Pearlitic Transformation by Isothermal Decomposition in Titanium and Titanium Free Micro Alloyed Steel

Abdulnaser Hamza Fadel
Al Zawia University, Faculty of Natural Resources, Al Zawia - Libya
E-mail: A.fadel@zu.edu.ly

Abstract
This work is focused on nucleation stages during isothermal austenite decomposition in two medium carbon Vanadium Ti / Ti free micro alloyed steels. Isothermal treatment was carried out in the temperature range 350 to 600^{o}C. Metallographic evaluation using optical and scanning electron microscopy (SEM) enabled determination of the nucleation onset phases of isothermally decomposed austenite. Mainly three phases are found to be relevant to this initiation stage of transformation: first is related to grain boundary nucleated ferrite (GBF), second is related to intra-granularly nucleated ferrite (IGF) and the third to pearlite (P). GBF and IGF are divided into the high temperature and the low temperature segments as consequence of either displacive or diffusion nature of transformation. Addition of titanium to V – micro alloyed steel in this work seems to be balanced by a slightly higher C and Mn content, leading to limited effect on nucleation stage of austenite decomposition. The results show that during continuous cooling, onset of pearlite phase can take place. It occurs at temperatures ≥ 500 C$^{\circ}$, followed by an incomplete reaction phenomenon. The main characteristics of pearlite is always nucleated on the surface between proeutectoid ferrite and austenite. Incubation time for onset of pearlite decrease with decrease of temperature.

Keywords: Micro alloyed Steel, Isothermal Transformation, Grain Boundary Ferrite, Pearlite Onset and Transformation, OM and SEM Microscopy.

1. Introduction

During isothermal transformation from fully austenite conditions, the mode of transformation (ferrite, cementite, bainite, etc.) is said to be depend on diffusivity and mobility of substitutional and interstitial atoms as well as concentration profile and spike width as suggested by Coats [1,2]. As the diffusivity and mobility of interstitial atoms are very high, they distribute themselves in an almost homogenized manner during such partitioning. However, in case of substitutional elements (e.g. Si, Mn, Cr,….etc.) such rearrangement of atoms creates a very high concentration in the advancing austenite (γ) / ferrite (α) interface and the extent of gradient of concentration in austenite depends on the mode of equilibrium (equilibrium modes), is it Para Equilibrium (PE mode), Negligible Partitioning - Local Equilibrium (NP-LE mode), Partitioning Local Equilibrium (P-LE mode) or Ortho equilibrium mode" [1-3]. On the other hand, thermodynamically, it is also possible to develop fully pearlitic structure even over range of carbon concentration at temperature lower than the eutectoid [4]. If the steel composition lies within the shaded region as shown in figure 1 [3] and if it is possible to suppress the transformation of austenite to other transformation products (e.g. ferrite, cementite, bainite, etc.) it is possible to get *austenite → Pearlite* transformation directly without forming any proeutectoid phase. The extrapolated AC_M line of Figure 1 shows the composition of the austenite in equilibrium with cementite. However, direct formation of pearlite in this way becomes more and more difficult with lowering of C because of the following three reasons [3]. First, with lowering of C, a lower temperature is required for the direct austenite to pearlite transformation to begin; however, steel with lower C has higher Bs temperature as a result of which it might so happen that before the austenite to pearlite transformation initiates, bainite formation would start. Second, at lower temperature, the

transformation kinetics will be very slow, so a very long holding time would be required for the transformation to take place and third, a very fast cooling rate is required to bring down the temperature to isothermal range. Numerous excellent works have been published by different research groups [5-13,26]. These studies are very important in understanding the austenite transformation mechanisms and have helped to develop the basic fundamentals of such transformations. By contrast, the data related to nucleation of pearlite phase starting from very low isothermal temperature treatment (350 C°) and short holding time (2s) under isothermal decomposition condition seems to be lacking. Therefore, the main goal of the current work will focus on previous point and describe primarily all the different aspects of austenite to pearlite transformation carried out in two types of medium carbon Vanadium Ti / Ti free micro alloyed steels under isothermal treatment.

