MICROSTRUCTURAL EVALUATION AND CONTINUOUS COOLING TRANSFORMATION OF A MEDIUM CARBON MICROALLOYED STEEL

Nicélio José Lourenço
Centro Técnico Aeroespacial – Instituto de Aeronáutica e Espaço – Divisão de Materiais – Pça. Mal. Eduardo Gomes, 50 V. das Acácias – S.J. dos Campos-SP – CEP: 12228-904 (present address)
nicelio@iae.cta.br

João Manuel Domingos de Almeida Rollo
Universidade de São Paulo – Escola de Engenharia de São Carlos – Departamento de Engenharia de Materiais, Aeronáutica e Automobilismo – Av. Trabalhador Sancarlense, 400 – São Carlos-SP – CEP: 13560-970.
tfase@usp.br

Abstract. *The aim of this work was to study the phase transformation phenomena in a medium carbon microalloyed steel by using the dilatometry technique. This technique allows the construction of a diagram, usually denominated CCT (Continuous Cooling Transformation). At the same time, scanning electronic microscopy studies were accomplished for the characterization of the microstructures obtained. The study showed that for low cooling rates, below* $1^oC/s$*, the transformation resulted is a predominantly pearlitic microstructure. For intermediary cooling rates (from* $3^oC/s$ *to* $10^oC/s$*), a mixed microstructure containing pearlite and bainite was observed. Finally, at higher cooling rates (from* $30^oC/s$ *to* $70^oC/s$*) the transformation was completed with predominantly martensitic microstructure.*

Keywords. *Automotive industry, CCT diagram, Dilatometry, Microalloyed steel, Microstructure.*

1. Introduction

Steel is one of the metallic materials which has been having a continuous evolution in last century with a large range of production. Among the several kinds of steel available in the market, it is possible to highlight the microalloyed steel, which had a significant advance in the 1970's. Microalloyed steels contain special elements, such as Nb, V, Ni, and Ti in a concentration usually lower than the 15% (HONEYCOMBE, R.W.K; JAHAZI, M.).

Because of its mechanical properties, microalloyed steels are largely applied in automotive industry. Vanadium microalloyed steel is applied in forging products such as crankshafts and connecting rods (PICKERING, F.B.; MUSSCHENBORN, K. P.). The knowledge of its microstructure is fundamental for the correct application in industrial scale, thus encouraging the study of the metallurgical phenomena and processing schedule which involve this specific steel.

In this context, the aim of this work was to investigate phase transformations which may occur in a vanadium microalloyed medium carbon steel by using dilatometry tests. Continuous cooling transformation diagram (CCT diagram) was also performed. Afterwards scanning electronic microscopy was employed to observe the microstructures obtained.

2. Experimental procedure

The material used was a medium carbon steel containing vanadium as the microalloying element. Its chemical composition is given in Tab. (1).

Table 1. Chemical composition of the vanadium microalloyed medium carbon steel (% weight).

C	Si	Mn	V	P	N	Al
0,39	0,62	1,30	0,11	0,016	0,013	0,025

Samples of the investigated steel were supplied as cylindrical bars with 2.54 cm of diameter and 15 cm in length. Bars were worked to the final geometry showed in Fig. (1).

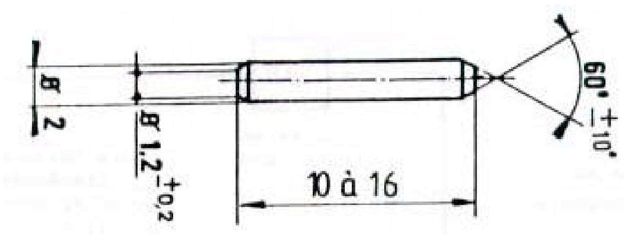

Figure 1. Sample geometry for dilatometry tests. The numerical values are in millimeters.

2.1 Dilatometric tests

The dilatometric tests were performed in an ADAMEL LHOMARGY (DT 1000 model) dilatometric test equipment to determine the steel behavior under several different cooling rates. In this work, the soaking temperature used was 1150^{o}C, for 10 minutes. This temperature and time assure a complete austenitic field. Cooling rates employed were 1, 5, 10, 15, 20, 30, 40, 50, and 70^{O}C/s. The schematic representation of the thermal cycle employed in cooling may be seen in Fig. (2). An example of the graphic result supplied by the dilatometric tests equipment is showed in Fig. (3).

