KINETICS OF ISOTHERMAL TRANSFORMATION OF HIGH-CARBON LOW-ALLOYED AUSTENITE AND ITS MICROSTRUCTURE AFTER SUCH TREATMENT

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Abstract

In this study experiments were carried out on the kinetics of transformation of high-carbon low-alloyed austenite with carbon mass percentage of 1.2% and manganese mass percentage of 3% in the temperature range from 200 to 300 °C. It was found, that at 200°C austenite transformation starts after $5 \times 10^5$ s; after $5 \times 10^6$ s the content of the $\alpha$-phase reaches a level of 94%. A further increase in processing temperature results in shorter incubation periods but significantly lower completeness of transformation. A modification of the chemical composition of the austenite phase also results in higher transformation speed. So for a composition of austenite with 1.2 %C, 3 %Mn and 2 %Si heat treatment at 250-270°C allowed to obtain hardness levels of 400HV as fast as after 1 day. It could be observed a difference in fine structure of bainite resulting from transformation of austenite without silicon and austenite with silicon mass percentage of 2%. Silicon favours the formation of long and very thin bainite platelets with plate thicknesses in the range of 60-150 nm.

In (1, 2) results of experimental studies on abrasion resistance of steels and cast irons were demonstrated. It was shown, that maximum abrasion resistance of iron-based alloys is obtained by materials with high carbon metastable austenite matrix, which is much higher than abrasion resistance of non-tempered martensite with 0.8%C and of hard steels after thermo-mechanical treatment (3). A low alloyed steel with 1.2 %C and 3 %Mn was proposed which consist of practically 100% of high carbon metastable austenite after quenching from temperatures in the range 950-970°C. This relatively cheap material shows a very high abrasion resistance.

It is a known fact, that tempering of austenite at temperatures above martensite start point causes the formation of some specific structure (4) named bainite since 1942 (5). If the temperature of such treatment is quite low (in the range 200-300°C), a unique combination of mechanical strength and ductility may be obtained (6). Experiments on this subject were carried out for steels with carbon content of 0.8%. The aim of the current study is the experimental investigation of the transformation kinetics of low-alloyed austenite with carbon content of 1.2% in the temperature range 200-300°C. In case that transformation speeds are technologically acceptable, the range of application of the proposed steel 120Mn3 will be spread much wider: high abrasion resistance material after quenching from 950-970°C to metastable austenite state and high strength material after additional tempering on bainite structure with optimum parameters.

Experiments were carried out on two materials with different chemical composition according to Table 1. Tempering was done in a programmable muffle furnace with temperature measurement by a type-K thermocouple. Phase composition was analysed on Rigaku Ultima IV and Bruker D8 ADVANCE diffractometers. For observation of the microstructure a Carl Zeiss Jena optical microscope Neophot 32 and a Zeiss scanning electron microscope Ultra 55 were used. Hardness measurements according to Vickers were performed by ТВП-5012 and Fischerscope hardness testers.
At the first step of the investigations kinetics of bainite formation were studied on steel 120Mn3 according to Table 1, alloy №1 at a temperature of 200°C in order to clarify the principal technological feasibility of such heat treatment on austenite with 1,2% carbon mass percentage.

Table 1 - Chemical composition of experimental steels in wt.%

<table>
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<tr>
<th>Alloy №</th>
<th>Elements</th>
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Specimens of alloy №1 were quenched into water from 950 °C. The metallic matrix after such treatment was pure austenitic (Fig. 1), hardness was 260 HV.

Figure 1  Diffractogram of steel 120Mn3 after quenching from 970°C

Kinetics of the austenite - bainite transformation of 120Mn3 steel are shown on Fig. 2, a. Diffractogram of the material after maximum time of tempering (5x10⁶ s or 57 days) is demonstrated on Fig. 3. After such treatment the metallic matrix of the material consists of ~ 94% α-phase.

The experiment gives rise to the following conclusions: Transformation starts after 5x10⁵ s or 5,8 days and continues with sufficient speed until 10⁶ s or 11,6 days (obtained hardness of 550 HV) slowing down then significantly further increasing the hardness to a level of 600HV after 5x10⁶ s or 57 days.
The result obtained is in good conformance to those got earlier on steels with very similar composition by Houdremont (7).

In the next step a more detailed investigation of the transformation kinetics of austenite of the alloys №1 and №2 (Table 1) was performed. It is a well recognised fact, that silicon suppresses the formation of cementite in bainite (6), so steel №2 was alloyed by some amount of silicon targeting to get a structure without cementite.

The specimens were quenched from 970 °C (№1) and 1000°C (№2). The hardnesses after quenching were 220HV (alloy №1) and 260 HV (steel №2). In steel alloy №2 some amount of coarse martensite needles could be observed (Fig. 4). Probably this results from the fact that the martensite start temperature in steel of that chemical composition is slightly above room temperature.
After quenching specimens of steels №1 and №2 were tempered at temperatures 250°C, 270°C and 300°C. A map demonstrating the kinetics of isothermal austenite-bainite transformation was obtained as demonstrated on Fig. 5. We emphasise the interesting fact that on steel №2 a hardness of 400 HV was reached by treatment at temperatures 250°C and 270°C after just 1 day, which is quick enough for such kind of thermal processing. This thermal processing is broadly used for treatment of cast iron to get so called austempered, bainitic or ausferritic ductile iron which combines high strength and ductility even at a hardness level of 300 HV (8).

![Figure 4](image1.png)  
**Figure 4**  
Microstructure of steel №2 after quenching from 1000°C into water, microscopic magnification 400x

![Figure 5](image2.png)  
**Figure 5**  
Hardness map of steels 120Mn3 and 120Mn3Si2 after quenching into austenitic state and isothermal tempering at different temperatures
Investigation of the microstructure of alloys №1 and №2 after quenching on austenite and isothermal tempering showed significant differences. These differences are visible even in optical microscope at quite low magnifications as shown on Fig. 6 and Fig. 7.

**Figure 6** Structure of steel 120Mn3 after quenching on austenite and tempering at 250°C for 4 days, microscopic magnification 400x

**Figure 7** Structure of steel 120Mn3Si2 after quenching on austenite and tempering at 250°C for 4 days, microscopic magnification 400x

At a 400x microscopic magnification the bainitic regions in steel 120Mn3 are dark areas without distinguishable fine structure whereas in steel 120Mn3Si3 long and very thin platelets mainly consisting of ferritic phase can be observed. The differences in fine structure of bainite become more obvious at higher magnification levels (Fig. 8 and Fig. 9).
Figure 8  Microstructure of steel 120Mn3 after quenching and isothermal tempering at 200°C; magnifications a) 5000x; b) 10000x; c) 20000x
**Figure 9**  Microstructure of steel 120Mn3Si2 after quenching and isothermal tempering at 250°C; magnifications a) 2000x; b) 15000x; c) 25000x
Summarising the obtained results there was demonstrated a new area of application of low-alloyed high-carbon steels quenched into austenitic state beyond usage at high abrasion loads, namely additional isothermal tempering at temperatures in the range 200°C – 300°C leading to sufficient hardening after processing times suitable for technological operations. Therefore to get closer to real practical applications some directions of further investigations can be proposed as follows:

1. Tests for the definition of mechanical properties of steels 120Mn3 and 120Mn3Si2 after quenching into austenite and isothermal tempering at temperatures in the range of 250°C-270°C up to different hardness levels (300 HV, 400 HV, 500HV).
2. Investigation of the fine structure of steels 120Mn3 and 120Mn3Si2 after such heat treatment.
3. Investigation of the influence of such heat treatment on the abrasion resistance of these steels.

**Literature**