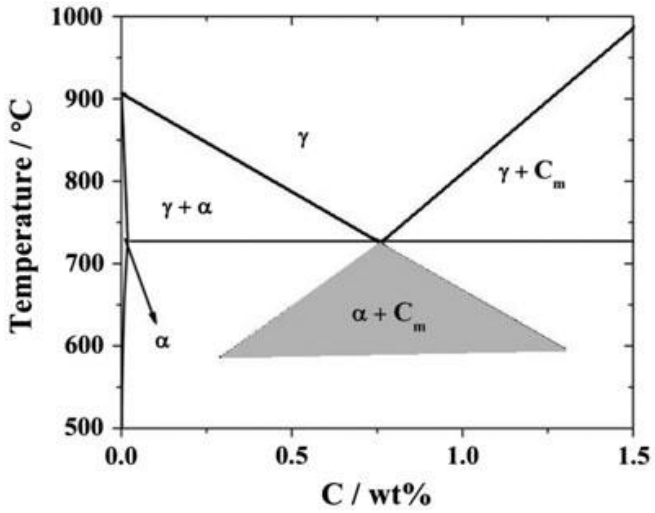

Figure 1. Schematic Fe-C phase diagram showing the Hultgren extrapolation.

2.Experimental Procedures

2.1 Materials

Two commercial vanadium medium carbon micro alloyed forging steels with and without titanium addition have been studied. The chemical compositions of these steels are given in Table 1. Both steels were industrially casted and hot-rolled into 22mm (V-Ti steel) and 19mm (Ti free steel) diameter bars. In order to break the dendritic structure, bars were homogenized at 1250 °C for 4 hours, in argon as protective atmosphere and subsequently oil quenched. Specimens of 12mm height were cut and austenitized at 1100 °C for 10 min in an argon atmosphere. After austenitization, specimens were isothermally held at temperatures ranging from 350 C° to 600 C° for different holding times (between 2 to 1200s).

Table 1: Chemical composition of the experimental steels (wt.%)

Steel	C	Si	Mn	P	S	Ti	V	N
V-Ti	0.309	0.485	1.531	0.0077	0.0101	0.011	0.123	0.0221
Ti free	0.256	0.416	1.451	0.0113	0.0112	0.002	0.099	0.0235

2.2 Microstructural Characterization

General characteristics of microstructure were observed under optical microscope with sample polished following standard procedure and etched by 2% NITAL. In order to reveal the fine features in detail, etched samples were also observed by a Field Emission Gun Scanning Microscope (FEGSEM). Elemental analysis in a fine scale was carried out with an Electron Probe Micro-Analysis (EPMA). Camera SX 100 instruments were used for such purpose with an acceleration voltage of 15 kV, beam current 20 mA and with beam diameter of 1 µm.

Results and Discus

3.1 Nucleation Onset Time

As represented in Table 2. Three phases are found to be relevant for initiation stage of transformation:

Table 2. Experimentally determined nucleation onset time by (s) for different phases in both steels investigated.

Treatment Temperature	Ti free-V					Ti steel-V				
°C	GBF	IGF	BS	P	$_{f}$R	GBF	IGF	BS	P	$_{f}$R
350	7	-----	10	-----	600	7	-----	10	-----	600
400	2	-----	20	-----	600	5	-----	10	-----	600
450	2	-----	-----	-----	1200	2	-----	-----	-----	600
500	3	10	-----	80	1200<	5	10	-----	120	1200
550	5	20	-----	45	1200<	7	30	-----	80	1200<
600	7	30	-----	30	1200<	10	60	-----	60	1200<

Grain Boundary Ferrite (GBF), Intra-Granular Ferrite (IGF), Bainite Sheaves (BS), Pearlite (P) and Reaction Finish (Rf) and time given by second.

first phase, is related to grain boundary nucleated ferrite (GBF), is the first phase to nucleate over the entire isothermal treatment temperature range tested second phase is related to intra-granularly nucleated ferrite (IGF) and the third to the pearlite (P) phase as shown in figure 2. The GBF and IGF phases are divided into the high temperature and the low temperature segments as consequence of either displacive or diffusion nature of transformation.