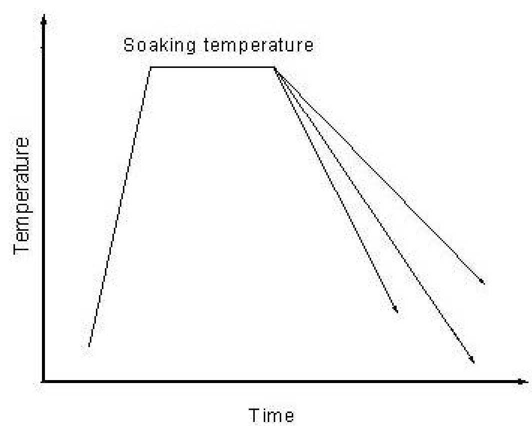

Figure 2. Schematic illustration of the thermal cycle employed in the dilatometric tests performed.

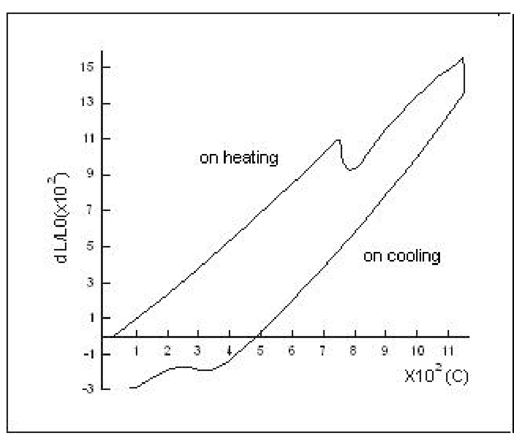

Figure 3. Typical dilatometric curve obtained during the experiments.

3. Results and Discussion

3.1 CCT Diagram

From the dilatometric curves obtained, it was constructed the CCT diagram showed in Fig. (4). Table 2 shows the initial and final austenite decomposition temperatures, Ar_3 and Ar_1, respectively, along with the martensitic beginning, Ms, and finishing, Mf, temperatures resulted.

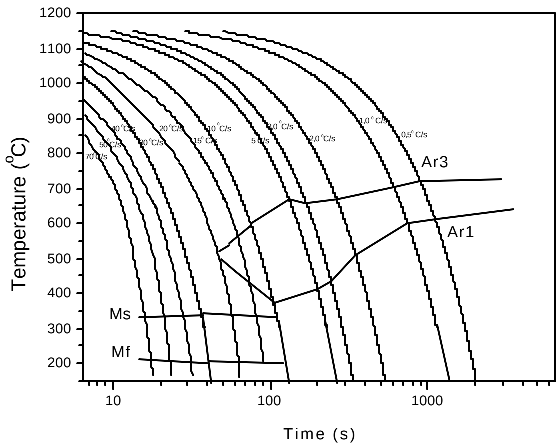

Figure 4. CCT diagram elaborated from the dilatometric curves. Abbreviations: Ar_3, initial austenite decomposition temperature; Ar_1, final austenite decomposition temperature; Ms, initial martensite formation temperature; Mf, final martensite temperature.

Table 2. Phase transformation temperatures obtained at various cooling rates. Abbreviations: Ar_3, initial austenite decomposition temperature; Ar_1, final austenite decomposition temperature; Ms, initial martensite formation temperature; Mf, final martensite temperature.

