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# The kinetics of phase transformations during tempering in structural steels with nickel

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**Abstract:** The kinetics of phase transformations during continuous heating (tempering) from quenched state by means of the CHT (Continuous Heating Transformation) diagrams was presented. On these diagrams ranges of temperatures of ε carbide and cementite precipitation and retained austenite transformation were marked. The effect of chemical composition and cooling rate on ranges of temperatures these transformations were determined. For investigation four model alloys of the variable concentration of Ni and constant concentration of carbon and other elements were used.

**Keywords:** CHT diagram, ε carbide, Cementite, Retained austenite

## 1. INTRODUCTION

The kinetics of phase transformations during tempering of steel by means of the CHT (Continuous Heating Transformation) diagram was executed for the first time in the work [1]. The results of this investigation, for high-speed steel, were used for optimum heat treatment technology of these steels for improved properties, especially fracture toughness [2].

In the works [3,4,5] the effect of Mn, Si, Cr and V on the kinetics of phase transformations during tempering of structural steels were described. It was observed that in the range of low concentrations (to about 1%) these elements have no effect on cementite precipitation and transformation of retained austenite. Higher concentrations of these elements raised the range of these transformations towards higher temperatures.

In this work the investigations of the kinetics of phase transformations during tempering on four model alloys of the variable concentration of nickel were executed.

## 2. MATERIALS AND HEAT TREATMENT

For investigations the authors used four model alloys of constant concentration of C (about 0,30%) and the variable concentration of Ni (0,33÷4,10%). The concentration of other elements was kept constant. Table 1 presents the chemical compositions of the tested alloys.

The samples in the form of cylinder ϕ2×12 mm, made of the above alloys, were quenched in water (alloy No 1÷4) or at cooling rate 10°C/s (alloy No 3 and 4) from the temperatures:

alloy No 1 - 855°C    alloy No 2 - 830°C
alloy No 3 - 800°C    alloy No 4 - 805°C

These temperatures, higher than $Ac_3$ + 50°C, were determined in [6]. The samples quenched in this way were heated in the dilatometer grip at the following rates: 0,05; 0,1; 0,5; 1; 5; 10; 15; 35°C/s up to 700°C (alloy No 1÷3) or to 665°C (alloy No 4).

Table 1.
Chemical compositions of the tested alloys

| Alloy No | % by mass | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | S | Cr | Ni | Mo | Al | Cu |
| 1 | 0,28 | 0,79 | 0,24 | 0,020 | 0,020 | 1,65 | 0,33 | 0,35 | 0,02 | 0,14 |
| 2 | 0,30 | 0,78 | 0,24 | 0,015 | 0,025 | 1,62 | 1,00 | 0,40 | 0,04 | 0,07 |
| 3 | 0,31 | 0,73 | 0,15 | 0,008 | 0,016 | 1,59 | 2,50 | 0,35 | 0,03 | 0,03 |
| 4 | 0,31 | 0,78 | 0,17 | 0,020 | 0,020 | 1,45 | 4,10 | 0,35 | 0,02 | 0,13 |

## 3. INVESTIGATION METHODS

The DT-1000 dilatometer, manufactured by Adamel, was used for investigating the kinetics of phase transformations during tempering (at continuous heating). The changes of relative lengthening $\Delta l/l_o$, depending on the temperature T, were recorded. As it was possible to differentiate these curves, it facilitated determining the temperatures of beginnings and ends of respective transformations.

## 4. INVESTIGATION RESULTS AND DISCUSSION

The CHT diagram of tested alloy No 1÷4 determined based on dilatograms of heating samples from quenched state. Continuous lines denote the ranges of ε carbide and cementite $M_3C$ precipitation while broken lines denote the range of the transformation of retained austenite, additionally gray.

As it can be seen, the increase of Ni concentration from 0.33% to 4.10% in tested alloys has the weak effect on the ranges of transformations during tempering.

The temperature of the beginning of the ε carbide precipitation $\varepsilon_s$ raises from about 80°C to about 110°C and the temperature of the end of its precipitation $\varepsilon_f$ raises from about 180°C to about 270°C with increasing the heating rate from 0.05°C/s to 35°C/s. Stronger contraction in the range of ε carbide precipitation for alloys with higher Ni content (alloys No 2, 3 and 4) would suggest that nickel can extend intensity of ε carbide precipitation, but the temperature Ms of these alloys is lower, according to the date of [6] is 315÷280°C and for alloy No 1 (0.33% Ni) this temperature equals 370°C. The higher temperature Ms in alloy No 1 could cause the ε carbide to start precipitate during cooling at quenching.

The fact of distinct contraction in the range of ε carbide precipitation in tested alloys would be unexpected, although according to [7] the concentration limit of carbon above which the ε carbide should precipitate is 0.2%, but in the investigation [3] this precipitation would not be observed in steel with 0.3% C and 0.8% Mn. Most likely, Ni, Cr and Mo addition in steel could increase ε carbide precipitation during tempering.

