

## Evaluating the impact of titanium or equivalent carbon on the hot ductility of medium carbon steels

### *Avaliação do impacto do titânio e carbono equivalente na ductilidade a quente dos aços médio carbono*

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#### **Resumo**

O objetivo desse trabalho é avaliar o impacto do titânio e carbono na ductilidade a quente de aços médio carbono com e sem a presença de titânio. Para isto, foi utilizado o simulador termomecânico Gleeble® 3500, na realização dos ensaios de ductilidade a quente e o Microscópio Eletrônico de Varredura (MEV), para análise do aspecto da fratura. Para análise microestrutural, foi utilizado microscópio ótico. Foram estudados cinco tipos de aço. Dois destes aços contêm 0,02% de titânio em sua composição e os demais contêm apenas valores residuais desse elemento. Os resultados indicaram que a relação Ti/N entre 3 e 5 apresenta menores perdas de ductilidade nas temperaturas entre 700°C e 800°C, além disso, verificou-se que os aspectos das fraturas mostraram-se não dúctil. Os aços contendo titânio em sua composição também apresentaram menores tamanhos de grãos austeníticos nas temperaturas próximas à de transformação da austenita para ferrita (Ar3). Foi observado que a temperatura de aparecimento de fragilização do aço é inversamente proporcional ao aumento do teor de carbono equivalente, nas temperaturas entre 700°C e 800°C.

**Palavras-chave:** Titânio, carbono, ductilidade a quente.

#### **Abstract**

*In this work were evaluated the titanium and carbon effects on the hot ductility of medium carbon steels. In order to achieve this, used were the thermomechanical simulator Gleeble® 3500, for the hot tensile tests, and Scanning Electron Microscope (SEM) to analyze the aspect of the fracture. Microstructure analysis was done by an optical microscope. Five types of steel were studied. Two of them contained 0.02% of titanium and the others contained only residual amounts of this element. The results indicated that the Ti/N ratio between 3 and 5 regards lower loss of ductility at temperatures between 700°C and 800°C and at these temperatures the fractures are non-ductile. Steels containing titanium also show lower austenitic grain size at temperatures near to the austenite to ferrite transformation (Ar3). Moreover, the low ductility temperature was found to be inversely proportional to the equivalent carbon content.*

**Keywords:** Titanium, carbon, hot ductility.

## 1. Introduction

Transverse corner cracks currently represent one of the main surface issues in medium carbon steels produced in continuous casting machines. This type of crack is usually associated with regions of low ductility at temperatures above 600°C during strand unbending in a continuous casting machine.

There are three Brittle Temperature Ranges (BTR) (Suzuki, 1982). In these regions the steel embrittlement is noticed due to the reduction of its ductility and they are expressed as zones I, II and III, as shown in Figure 1.

Zone III is the region where the transverse cracks are usually generated during the continuous casting process (Brimacombe & Shorimachi, 1977). In this zone, the steel embrittlement relates

to the coexistence of austenitic and ferritic phases from Ar<sub>3</sub> temperature associated to precipitation, mostly nitrides, in the grain boundaries. The presence of primary ferrite and precipitates in the austenitic grain boundaries generate internal stresses and micro-voids if the steel is subjected to continued tension. It's harmful to the grain cohesion (Carpenter & Dippenaar, 2009).

It's well known that the steel chemical composition has an important role on steel embrittlement at temperatures above 600°C (Mintz, 1999, Cho et al., 2011 and Mohamed, 2002).

Abushosha et al (1991) and Mintz et al (1991) showed in their studies that reducing carbon levels in the steel composition induces primary ferrite to form at higher temperatures, increasing the tem-

perature of steel embrittlement in zone III.

The titanium effect on hot ductility is associated to preferential formation of TiN at high temperatures, preventing the formation of AlN. The TiN precipitates uniformly in the austenitic matrix and it is less prejudicial than the AlN precipitation, which occurs chiefly at the grain boundaries. Titanium improves the hot ductility when the ratio Ti/N is higher than 3.4 (Mintz, 2000).

Therefore, in order to understand the steels embrittlement mechanism aiming to prevent or minimize the appearance of corner cracks in slabs produced by continuous casting, this paper studies the effect of titanium and carbon on hot ductility of medium carbon steels, focusing on zone III.

