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The influence of continuous heating rate on the austenite formation in the medium carbon TRIP steel

A. Kokosza*, J. Pacyna, P. Bała, R. Dziurka
Faculty of Metals Engineering and Industrial Computer Science,
AGH-University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland
* Corresponding e-mail address: akokosza@agh.edu.pl

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ABSTRACT

Purpose: The purpose of the hereby work was to determine the influence of heating rate on the austenite formation range and to draw the time-temperature-austenitizing diagram at continuous heating for TRIP 41MnSi6-5 steel.

Design/methodology/approach: The dilatometric analysis was applied as the basic investigation method. Samples of the tested steel were heated to 1100°C with various heating rates. Changes in the relative elongation (ΔL) were recorded as a temperature function (T), during heating. On the basis of analysing such dependencies, for each heating rate the critical temperatures were determined.

Findings: It was found, that during heating of the 41MnSi6-5 steel the austenite formation starts at the higher temperature the faster is

the heating. It was observed, that directly before the start of the austenite formation, an unidentified (in the presented here investigations) transformation occurs in the investigated steel, causing its volume increase.

Research limitations/implications: The performed investigations indicate that during heating of elements of small thickness or cross-sections - within the critical temperature range - the method of their heating to the required temperature becomes very important. At short heating times incorrectly selected the heating conditions can be the reason of significant errors of the heat treatment.

Practical implications: The developed diagram: time-temperature-austenitizing, at a continuous heating (CHT), can be a useful tool supporting the proper selection of heating parameters within the critical temperature range.

Originality/value: The dependence of the heating rate and the temperature range, in which austenite is formed in the tested 41MnSi6-5 steel, was found. It was observed that heating of the investigated steel with rates lower than 1°C/s has an insignificant influence on the temperature range within which the austenite formation occurs.

Keywords: Dilatometric analysis; CHT Diagrams; Heat treatment; Critical temperatures; TRIP steels

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Multiphase steels with mechanically unstable retained austenite belong to materials, which are effectively meeting expectations of modern industries. These steels can be successfully applied in situations where the material is required to have a good formability and when it is finished-good strength properties.

During their formation steels are strengthened due to a plastic austenite transformation into a strength martensite. From this type of transformation these steels are called the TRIP steels (TRansformation Induced Plasticity) [1-8]. Their chemical composition is the reason that these materials are not expensive and the basic problem (and cost) at their production is the properly selected and performed heat treatment, which is schematically presented in Fig. 1. Properly performed heat treatment of sheets or profiles, produced from this type of steel should allow to create in them a microstructure consisting of ferrite, martensite or bainite and-first of all-large amounts (5-15% vol.) of mechanically unstable retained austenite. Such microstructure should ensure the produced elements suitable properties, it means a high plasticity and after the plastic working also a high strength [9-12].

The development of optimal, without defects and easy for implementation heat treatment technology for TRIP steels is not an easy task. First of all - such technology should allow leaving in the microstructure the mentioned above structural components in proper proportions. On the other hand - the selection of optimal parameters of heating, soaking and cooling should take into account the chemical composition of melted steel, size (thickness) of treated elements, technical conditions available at their producers as well as expectations of customers.

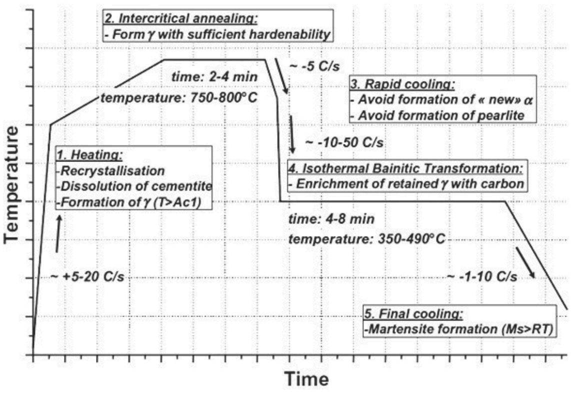

Fig. 1. The scheme of heat treatment for cold rolled TRIP steel: the main features of the 5 processing stages are indicated [13]

