Dilatometric Identification of Bainitic Transformation during Q-P Processing of 42SiCr Medium Carbon Steel

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Q-P process is one of the latest techniques for heat treatment of high-strength steels with increased silicon levels. It is believed to be based on diffusion and migration of carbon between martensite and untransformed austenite, where the latter becomes enriched with carbon, and therefore becomes thermodynamically stable. However, the question remains whether much of the carbon partitioning in the Q-P process might be the result of the competing bainitic transformation induced by arrested quenching below the M_s temperature. This paper explores the use of dilatometry for identifying the products of austenite decomposition during Q-P processing of medium-carbon 42SiCr low-alloy steel.

Keywords: Q-P processing, martensite, bainite, dilatometry

1 Introduction

The key steps in Q-P processing (quenching and partitioning) of steel are interrupted quenching below the Ms (the quenching stage) and subsequent reheating to the partitioning temperature. The typical partitioning temperature is above the M_s of the steel [1, 2]. Untransformed austenite becomes stabilised by absorbing carbon which migrates from martensite at the partitioning stage [3]. However, the underlying processes are not quite clear. Where austenite is homogeneous prior to Q-P processing and since martensitic transformation is diffusionless, the martensite which forms during quenching will have the same chemical composition as untransformed austenite. The question then arises what the driving force for carbon diffusion during the partitioning stage is – because no carbon concentration gradient between martensite and untransformed austenite can be expected to exist. Besides, one cannot expect carbon partitioning to be induced by martensite tempering which involves short-range migration and typically occurs at very low temperatures. Yet, experiments revealed that untransformed austenite does become enriched with carbon during the partitioning stage [4]. One plausible and very likely explanation for this paradox is that enrichment of untransformed austenite occurs with carbon whose source is not fresh martensite formed during quenching but bainitic ferrite which emerged in the partitioning stage because bainitic transformation was accelerated by previous martensitic transformation [5]. This dilatometer-based investigation explored the phase transformations which are induced in

42SiCr steel by Q-P processing and aimed to clarify whether untransformed austenite may transform to bainite during Q-P process.

2 Materials and methods

The experimental material was medium-carbon low-alloy steel with 0.43% C, 0.55% Mn, 2% Si and 1.45% Cr. It was supplied in the form of 60-kg ingots. They were sectioned and homogenized for 6 hours at 1200°C in an argon atmosphere and normalized at 950°C for 2 hours. The annealed parts of the ingots were hot-forged into bars 18 mm in diameter. The forged bars were then homogenized at 1200°C for 3 hours in a protective atmosphere and normalized at 950°C for 2 hours. Specimens were machined from the bars and processed in L78 RITA quenching dilatometer.

Time-temperature-transformation (TTT) and time-temperature-austenitization (TTA) diagrams for the steel were determined by calculation using JMatPro. Based on this data, an approximate temperature and time for full austenitization and homogenization of austenite were determined (Fig. 1). Using a dilatometer, the value of $M_s = 280°C$ was found for the cooling rate of 50°C/s.