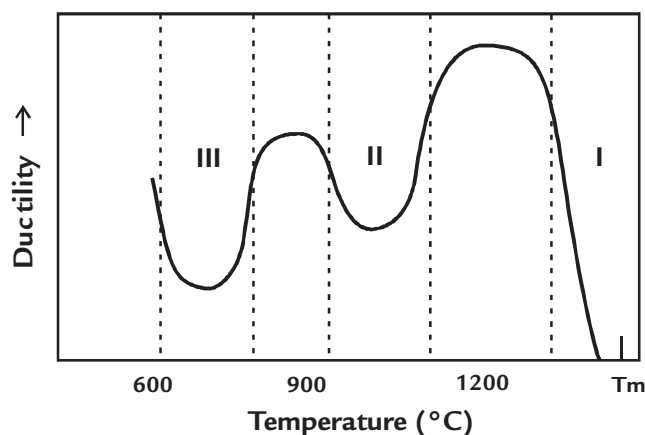


Figure 1  
Schematic representation of BRT zones (Carvalho, 1988).

## 2. Methodology

Five medium carbon steels were selected. Two of them titanium alloyed and the others containing just residual amounts of this element. The equivalent

carbon (CE) was calculated according to the formula 1, proposed by the International Institute of Welding (IIW/IIS, 1974). The samples were submitted

to chemical composition analysis by an optical spectrometer. Table 1 shows the results of the analysis as well as the values of Ti/N and CE.

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (1)$$

C, Mn, Cr, Mo, V, Ni and Cu are expressed in %wt in formula 1.

Steel	C	Si	Mn	S	P	Al	Ti	N	CE	Ti/N
A	0.16	0.37	1.4	0.0096	0.014	0.03	0.02	0.0037	0.40	4.86
B	0.15	0.37	1.47	0.0042	0.016	0.04	0.02	0.0055	0.39	3.09
C	0.17	0.15	0.68	0.0057	0.015	0.03	0.001	0.005	0.29	0.20
D	0.16	0.35	1.41	0.0059	0.019	0.04	0.002	0.0026	0.38	0.77
E	0.17	0.24	1.22	0.0068	0.015	0.03	0.003	0.0037	0.39	0.81

Table 1  
Steels chemical composition.

Cylindrical specimens (SPEC) with 9.53 mm of diameter were prepared. In the half part of each SPEC a "neck" with 9.02 mm of diameter were made accord-

ing the sketch showed in Figure 2. The SPEC were subjected to hot tensile tests in Gleebe® 3500 at temperatures from 650°C to 900°C in steps of 50°C. Prior to

performing the hot tensile test, the SPEC were subjected to heat treatment in order to allow complete austenitic formation and growth to similar size for all samples

and to promote precipitate dissolution (Mintz, 1999) at 1350°C for 5 minutes and then cooled to a test temperature at 1°C/min ratio. The hot tensile test results are expressed as a function of the SPEC

reduction of area (% RA) in the fracture region. The %RA represents the ductility of the material. Increasing the %RA represents higher values of ductility and vice versa.

After hot tensile tests, the SPEC was cooled at a rate of 9°C/s approximately. The fractures were analyzed by scanning electron microscopy and the microstructure by an optical microscopy.

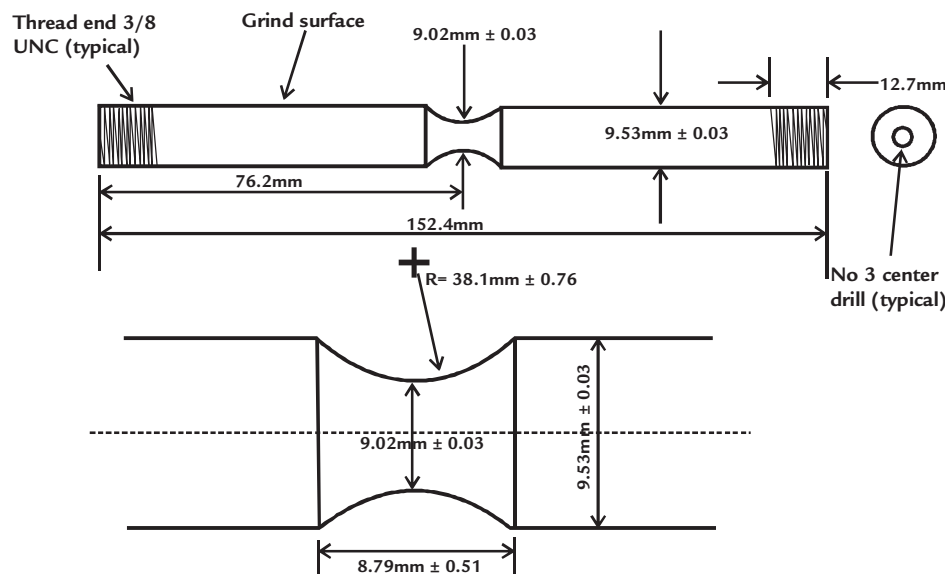


Figure 2  
Schematic design of the specimens.