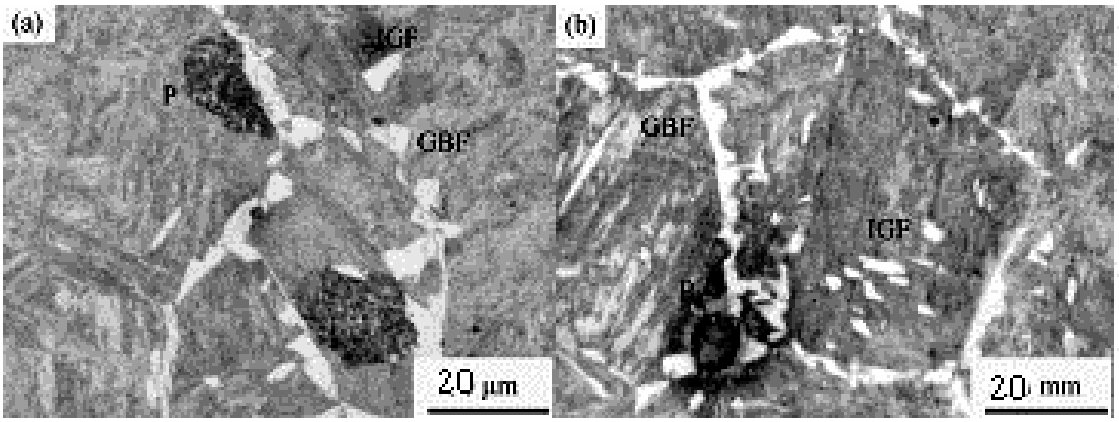

Figure 2. Optical micrographs showing intra-granularly nucleated ferrite (IGF) combined with grain boundary ferrite (GBF) and pearlite (P) after 120s. For Ti steel at: (a) 600 °C, (b) 550 °C.

3.2. Effect of Ti addition

In regard to the effect of micro-alloying elements on the kinetics of isothermal transformation it has been shown that presence of vanadium delays the nucleation of ferrite, whereas Ti speeds it up [14 - 16,25,26]. In the V-Ti Steel, a slightly higher carbon and manganese content which delays transformation seems to balance the influence of Ti addition. Therefore, as represented in table 2, the

temperature at which the incubation time for ferrite nucleation is at minimum value is approximately the same for both steels (2s at 450 °C). The incubation time is the minimum time at which it is possible to find some ferrite nucleated at the austenite grain boundary. In this sense Ti addition does not exert any influence on this temperature; neither the prior austenite grain size has any clear effect on the transformation as a whole.

3.3. Incomplete Transformation

The transformation after1200s of isothermal treatment at 550 and 600 °C reveals that a fraction of austenite remains untransformed (UA), as can be seen in Fig.3. This phenomenon has been described by Bhadeshia and another studies [16 - 22,26] and is known as incomplete reaction phenomenon.