Especially difficult can be the exact determination of soaking parameters of the TRIP steel in a range of critical temperatures, to which the stage 2 in Figure 1 corresponds. At different sizes of heat treated elements, already at the stage 1 of the heat treatment (see Fig. 1) problems with the proper selection of this process parameters can occur. In an extreme situation, at short soaking times, the results of these problems will be the lack of expected changes in the soaked element regardless of obtaining the optimal temperature. It can happen in such a way since with an increased heating rate the critical temperatures can be changed, as it was shown in Figure 2a.

In addition, at selecting of the proper heating temperature-especially in the range between Ac_1 and Ac_3-it should be taken into account, that in steels due to the presence of alloying elements one should not talk about the constant Ac_1 value but about its range given by Ac_{1s} and Ac_{1f} (see Fig. 2b).

The detailed dilatometric analysis of transformations occurring in the steel microstructure can help in the proper selection of steel heating parameters within the critical temperature range. On its basis it is possible not only to determine the heating rate influence on the range of the austenite formation in the soaked steel but also to prepare the transformation kinetics diagram at continuous heating, called the CHT (Continuous heating transformation) diagram [14,15].

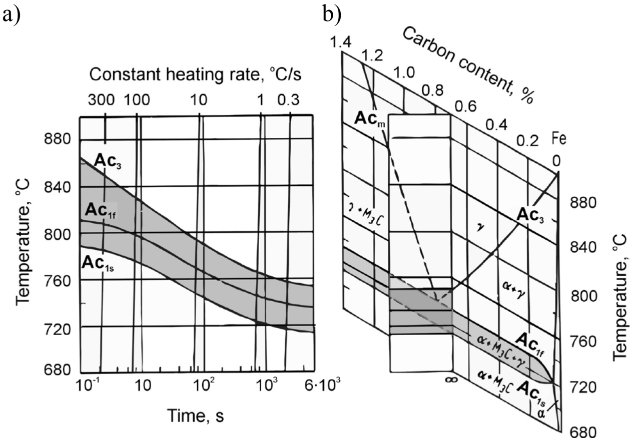

Fig. 2. The influence of heating rate on the changes of hypoeutectoid steel critical temperatures (a) and position Ac_{1s} temperature and Ac_{1f} in the Fe-C diagram (b) [14]

Knowledge of the CHT diagrams, especially transformation ranges: pearlite→austenite and ferrite→austenite, should contribute to an easier and more precise determination or selection of TRIP steel heating parameters within the critical temperature range. Owing to the CHT diagrams it is possible to adjust parameters of this procedure to size or thickness of soaked elements and to perform such soaking in the technological lines of steel manufacturer.

2. Material for tests

Investigations were performed for the TRIP steel, which chemical composition is given in Table 1. On the bases of the most important elements content, in accordance with the standard PN-EN10027, this steel grade is: 41MnSi6-5.

Table 1.
The chemical composition of the investigated 41MnSi6-5 steel

The mass content of elements, %										
C	Mn	Si	S	P	Cr	Ni	Cu	Al	N	O
0.41	1.52	1.22	0.015	0.015	0.02	0.02	0.05	0.019	0.004	0.003

Manganese and silicon content in the investigated steel, is within the concentration range for the classic TRIP steels, it is: 1.0-2.0 %Mn and 0.5-2.0 % Si [3,7]. However, it should be noticed that the investigated steel is characterized by a relatively high carbon content (0.41%). According to [16], such carbon content provides the possibility of obtaining a high strength. Simultaneously, after finishing the heat treatment, such steel should be of a high ductility and plasticity since a smaller ferrite fraction in its microstructure can be compensated by an increased fraction of the retained austenite.

The microstructure of the investigated steel in as-delivered condition is presented in Figure 3.