### 3. Results and discussion

After the hot tensile tests, the reductions of area were calculated for each SPEC to be used as a measure of ductility and are shown on Table 2.

According to Table 2 all steels showed significant loss of ductility at temperatures between 700°C and 800°C. The losses of ductility in the steels containing titanium (steel A and B) were lower than the rest (steels C, D and E) as shown in Table 2.

As the chemical composition of steels A and D vary basically on the titanium content, they were selected to evaluate the fracture aspects by SEM. The SPEC was tested at 700°C and 750°C that represents regions of high and low ductility of each steel. The SEM analyses are shown in Figure 3.

By comparing the images “A” and “F”, shown in Figure 3, it is observed that steel D’s fracture seems less ductile than the steel A fracture. These steels showed ductility troughs at 750°C. The difference

in %RA between steel A and D is approximately 20%, indicating greater ductility of steel A in the region of embrittlement.

Table 1 shows that the Ti/N value for steel A is approximately six times higher than steel D. The best ductility of steel A at the zone III ductility trough may be associated to the presence of titanium. When the steel is titanium alloyed, TiN will be formed preferentially to AlN, which doesn’t occur with titanium alloyed steels. TiN is considered less harmful to hot ductility than AlN (Vedani et al., 2009).

In order to evaluate the effect of the Ti/N ratio on hot ductility in zone III, a curve correlating %RA at the zone III ductility trough and Ti/N values was plotted. The curve is shown in Figure 4.

It is observed in Figure 4 that increasing Ti/N implies higher %RA after hot tensile tests at zone III temperatures, indicating better ductility for higher Ti/N values at these temperatures. This can be associated to the preferential formation of

TiN, reducing the availability of nitrogen to form AlN. When Ti/N is higher than 3, the %RA exceeds 45% at zone III ductility trough.

In order to evaluate the microstructure, the samples tested at 750°C of steel A and D, were sectioned transversely and analyzed by optical microscopy. Figure 5 shows the images made. The white region is the primary ferrite formed at the austenite grain boundary.

It is observed in Figure 5 that steel A (titanium alloyed) presents smaller austenitic grain sizes than steel D. It is estimated that the austenitic grain size in steel A is at least three times smaller than in steel D. According to Abushosha et al (1991) the presence of TiN particles promotes the refinement of austenite grain size and improves the steel ductility by increasing the triple point concentration. The triple points act as barriers preventing crack propagation. The microstructure analysis of steels A and D showed that the titanium

Table 2  
Reduction of area for the  
SPEC tested (%RA).

Test Temp. (°C)	Steel A	Steel B	Steel C	Steel D	Steel E
900	81.9	84.7	89.6	89.6	86.4
850	75.7	73.2	87.7	85.8	82.0
800	76.0	78.3	27.1	60.2	83.6
750	52.6	55.8	40.4	31.2	27.7
700	74.7	46.6	79.7	53.6	54.0
650	75.3	76.7	66.6	73.8	56.1