Dilatometer measurement was then performed on the test specimens. The sequences were simulations of defined Q-P process routes (Fig.2). Their design was to enable monitoring of the effect of quenching and partitioning temperatures – above and below the M_s – on specimen expansion and contraction in response to the phase transformation taking place.
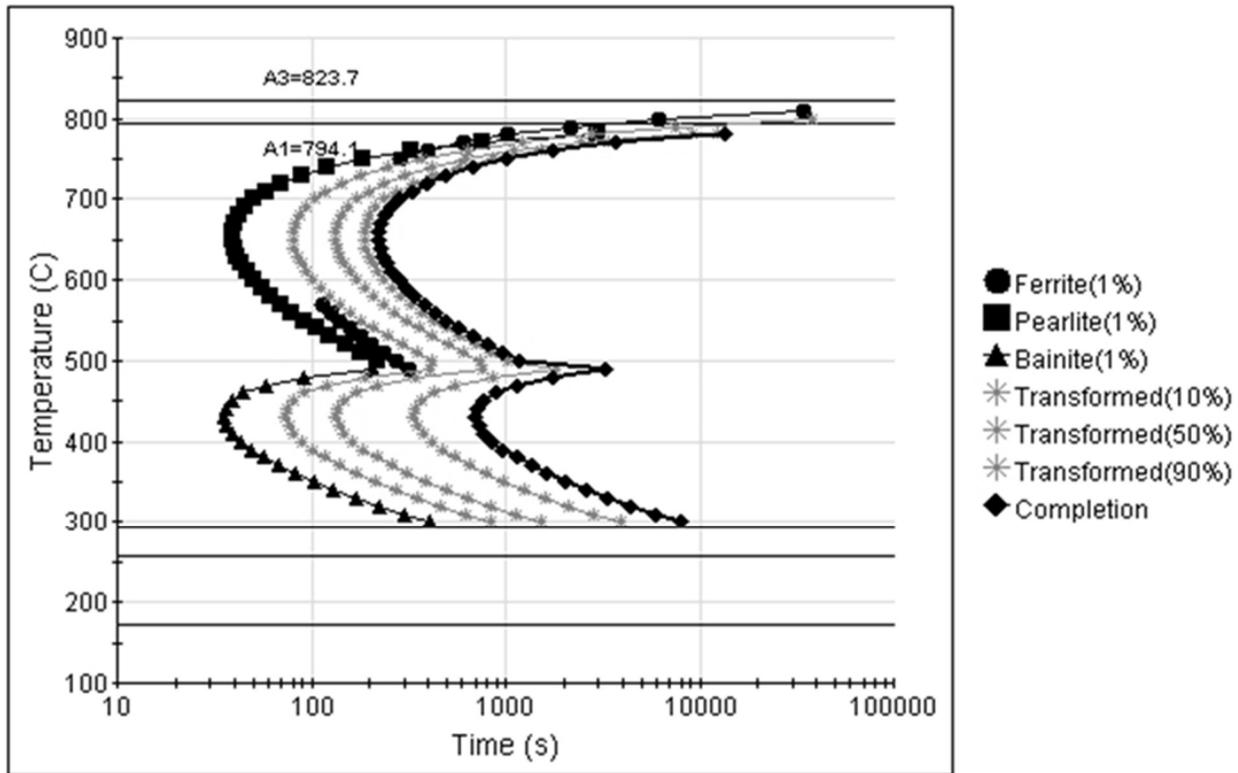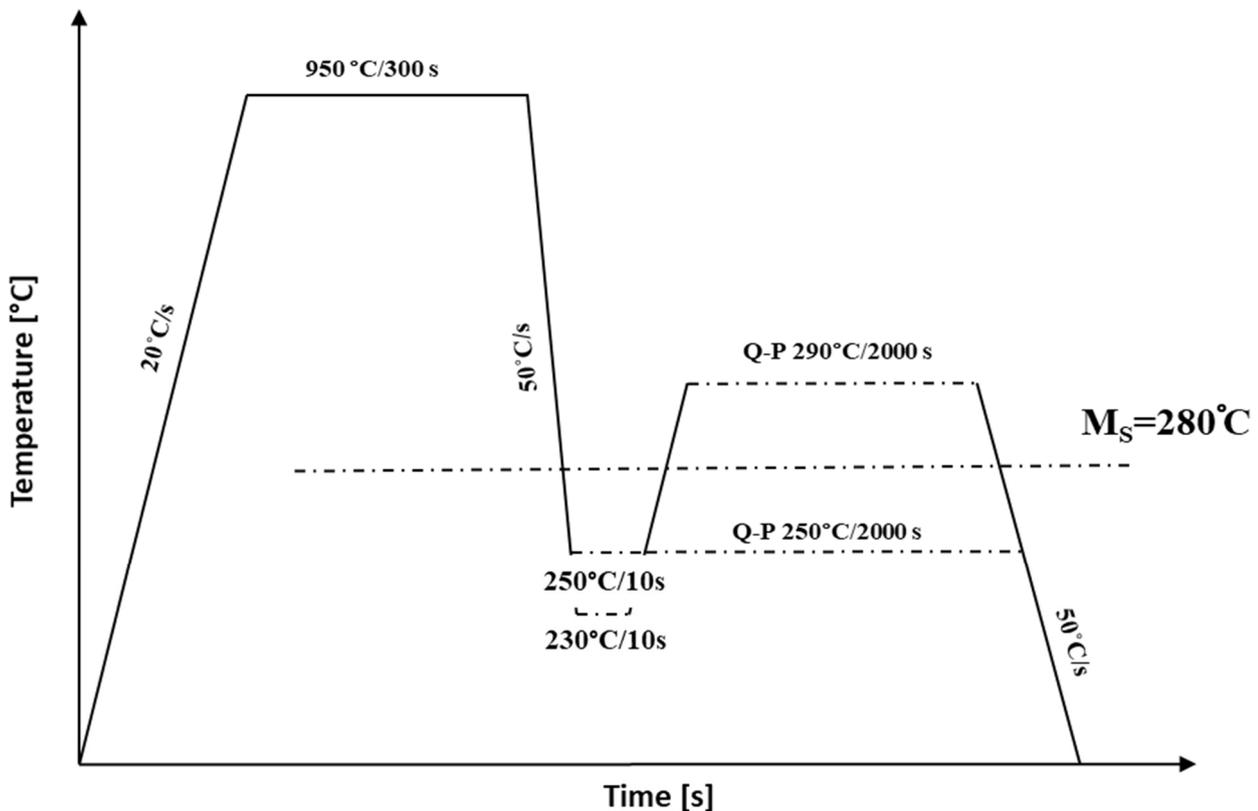
Fig. 1 *TTT diagram of the 42SiCr steel*