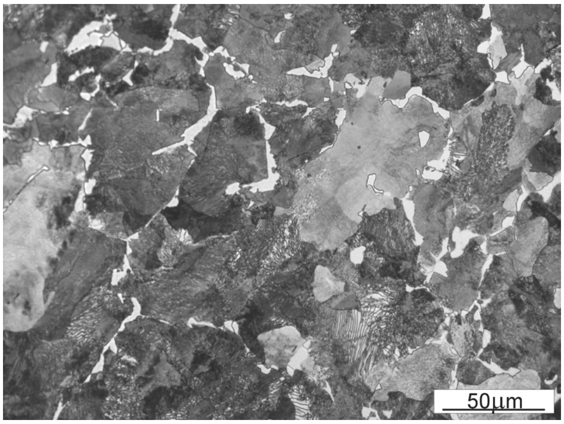

Fig. 3. The microstructure of investigated 41MnSi6-5 steel in as-delivered condition (etched with. 2% nital)

The 41MnSi6-5 steel is the hypoeutectoid steel of a significant, nearly 85vol.%, pearlite fraction. It can be assumed, that the manganese and silicon additions, which contribute to shifting the eutectoid point to lower carbon concentrations, are responsible for such substantial pearlite fraction in the steel microstructure (see Table 1).

3. Methodology of investigations

The dilatometric analysis was applied for the determination of the heating rate influence on the austenite formation process in the steel. Tests were performed by means of the dilatometer L78 R.I.T.A. of the Linseis Company on samples of dimensions: ϕ3x10 mm. Samples were heated with various rates: 0.1; 0.5; 1; 5; 10; 25; 50; 100; 200°C/s up to a temperature of 1100°C. After reaching this temperature samples were immediately cooled to the ambient temperature with a rate of 1°C/s. For each heating rate the relative elongation changes were numerically recorded (ΔL) as a temperature function (T). Then, in order to more precise reading of the critical temperatures, the curves were differentiated.

Temperature ranges within which the largest dilatation changes occurred were determined on the bases of dilatometric curves. During these tests the special attention was directed towards such dilatation effects which could be the results of starting or finishing of transformations related to the austenite formation in a microstructure of the heated 41MnSi6-5 steel. The critical temperatures for each heating rate were determined on the basis of positions of such dilatation effects [17-20]. The way of marking and defining these temperatures, which is applied in the hereby paper, is given in Table 2.

Table 2.
Symbols and description of critical temperatures determined during heating the investigated 41MnSi6-5 steel

Symbol	Process description	Changes in microstructures during heating
Ac_{1s}	Start of the pearlite → austenite transformation	First precipitates of austenite (γ) occur
Ac_{1f}	Finish of the pearlite → austenite transformation	Last precipitates of pearlite (pearlitic cementite) disappear
Ac_3	Finish of the ferrite → austenite transformation	Last precipitates of ferrite (α) disappear

The critical temperatures determined on the grounds of the dilatometric analysis were used for the determination of the austenite formation range in the 41MnSi6-5 steel. On the basis of this dependence the diagram: time-temperature-austenitizing at the continuous heating (CHT) was prepared for the tested steel.

4. Investigation results and discussion

The dilatogram ΔL=f(T) of heating with a rate of 0.1°C/s to 1100°C together with the corresponding differential curve d(ΔL)/dT=f(T) is presented in Figure 4.

It can be easily observed that with a temperature increase to 700°C, an elongation of the heated sample increases proportionally. The monotonic character of this dependence as well as a lack of any oscillations in ΔL=f(T) curve, within this temperature range, indicates that there are no transformations in the tested sample. Such observation is confirmed by the differential d(ΔL)/dT, which value remains constant up to 700°C.