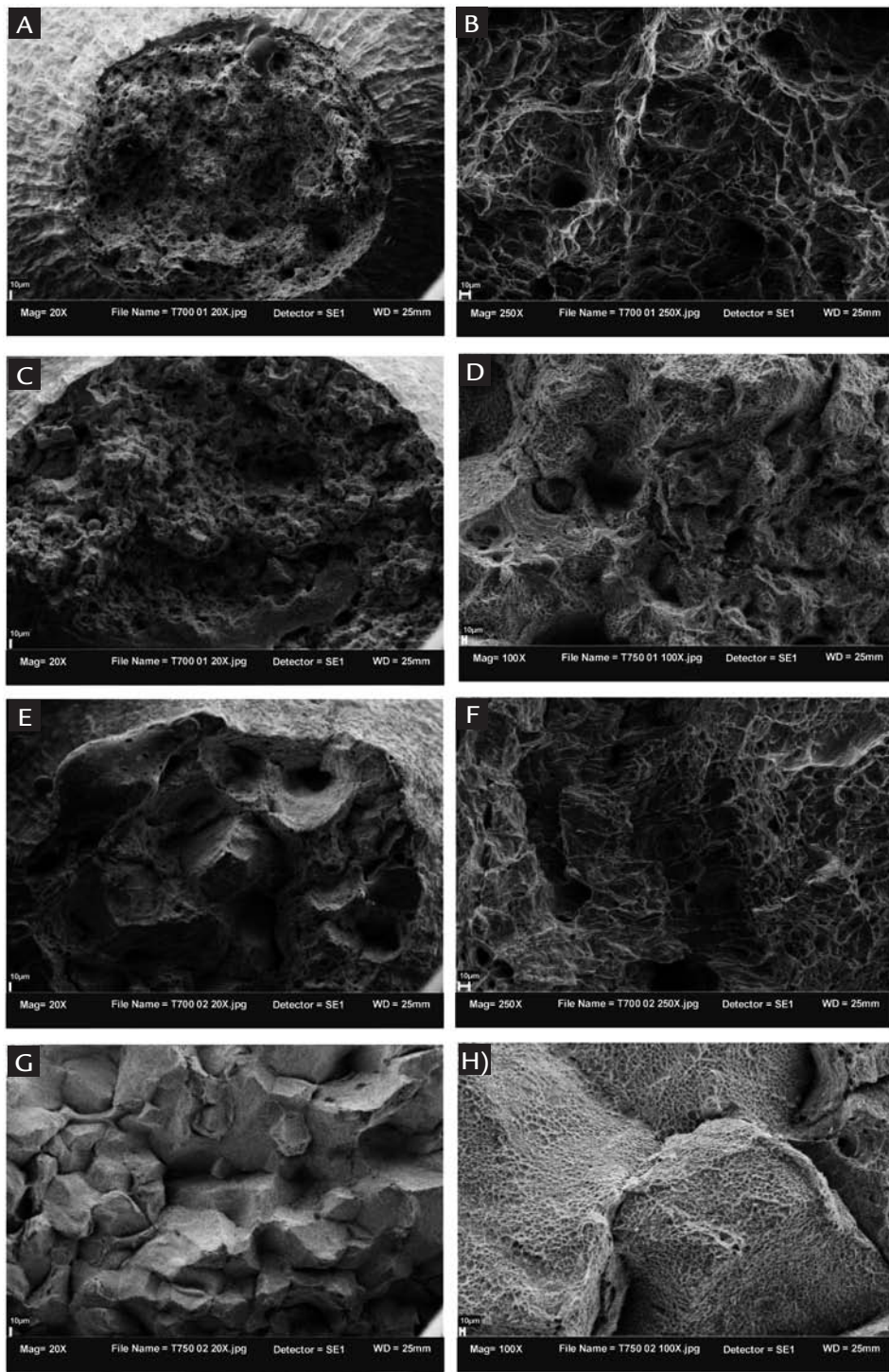


Figure 3  
Fracture aspects of SPEC analyzed at 700°C and 750°C.  
(A) Steel A 700°C 20X.  
(B) Steel A 700°C 250X.  
(C) Steel A 750°C 20X.  
(D) steel A 750°C 100X.  
(E) Steel D 700°C 20X.  
(F) Steel D 700°C 250X.  
(G) Steel D 750°C 20X.  
(H) Steel D 750°C 100X.

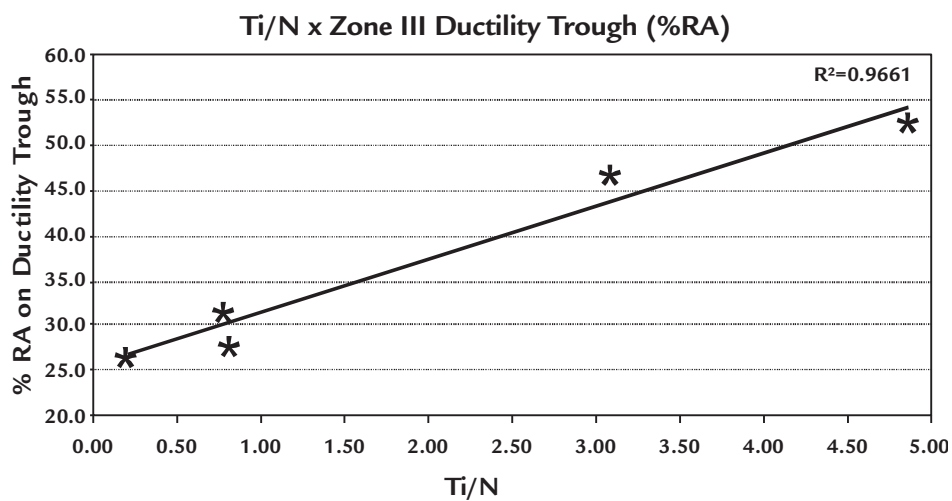


Figure 4  
Correlation between %RA at zone III ductility trough and Ti/N values.



alloyed steels presents lower austenitic grain sizes than titanium free steels.

