure 20. Comparison of the relation between transition temperature and ageing time at various tempering temperatures

When after the heat treatment the resultant structure was according to Figure 4, in the course of the heat exposition the disintegration of the sorbitic structure in its primary components occurs. It is presented in Figure 14. The precipitation of complex carbides (Fe, Cr) (Figure 19) occurs in the course of the sorbitic structure disintegration. Their chemical composition is presented in Table 2. Owing to these processes the transition temperature increases from –65°C to –42°C.

Table 2. Chemical composition of the carbide and of the near neighbourhood of the carbide

	Al	Si	Ti	Cr	Mn	Fe
Carbide	0.11	0.15	0.17	0.22	1.33	98.02
Near neighbourhood of the carbide	0.09	0.11	0.14	0.0	15.47	84.19

Owing to the precipitation the near neighbourhood of this carbide deprived of ferrum and chromium and its chemical composition is presented in Table 2.

The method of heat treatment affects not only the transition temperature, but above all the rate of the transition temperature change in dependence on the heat exposition time.

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Abstrakt

Chotěborský R., Müller M., Medlín R., Hrabě P., Herák D. (2006): **Vliv tepelné expozice na tranzitní chování oceli 21MnTiB**. Res. Agr. Eng., **52**: 156–162.

Konstrukční materiály vlivem provozních podmínek mění svoje vlastnosti. V konstrukci jsou za nejdůležitější vlastnosti považovány materiálové vlastnosti a charakteristiky. Jednou z vlastností je i houževnatost materiálu použitého na konstrukci. Houževnatost konstrukčního materiálu, jako je ocel, je výrazně závislá na teplotě. Tato závislost, tranzitní chování, se může měnit v závislosti na degradačních procesech probíhajících v materiálu. V článku se věnujeme problematice změny tranzitního chování oceli 21MnTiB v závislosti na druhu tepelného zpracování a vlivu tepelné expozice na tuto ocel.

Klíčová slova: ocel; nárazová práce; tranzitní křivka

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