Fig. 2 *Diagram of Q-P processing routes*

3 Results and discussion

The dilatometer measurement led to several conclusions. In all the routes, the specimens showed linear expansion in the partitioning stage. (Fig.3) [6,7]. It occurred immediately after the specimen had reached the partitioning temperature.
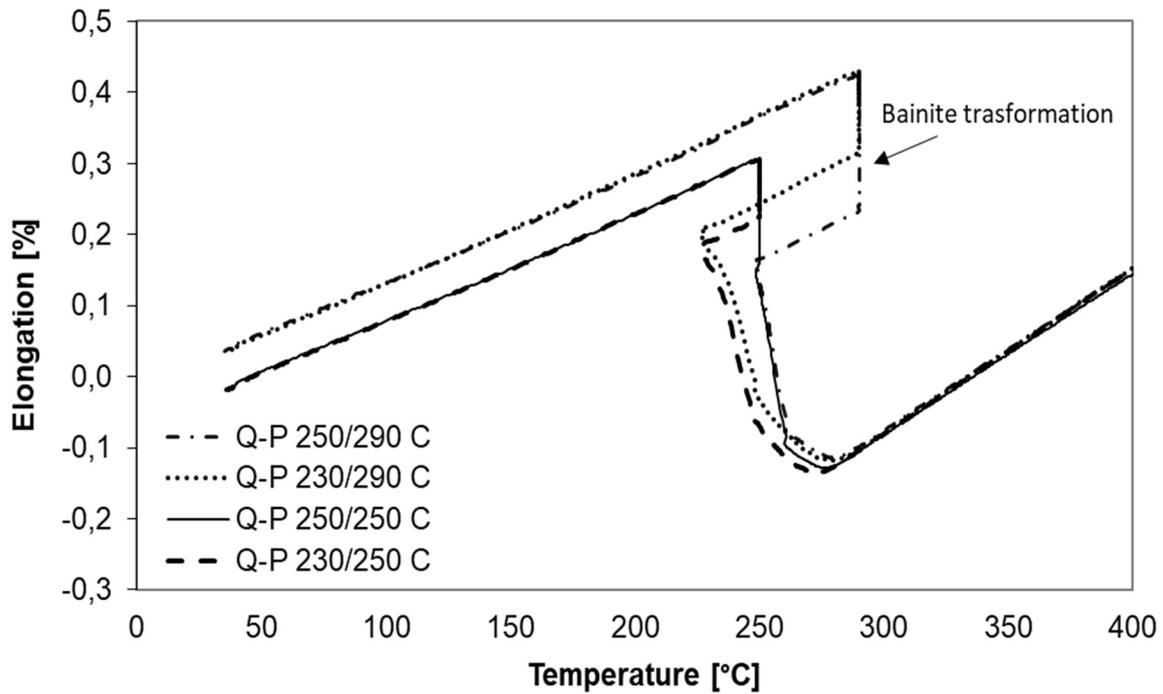
Fig. 3 *Dilatometer curves for various Q-P process conditions*

As transformation of austenite to martensite is athermal, it is certain that this linear expansion was not related to martensitic transformation. Also, the expansion appears not to have been related to carbon diffusion, specifically to tempering of martensite produced by quenching. This is based on numerous conclusions presented in professional resources where contraction was reported for all dilatometer measurements on test specimens [8,9]. In this case, the segments of dilatometer curves related to the partitioning temperature showed expansion for all specimens (Fig. 4 through 11) [10].
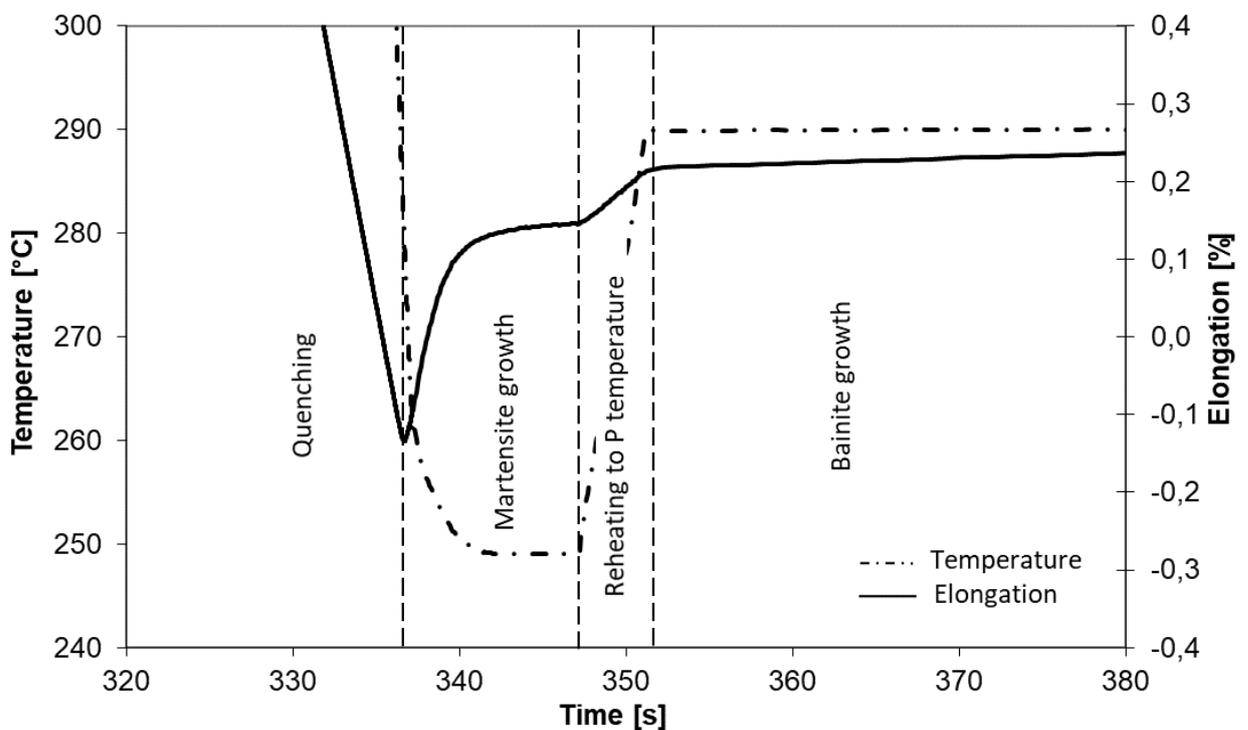