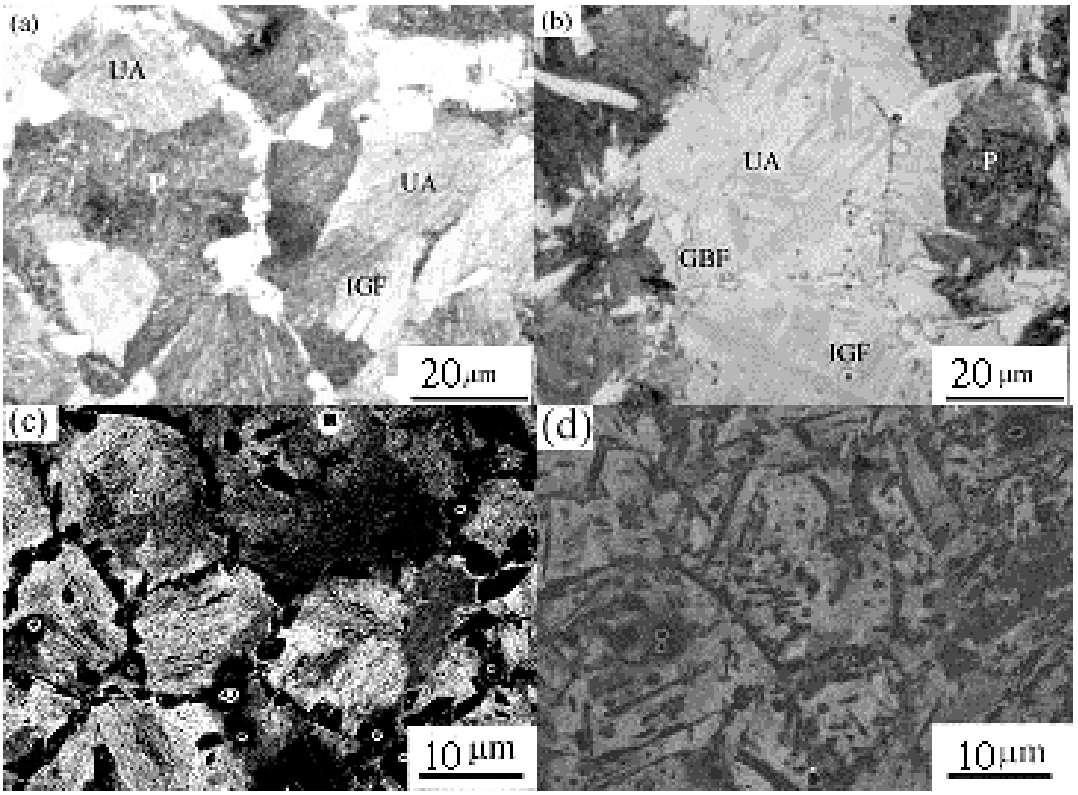

Fig. 3. Optical micrographs (a and b) and SEM (c and d) of Ti steel showing the presence of incomplete austenite transformation (UA) and proeutectoid ferrite obtained after 1200s (a, c) 600 °C; (b, d) 550 °C.

3.4. Pearlitic Transformation

Pearlite is always nucleated on the surface between proeutectoid ferrite and austenite (fig. 2 & 4). Typical microstructures showing onset of pearlite are presented in figures 4(a) to 4(d). The times by second for onset of austenite to pearlite transformation for both steels are given in table 2. Nucleation of pearlite directly depends on the chemical composition of austenite after interlocked acicular ferrite is formed (at 450 °C for both steels). Due to faster growth of interlocked acicular ferrite, especially in the case of Ti free steel, supersaturation of remaining austenite is earlier achieved, enabling start of pearlite transformation. It is worth noting that pearlite occurs in isothermal treatment region 500-600 °C in the presence of proeutectoid ferrite in both types of steel investigated as illustrated in figure 2 and figure 4. Pearlite is diffusional transformation so its growth requires the diffusion of all elements including iron. Pearlite has never been shown to grow by the para equilibrium transformation of austenite [23]. As illustrated in Figure 4. The dark-etched pearlite is located at the ferrite grain boundaries. Because of the higher manganese content for both steels investigated. This is good agreement with published data [24]. The presence of a hemispherical shape nodules of pearlite at austenite grain boundary is attributed to sideways nucleation and then by increase the treatment time it gradually growing into austenite grains by edge-ways growth, as can be clearly seen in Fig. 4 (a, d). Because the nucleation of

pearlite will depend on the diffusion of carbon in austenite. By contrast as reported by MEHL and co-workers [18], the growth rate of pearlite will depend on both, diffusion coefficient of carbon in austenite and pearlite interlamellar spacing. Consequently, as the temperature is lowered the pearlite interlamellar spacing is reduced its, compensate decrease in diffusivity with decreasing temperature.