Slightly above 700°C, on the elongation curve unexpectedly appears at first a shrinkage and then a positive dilatation effect, accompanied by a small increase of a differential value. The reason of such positive dilatation effect can be a change of magnetic properties of Fe-C alloys, observed in a similar temperature range [18]. It is also possible, that this effect is due to dissolving of tertiary cementite in ferrite, which can be also indicated by the temperature increase, at which such dilatation effect starts (see Figs. 5-7 and Table 3). Since an explicit explanation what is the reason of a shrinkage followed by volume increase would require additional investigations (by the electron microscope or physical) the authors limited themselves to determine-in the hereby paper-only the temperature range, within which this dilatation effect occurs. For the needs of these investigations, the temperature at which the elongation curve looses its linear character and the increase is observed on the differential curve was marked as Ac_x.

At the heating rate of 0.1°C/s (Fig. 4) at a temperature of app. 720°C austenite starts forming, causing a visible shrinkage on ΔL = f(T) curve. Further heating-in a range from 720°C to 770°C- contributes to a smaller and smaller shrinkage observed on the elongation curve ΔL. Simultaneously, within the same temperature range, the differential curve d(ΔL)/dT character changes, and from a monotonic decrease enters into an abrupt increase. Changes in both curves pathways observed in this temperature range are related to a gradually occurring transformation of pearlite into austenite. On the basis of the dilatogram from Fig. 4 it was found that this transformation finishes, the most probably, at the temperature at which a stop on the differential is seen, it means at 770°C. Thus, a temperature of 770°C was assumed as Ac_{1f} for the heating rate 0.1°C/s.

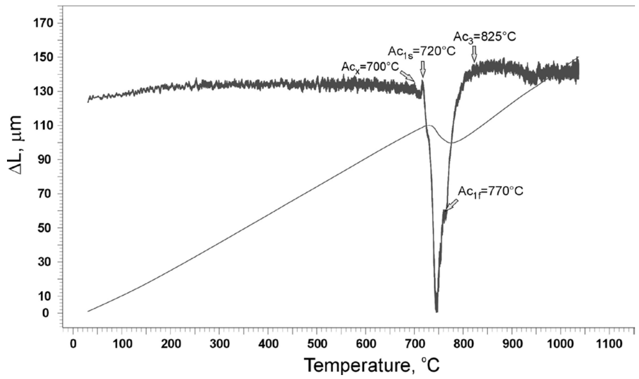

Fig. 4. Dilatometric curve ΔL of the heating rate 0.1°C/s and the corresponding differential curve d(ΔL)/dT

Above 770°C (Ac_{1f}) a weak increase of elongation of the heated sample is observed. Elongation increases-at a temperature above 770°C-are accompanied by a constant, monotonic differential increase.

Such change of the heating curve character is related to the fact that above 770°C the austenite is formed only from the not transformed earlier ferrite. Above 825°C again linear expansion increase occurs, which indicates that the ferrite transformation into austenite is finished. Therefore a temperature of 825°C was assumed as Ac_3 for the heating rate 0.1°C/s.

When the heating rate of samples was increased similar dilatation effects, as recorded and shown in Fig. 4, were observed. The sequence of their appearance, both on elongation curves ΔL=f(T) and differential curves d(ΔL)/dT=f(T), was also identical.

Table 3.
Heating rates and corresponding critical temperatures, determined during dilatometric investigations of 41MnSi6-5 steel

Heating rate, °C/s	Temperature, °C			
	Ac_x	Ac_{1s}	Ac_{1f}	Ac_3
0.1	700	720	770	825
0.5	700	720	780	825
1	710	725	770	830
5	710	730	785	850
10	710	740	800	850
25	720	745	815	865
50	710	750	810	875
100	735	760	840	880
200	720	760	860	900

Some examples of these investigations in a form of heating dilatograms with rates: 1, 10 and 100°C/s, are shown in Figures 5-7.

It is worth noticing, that the discussed above dilatation effects were the stronger delayed and shifted towards higher temperatures the higher was the heating rate.

All critical temperatures, determined on the basis of dilatometric investigations of samples of the 41MnSi6-5 steel, heated with various rates are listed in Table 3.

Determined for the 41MnSi6-5 steel and listed in Table 3 temperatures of the start and finish of transformations at heating (Ac_x, Ac_{1s}, Ac_{1f}, Ac_3) allowed to draw the time-temperature-austenitising diagram at the continuous heating (Fig. 8).