Fig. 4 *Detail of dilatometer curve – process route Q-P 250/290°C*

Considering the above arguments, the changes in length can be attributed to microstructural processes associated with the formation of bainitic ferrite and carbon diffusion [11-14]. Hence, carbon partitioning between ferritic and austenitic phases does occur during Q-P processing but that ferritic phase is in fact bainite, not martensite. This can also explain how migration (diffusion) of carbon occurs between the ferritic and austenitic phases (due to negligible solubility of carbon in bainitic ferrite) instead of migration from martensite in which carbon concentration is roughly the same as in untransformed austenite.
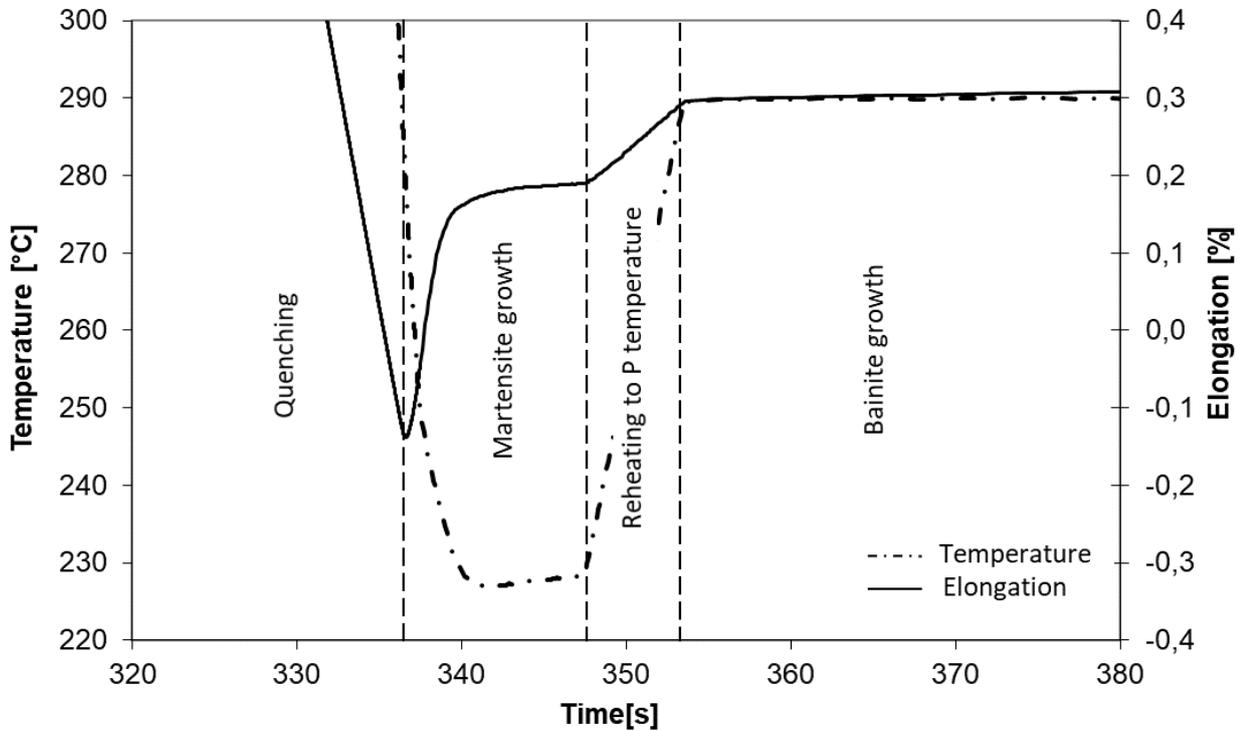