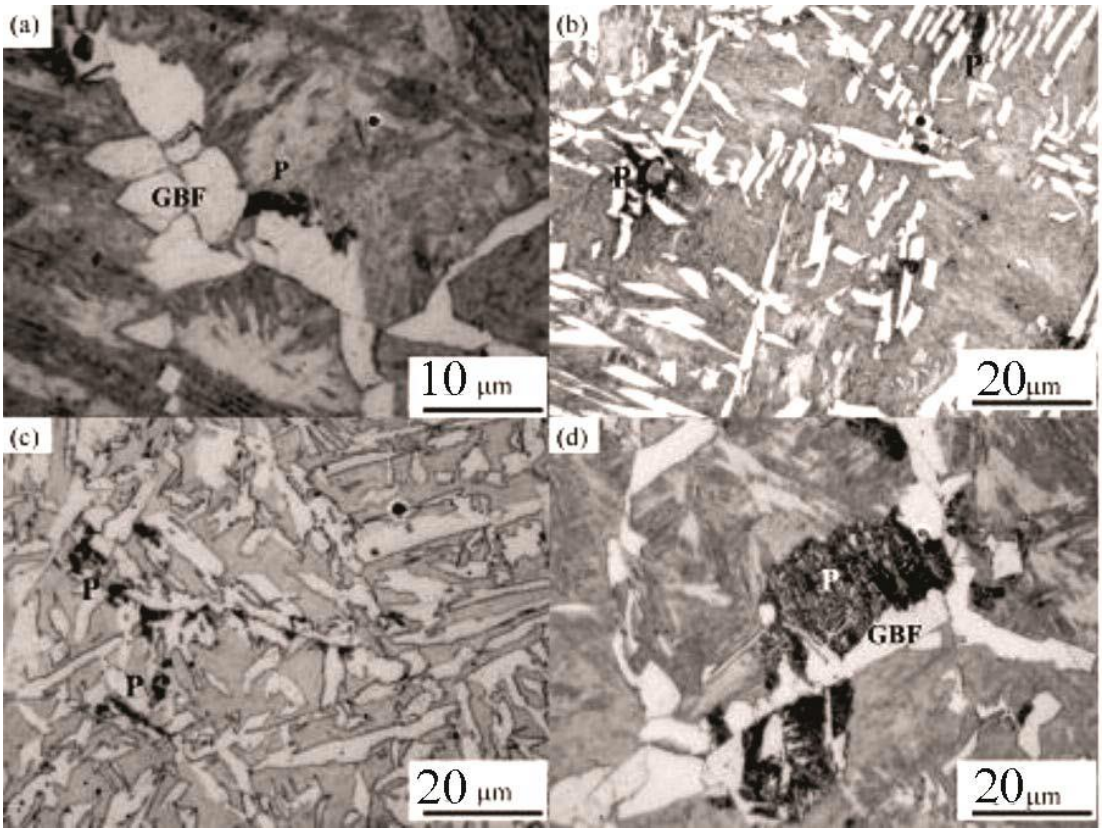

Figure 4. Optical micrographs of Ti free steel showing the onset of pearlite: (a) 30s at 600 °C. (b) 45s at 550 °C. (c) 80s at 500 °C (d) 60s at 600 °C.

4. Conclusion

The aim of the present study was to clarify the influence of isothermal transformation temperature, time and titanium addition on the nucleation and transformation of pearlite and indirectly, on the nucleation of the other phases in two types of V micro alloyed forging steels with and without titanium addition. Metallographic studies enabled determination of the nucleation phases of isothermally decomposition austenite in the two types of steel investigated. Three phases are found to be relevant to nucleation stage of transformation. First, GBF phase which extends over the entire temperature range studied (350-600°C) as represented in table 2, second, IGF phase which is divided into the high temperature polygonal and the low temperature acicular ferrite phase, and the third the pearlite (P) phase. On increasing the isothermal time further, the nucleation of pearlite (P), as shown in figure 4d. Addition of Ti to V-micro alloyed steel in this work seems to be balanced by a slightly higher C and Mn content. Finish of transformation was clearly observed at temperatures below 500 °C. However, at 550 and 600 °C, incomplete reaction phenomenon occurs. This be haviour is attributed to carbon enrichment in austenite and decrease of driving force for austenite decomposition.

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