Cooling rates ($^oC/s$)	**Ar_3 (^oC)**	**Ar_1 (^oC)**	**Ms (^oC)**	**Mf (^oC)**
0.5	720.5	610.2	-	-
1.0	705.0	600.3	-	-
2.0	669.5	510.3	-	-
3.0	660.5	436.7	-	-
5.0	670.6	410.4	-	-
10.0	600.4	370.7	330.1	200.7
15.0	566.8	431.3	332.5	205.4
20.0	510.5	443.9	335.7	212.8
30.0	-	-	340.8	204.0
40.0	-	-	323.5	206.4
50.0	-	-	318.5	210.5
70.0	-	-	321.5	208.4

The diagram CCT analysis associated with SEM microstructures showed that for cooling rates less than $1^oC/s$ ferritic-pearlitic microstructures occurred as it can be observed from Fig. (5-A). Cooling rates from $3^oC/s$ to $10^oC/s$ presented a mixed microstructure containing pearlite, ferrite and bainite as showed in Fig. (5-B). Higher cooling rates, more than $10^oC/s$ presented a typical martensitic microstructure, as it can be seen in Fig. (6-A-B).

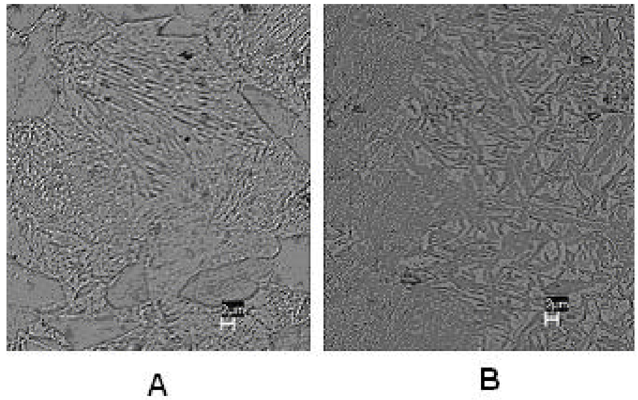

Figure 5. Scanning electronic microscopies showing a pearlitic microstructure in "A" obtained at 1°C/s cooling rate and bainitic microstructure obtained at 3°C/s cooling rate in "B".

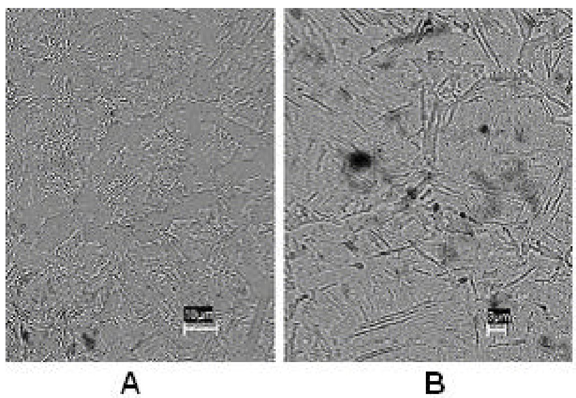

Figure 6. Scanning electronic microscopies showing a martensitic microstructures obtained at 10°C/s cooling rate (A) and at 30°C/s cooling rate (B).

Microhardness tests showed an increase in hardness with increasing cooling rates. Thus, at a cooling rate of 1°C/s it was obtained HV(10) = 298.2, meanwhile at higher cooling rates, for instance, at 30°C/s, it was obtained a value of HV(10) = 502.4. These results are in accordance with previous studies (GLADMAN, T.; BORDIGNON, P.J.P) reported for steels with similar chemical compositions.

Finally, the results presented in Tab. (2) showed a correspondent variation of the phase transformation temperatures with the cooling rates employed. Such variations occurred with the decrease of the temperatures at the beginning and at the end of the transformations, as the cooling rate was increased. It can also be noted that the temperature intervals in which the transformations occurred were depend on the cooling rates. Thus, at cooling rates below 1.0°C/s, the transformation was complete in intervals near to temperatures of 100°C. At intermediary cooling rates (from 3°C/s to 10°C/s), phase transformation was complete with temperatures ranging from 200 to 300°C. Increasing cooling rates (30°C/s), resulted in complete transformation at intervals near to 100°C.

4. Conclusions

- Ferritic-pearlitic microstructures were observed at cooling rates lower than 1°C/s. This cooling rate is ideal for this microalloyed steel to be used as a forged product.
- Intermediary cooling rates ranging from 3°C/s to 10°C/s showed mixed microstructure containing ferrite-pearlite and bainite.
- Cooling rates higher than 30°C/s presented martensitic microstructure formation.

5. Acknowledgement

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