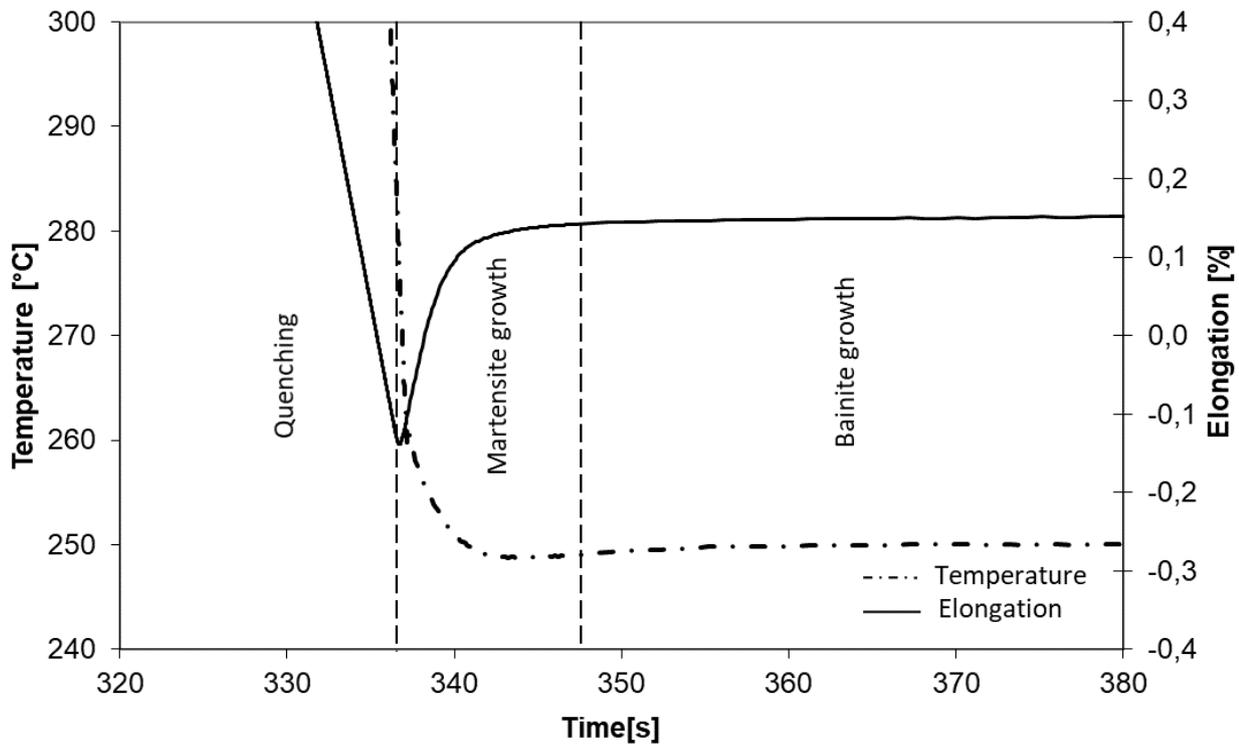*Fig. 5* Detail of a dilatometer curve – process route Q-P 230/290°C

Fig. 6 Detail of a dilatometer curve – process route Q-P 250/250°C

One important finding about the behaviour of phase transformations was that bainitic transformation took place at temperatures which were higher than the M_s (280°C) – process routes Q-P 250/290°C, Q-P 230/290°C – as well as lower than the M_s – process routes Q-P 250/250°C, Q-P 230/250°C. It appears certain that bainite formation is also possible in the temperature interval in which austenite decomposition to martensite is normally the only transformation to occur. The cause of this must have been a change in the thermodynamic driving force, leading to decomposition of austenite to bainitic ferrite. One can assume that untransformed austenite must have undergone changes which eventually depressed the M_s temperature and shifted the transformation curves towards shorter times.
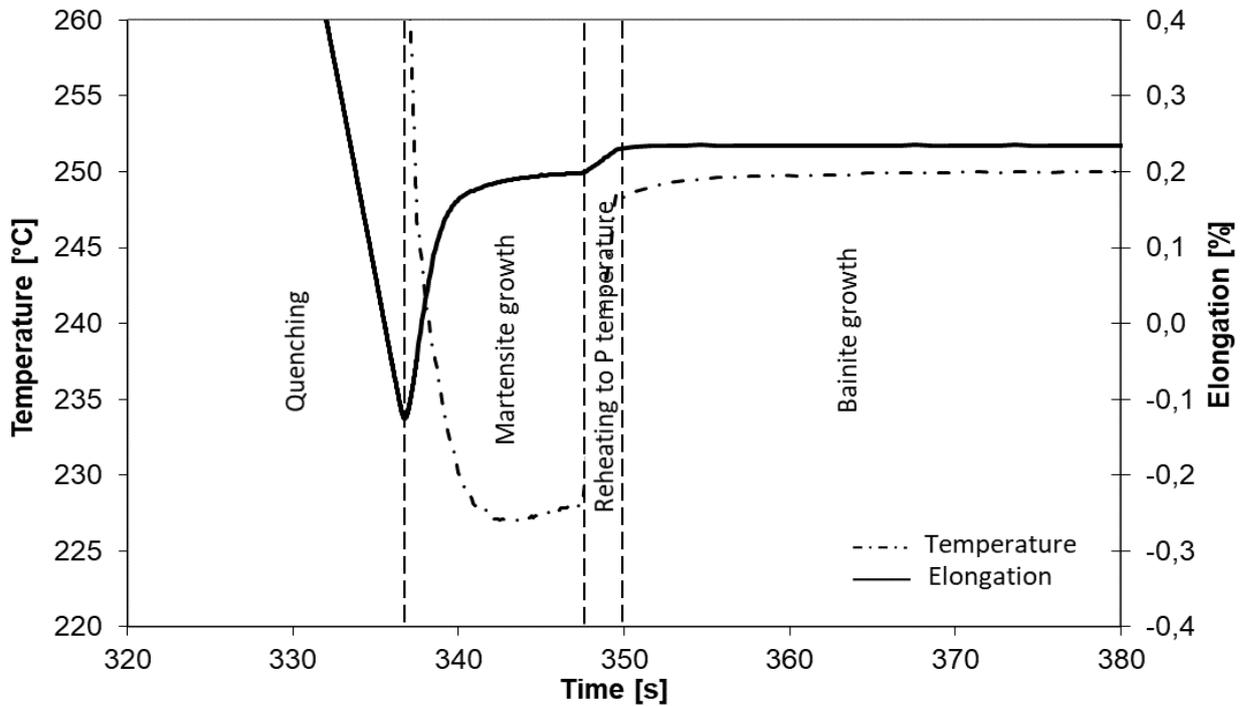