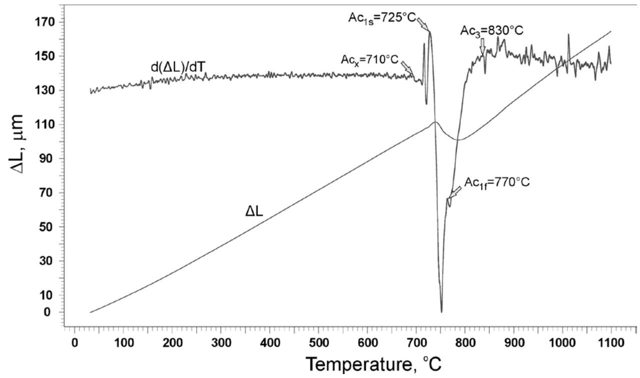

Fig. 5. Dilatometric curve ΔL of the heating rate 1°C/s and the corresponding differential curve d(ΔL)/dT

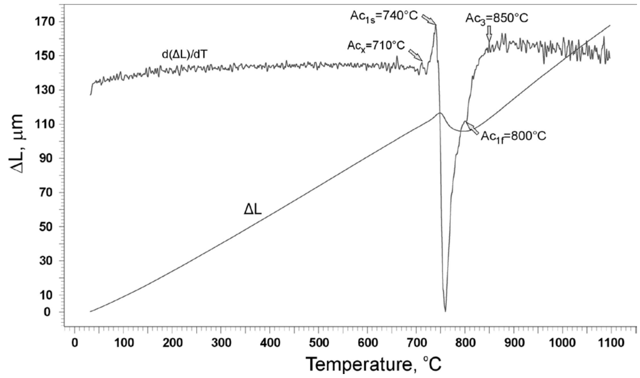

Fig. 6. Dilatometric curve ΔL of the heating rate 10°C/s and the corresponding differential curve d(ΔL)/dT

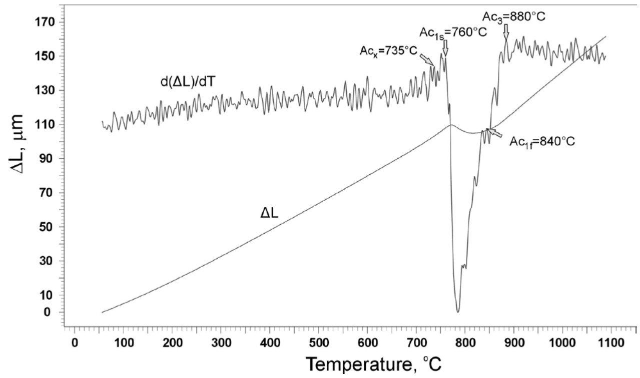

Fig. 7. Dilatometric curve ΔL of the heating rate 100°C/s and the corresponding differential curve d(ΔL)/dT