Analyzing the range of the temperatures of the cementite precipitation in tested alloys it can be observed that nickel have weak effect on it. Higher concentrations of Ni in alloys 3 and 4 (2,50% and 4,10%) caused slight reduction of the temperatures of the beginning and the end of cementite precipitation. For the heating rates about 0.5°C/s these temperatures are, respectively:

for the alloy No 1 (0.33% Ni) 250°C and 450°C
for the alloy No 2 (1.00% Ni) 250°C and 450°C

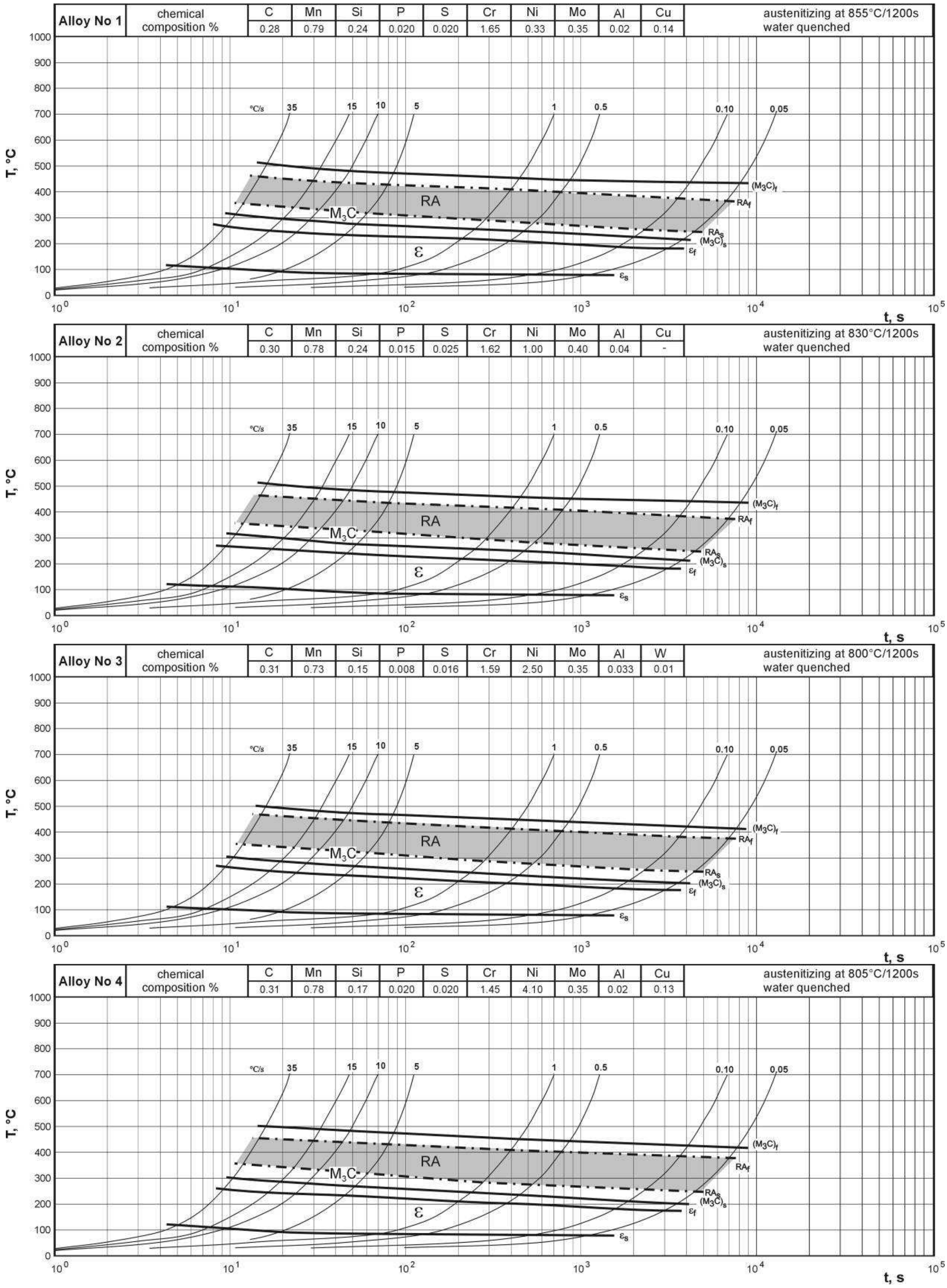


Figure 1. The CHT diagrams of the tested alloys No 1÷4

for the alloy No 3 (2.50% Ni) 235°C and 435°C
for the alloy No 4 (4.10% Ni) 235°C and 435°C

Increasing the heating rate from 0.05°C/s to 35°C/s raises the range of cementite precipitation by about 100°C.

The range of transformation of retained austenite RA is included in the range of cementite $M_3C$ precipitation in the all tested alloys and the increase Ni concentration does not affect meaningly on its location.

Moreover the investigation of kinetics of phase transformations during tempering (at continuous heating) after quenching at cooling rate 10°C/s for alloys No 3 and 4 were performed. These alloys, for the sake of higher Ni concentration, have higher hardenability [6]. The lower cooling rate caused the weaker contraction in the range of ε carbide precipitation. It is probably the result of self-tempering during quenching. Also the lower cooling rate caused the growth of the length of a sample in the range of the transformation of retained austenite, which would be result of forming the areas of higher carbon content during quenching, where remain more retained austenite.

## 5. CONCLUSIONS

The investigations of the kinetics of phase transformations during tempering of structural steel with the variable concentration of Ni proved that:

1. The increase of Ni concentration from 0.33% to 4.10% in tested alloys has no effect on the range of the temperatures of ε carbide precipitation.
2. The increase of Ni concentration to about 2.50% lowers the range of cementite precipitation by about 15°C.
3. Increasing the heating rate from 0.05°C/s to 35°C/s raises the range of cementite precipitation and retained austenite transformation by about 100°C.
4. The tested alloys, because of high Ms temperatures, are willing to self-tempering.

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