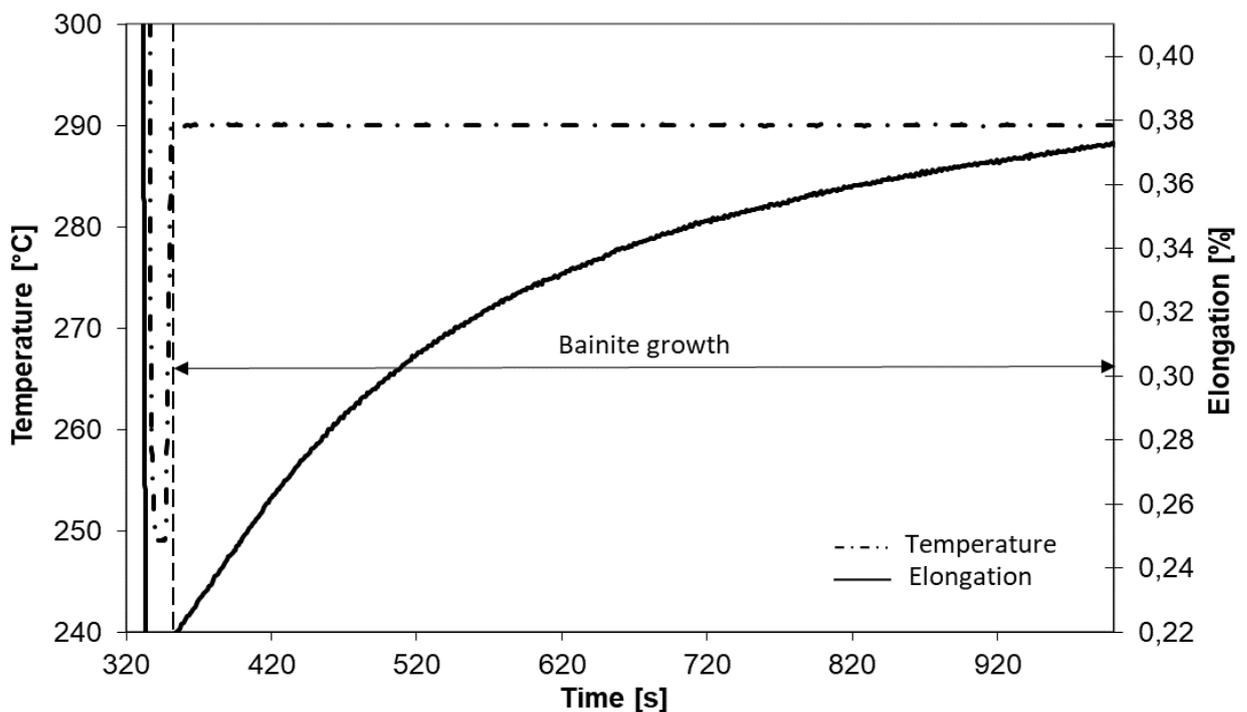**Fig. 7** *Detail of a dilatometer curve – process route Q-P 230/250°C*

Fig. 8 *Details of changes in length during the partitioning state – process route Q-P 250/290°C*

