



Correlation of isothermal bainite transformation and austenite stability in quenching and partitioning steels

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ABSTRACT

The possible decomposition of metastable austenite during the partitioning process in the high-end quenching and partitioning (Q&P) steels is somewhat neglected by most researchers. The effects of primary martensite and alloying elements including manganese, cobalt and aluminum on the isothermal decomposition of austenite during typical Q&P process were studied by dilatometry. The transformation kinetics was studied systematically and resulting microstructures were discussed in details. The results suggested that the primary martensite decreased the incubation period of isothermal decomposition by accelerating the nucleation process owing to dislocations especially on phase and grain boundaries. This effect can be eliminated by a flash heating which recovered dislocations. Co addition significantly promoted the bainite transformation during partitioning while Al and Mn suppressed the isothermal bainite transformation. The bainite transformation played an important role in carbon distribution during partitioning, and hence the amount and stability of austenite upon final quenching. The bainite transformation during partitioning is an important factor in optimizing the microstructure in Q&P steels.

1. Introduction

In emerging efforts on the development of light weight automotive and the implementation of advanced materials, the development of the 3rd generation advanced high strength steels (AHSS) represents a very important technical solution. Despite different concepts and process routes, the 3rd generation AHSS possess multi-phase microstructures, and rely on characters of the metastable austenite and corresponding mechanical properties through the transformation induced plasticity (TRIP) effect^[1-4]. Being one of the most promising concepts, quenching and partitioning (Q&P) steels^[5-7] are essentially prepared by a two-step treatment process, firstly a quenching process to partially transform the austenite to athermal martensite, followed by partitioning process for a full partition of C from athermal martensite into the metastable austenite so as to increase the austenite amount and stability upon final quenching. A large number of researches have been carried out in the last ten years to improve mechanical properties of Q&P steels by tailoring alloy composition and heat treatment parameters^[8-12]. Being

the most influential elements on austenite stability, large concentration windows of C and Mn have been explored. In order to optimize the effect of C on stabilizing the austenite, Si addition was usually employed to retard cementite formation and hence the bainite transformation^[13]. The effects of Al and Co on the kinetics of bainite formation have also been discussed from the thermodynamic driving force viewpoint^[14].

In the concept of Q&P steels, two critical ideal hypotheses were enforced: (1) a full partition of C from athermal martensite to retained austenite is assumed during partitioning process and (2) the isothermal decomposition of metastable austenite during partitioning is neglected. This may be true in some occasions; however, it was usually found that the amount of retained austenite upon final quenching was far from the value as predicted using the ideal hypotheses^[15]. Nevertheless, most previous studies only focused on the relationship between C partitioning and austenite stability, but ignored the effect of isothermal bainite transformation^[8,9]. Bohemen et al.^[16] found the experimental evidence of bainite formation below martensite start tempera-

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ture M_s in the Fe-0.66C-0.69Mn-0.3Si system which indicated the possible bainite transformation during partitioning below M_s . Mandal et al.^[17] reported that bainite could form during 1-step Q&P process at 20 °C below M_s and affected the austenite stability. Li et al.^[18] reported that in the 2-step Q&P process of 0.41C-1.27Si-1.30Mn-1.0Ni-0.56Cr steel, the yield strength increased upon prolonged partitioning, which was attributed to the bainite transformation during partitioning at 300 °C. However, no clear evidence or detailed kinetics was reported. Véronique and Thomas^[19] studied the effect of primary martensite on the bainite transformation during partitioning and compared with the isothermal bainite transformation without primary martensite at the same transformation temperature; their results suggested that the bainite transformation kinetics during partitioning with the presence of primary martensite was identical but shifted as the same amount of bainite was formed during the isothermal bainite transformation. Pinto da Silva et al.^[20] studied the bainite transformation in Fe-0.2C-1.65Mn-1.40Si-1.50Al-1.30Cu-1.05Ni-1.07Co steel subjected to 1-step Q&P process and established a model for the isothermal bainite transformation kinetics based on the nucleation theory.

Regardless of the presence of primary martensite, the isothermal bainite transformation could be affected by different factors. Bhadeshia^[21] showed that in nano bainite system in which the bainite transformation took place at a relative low temperature and with a slow kinetics, the bainite transformation could be accelerated by Al and Co alloying owing to increased driving force. Moreover, grain refinement could also speed up the bainite transformation because of a high nucleation rate. Furthermore, it was shown that uniaxial elastic stress could strongly enhance the growth of compliant variants in the bainite transformation and lead to an organized microstructure^[22]. Gong et al.^[23] studied the effect of ausforming on bainite transformation in nanobainite. The results showed that 5% ausforming dramatically accelerated the bainite transformation accompanied by strong variant selection owing to the fact that planar dislocations remained on the active slip planes. Navarro-López et al.^[24] studied the kinetics of isothermal bainite transformation above and below M_s temperature in Fe-0.2C-3.51Mn-1.52Si-0.25Mo-0.04Al steel. The results showed that the initial nucleation rate at transformation temperature below M_s was more than two orders of magnitudes higher than that above M_s , owing to the presence of primary martensite. Gong et al.^[25] also reported that the primary martensite could increase the dislocation density in austenite near the phase boundaries and hence accelerate the bainite transformation in

the Fe-0.79C-1.98Mn-1.51Si-0.98Cr-0.24Mo-1.06Al-1.58Cosystem. However, its effect was weaker than 15% ausforming, because ausforming could create dislocations in the whole grain.

In summary, the bainite transformation during partitioning either below or above M_s is possible to take place and its kinetic can be affected by many parameters. However, the isothermal transformation kinetics has not been investigated in details. Moreover, the isothermal decomposition of austenite during partitioning strongly influences the amount and stability of austenite upon final quenching, and eventually the mechanical properties. This is the key issue to tailor mechanical properties of Q&P steels. In this work, effects of Mn, Co, and Al additions and amount of primary martensite on isothermal bainite transformation kinetics during partitioning were systematically studied by dilatometry. The resulting microstructures were characterized in details and consequences on mechanical properties were discussed.

2. Material and Methods

Five experimental steels, named Ref, Ref + Al, Ref + Co, Ref – Mn and Ref + Mn respectively, were prepared by using a vacuum furnace and cast into 75 kg ingots. The compositions are shown in Table 1. The ingots were forged, cut to blocks, and homogenized at 1200 °C for 2 h before hot rolling. Strips of 6 mm in thickness were manufactured by seven passes hot rolling with a finish rolling temperature of 870 °C and finally quenched to room temperature by water.

Table 1

Chemical composition of investigated steels (wt. %)

Steel	C	Mn	Si	Al	Co
Ref	0.21	3.92	1.60	0.01	–
Ref+Al	0.21	4.05	1.65	1.40	–
Ref+Co	0.20	3.95	1.61	0.03	1.97
Ref–Mn	0.20	2.82	1.58	0.02	–
Ref+Mn	0.21	5.14	1.58	0.02	–

Dilatometry specimens of 4 mm in diameter and 10 mm in length were prepared. Dilatometry experiments were performed in a TA Instruments DIL805A/D dilatometer. In order to determine key transformation temperatures, a simple heating and quenching cycle was performed on each steel with parameters shown in Table 2.

Concerning the isothermal transformation kinetics, three types of dilatometer experiment cycles were performed: (1) In DIT (Direct Isothermal Transformation) process, after austenitization in the condition shown in Table 2, samples were directly quenched to isothermal transformation temperature, i. e. 400 °C and temperatures to obtain 30% of

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