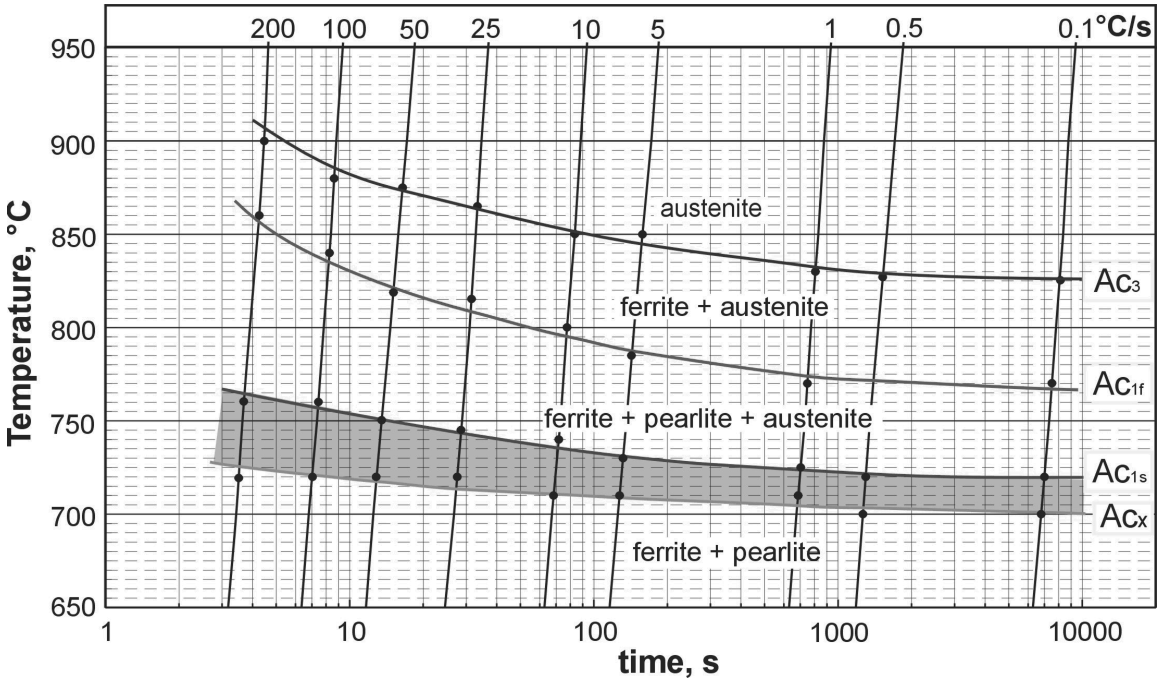

Fig. 8. The continuous-heating-transformation diagram of the 41MnSi6-6 steel

All-listed in Table 3 - temperatures are marked in the diagram as black points on curves illustrating heating rates from the range: 0.1-200°C/s. The approximation of these points allowed to determine ranges of the microstructure changes of the 41MnSi6-5 steel, during its heating. It is seen in the diagram that this microstructure is changing from the initial pearlitic-ferritic one (below Ac_{1s}), via pearlite→austenite and ferrite→austenite changes (during which individual microstructure elements coexist), up to the range in which there is only austenite, it means above Ac_3 temperature. In addition, the range of the transformation (not identified in these investigations), which during heating of dilatometric samples caused at first shrinkage and then insignificant volume increase, was marked in gray.

The data in Table 3 and the CHT diagram (Fig. 8) indicate the significant influence of the heating rates on the critical temperatures of the investigated steel. With the heating rate increase temperatures of beginnings and ends of individual transformations as well as ranges of their occurrence are increasing. At the heating rate of 0.1°C/s it is 100°C (720-820°C), while at the heating rate of 200°C/s it is already 140°C (760-900°C). Such influence of heating rates concerns first of all the transformation: pearlite→austenite (range: Ac_{1s} - Ac_{1f}) whereas the temperature range between Ac_{1f}- Ac_3 (it means in the range in which austenite is formed only from ferrite) remains similar. The application of the heating rate of 1°C/s and lower slightly changes the critical temperatures of the investigated steel.

5. Summary

The significant influence of the heating rates on temperatures of starts and finishes of individual transformations as well as on the temperature range of the austenite formation was found. Along with the heating rate increase the temperatures of beginnings and ends of individual transformations and the ranges of their occurrence also increase. Whereas the slow heating only insignificantly influence the critical temperatures of the investigated steel.

The CHT diagram carried out on the bases of the presented hereby results allows an accurate selection of the heating parameters of the 41MnSi6-5 steel in the critical temperature range, it means in the range in which austenite is formed. Such diagram allows to take into account - in the designing process of the heat treatment technology - the influence of the rate of heating to the selected temperature on the temperature range of the austenite formation. This diagram can be specially useful at selecting the heating parameters in the range of critical temperatures for elements of a very small thickness, which are heating very fast and require a short heating time.

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