In process routes Q-P 250/290°C, Q-P 230/290°C and Q-P 250/250°C, austenite-bainite transformation occurred almost immediately after the partitioning temperature had been reached (Fig. 8 through 10). In process route Q-P 230/250°C, the transformation was preceded by a delay of approximately 50 seconds.
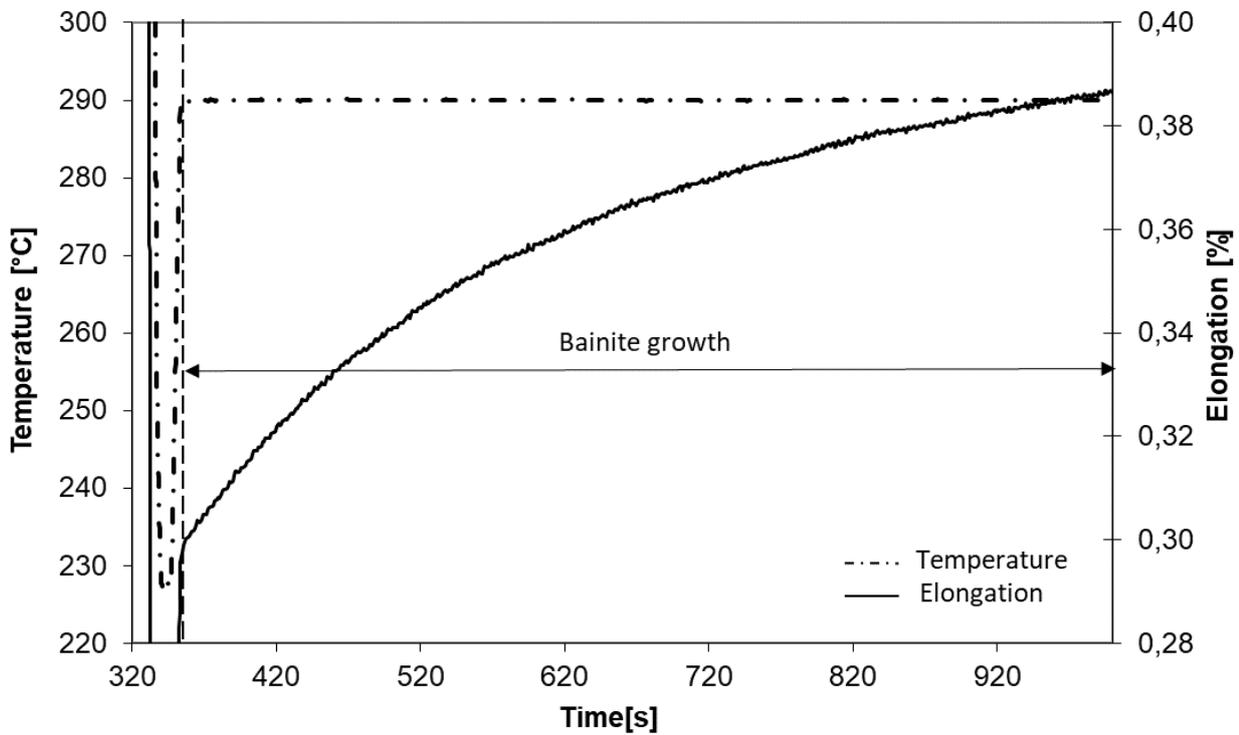

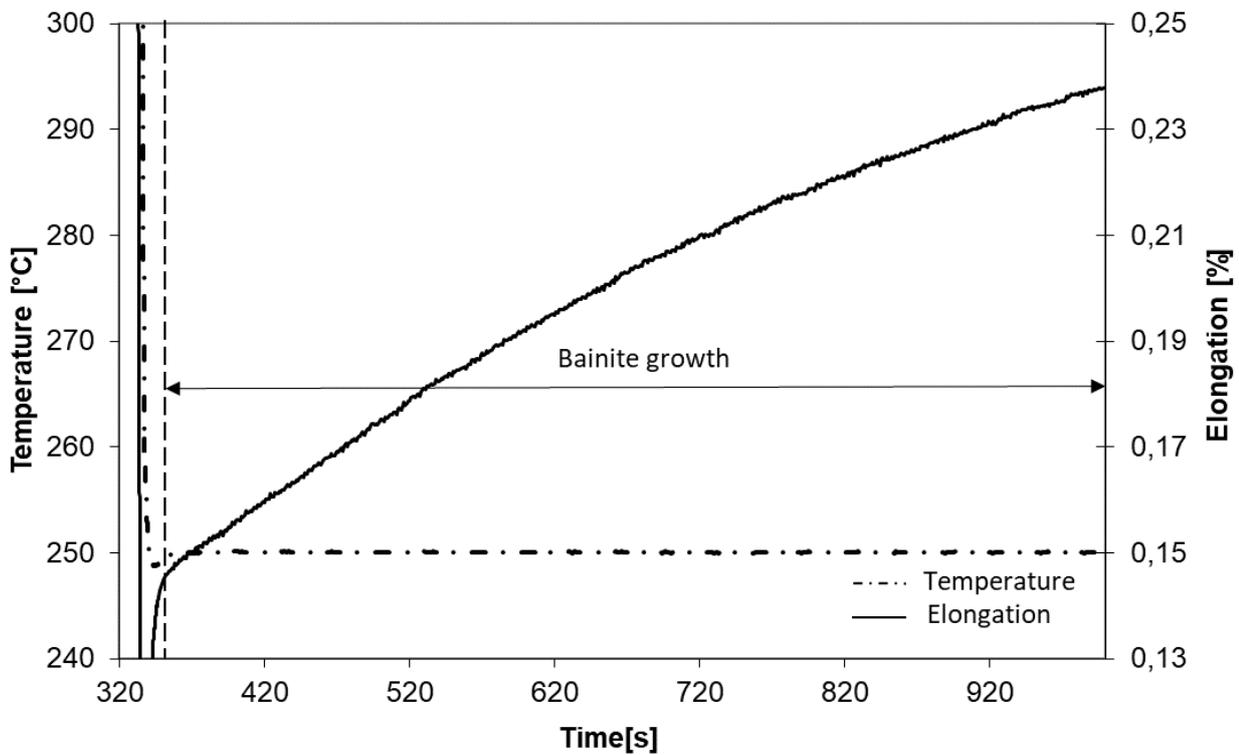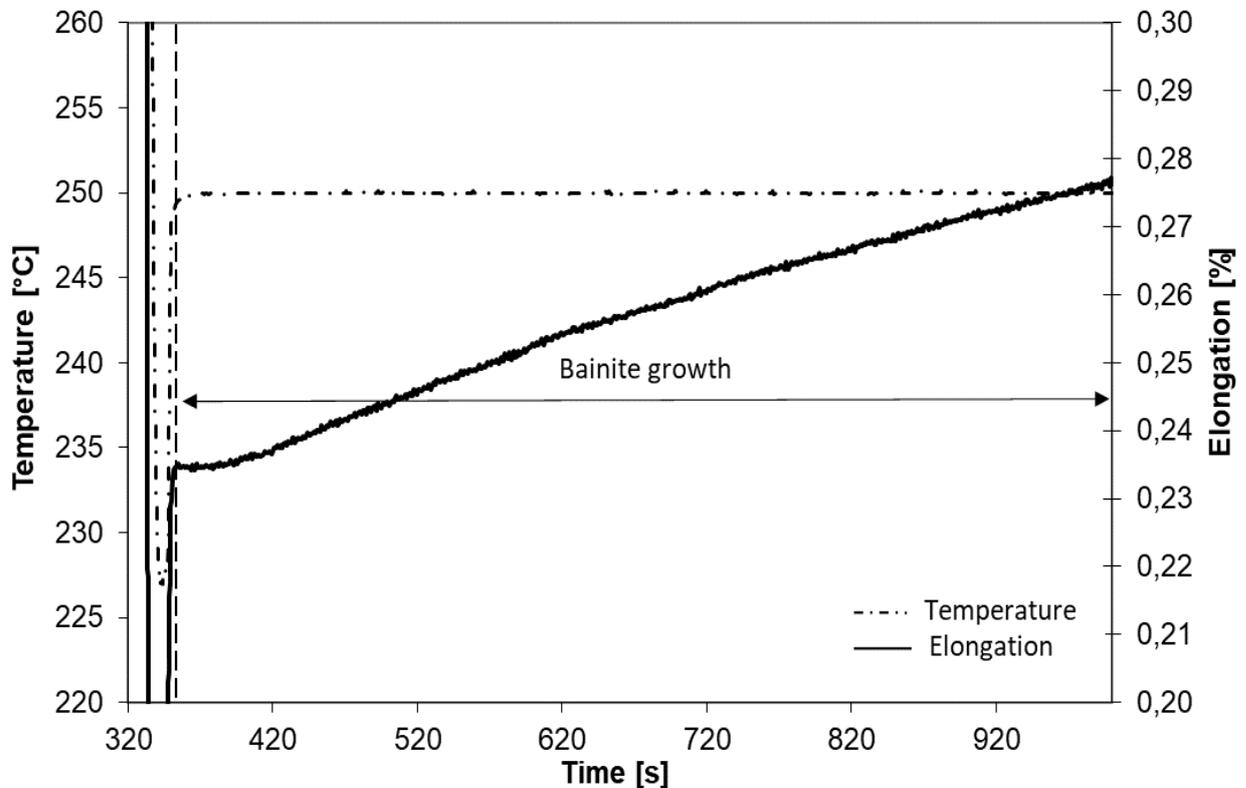**Fig. 9** *Details of changes in length during the partitioning state – process route Q-P 230/290°C*

Fig. 10 *Details of changes in length during the partitioning state – process route Q-P 250/250°C*

Higher quenching and partitioning temperatures (in process routes Q-P 250/290°C and Q-P 250/250°C) led to a markedly extensive bainitic transformation when compared process routes Q-P 230/290°C and Q-P 230/250°C.

An important question is the key factor which causes bainite to form in untransformed austenite. The presumed cause, operating also at temperatures below the M_s, is the combination of austenite refinement by the presence of martensite particles and plastic deformation at the martensite-untransformed austenite interface.

Fig. 11 *Details of changes in length during the partitioning state – process route Q-P 230/250°C*

4 Conclusion

The progress of austenite decomposition in the course of Q-P processing of medium-carbon steel with 0.43% C, 0.55% Mn, 2% Si and 1.33% Cr was explored. In a quenching dilatometer, specimens were subjected to process routes which enabled the progress of transformation to be monitored and correlated with the quenching and partitioning temperatures.

In all the Q-P process routes, bainitic transformation was induced during partitioning. Its progress was dependent on the Q-P process conditions. The higher the quenching and partitioning temperatures were, the more noticeable the signs of transformation on the dilatometer curve were – indicating higher content of bainite in the microstructure. In turn, lower quenching and partitioning temperatures led to a less pronounced signs of bainitic transformation on the dilatometer curve, which shows that there was less bainite in the microstructure.

Using dilatometer measurement, it was found that bainitic transformation initiated almost immediately after the partitioning temperature had been reached.

The only exception was the Q-P 230/250°C process route, in which there was about 50 second delay between these occurrences.

Martensite which formed by interrupted quenching had a favourable effect on the decomposition of the remaining austenite to bainite. One can therefore assume that interrupted quenching accelerated the subsequent bainitic transformation. The likely cause is the refinement of the austenite grain due to newly-formed martensite particles and microplastic deformation.

It appears that the decomposition of untransformed austenite to bainite during Q-P processing is the major factor which governs partitioning of carbon and enrichment of retained austenite in Q-P-processed steels.

Acknowledgement

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