In order to evaluate the effect of carbon on the ductility trough in zone III, the carbon concentration for each steel type and the ductility trough temperature in zone III are shown in Table 3.

The impact of the carbon content in the ductility trough in zone III did not follow the studies presented by Abushosha et al. (1991) and Mintz et al. (1991). In the present study, increasing the carbon content didn't result in lower temperatures in the ductility trough in zone III. Steel C has 0.17% carbon

content; the highest value among the steels examined. In addition, the ductility trough occurred at 800°C; higher than the others steels. According to Abushosha et al. (1991) and Mintz et al. (1991) it was expected that steel C would present the lowest ductility trough temperature, since it has the highest concentration of carbon steels examined.

According to Macedo (2007), the presence of alloying in the steel changes the stability phase. The alloys are classified as ferrite or austenite stabilizers. Such elements can expand or reduce the phase stability fields by changing the tempera-

tures for appearance at each phase. For a better evaluation of the temperature that the phases occur, it is recommended to use CE, since its formula already considers the effect of alloys.

The correlation between CE and the ductility trough temperature in zone III was plotted in order to evaluate the effect of CE on hot ductility. The correlation is shown in Figure 6.

It is observed in Figure 6 that increasing CE results in the reduction of ductility trough on zone III, indicating that the primary ferrite formations occur at lower temperatures.

Figure 5  
Micrographic analysis of steels A and D tested at 750°C.  
(A) Steel A.  
(B) Steel D.  
Attack 2% Nital.

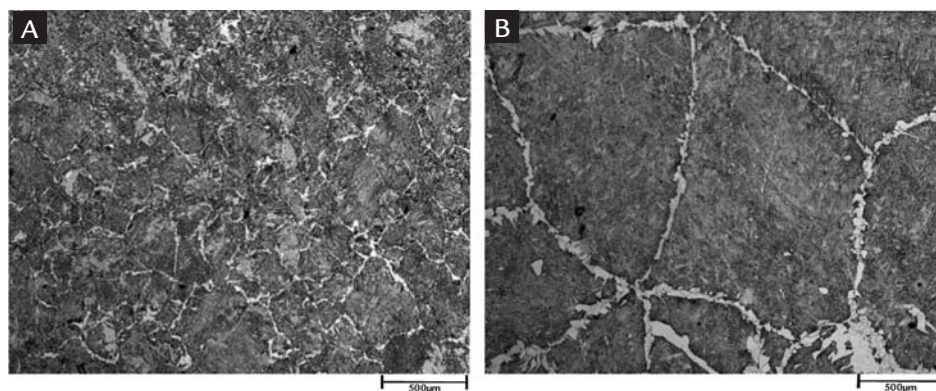
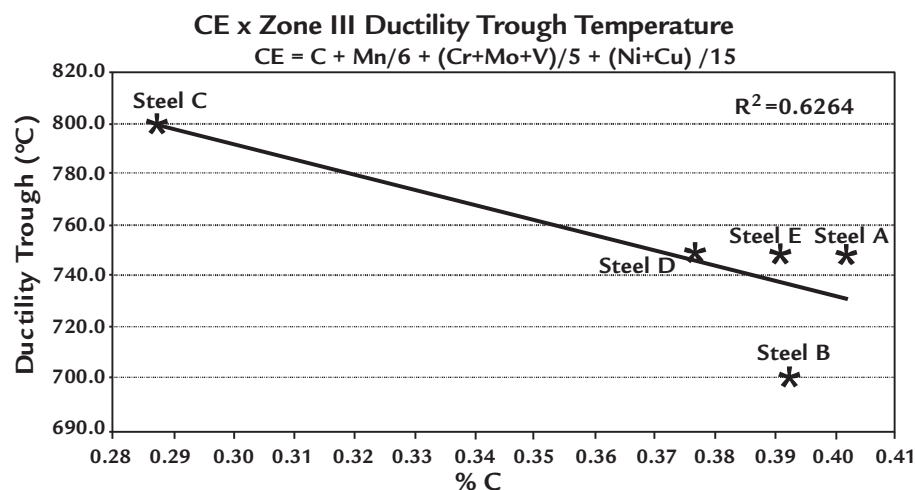


Table 3  
Ductility trough in zone III temperature and carbon concentration.

	Steel A	Steel B	Steel C	Steel D	Steel E
Ductility trough in zone III (°C)	750	700	800	750	750
C (%)	0.16	0.15	0.17	0.16	0.17

Figure 6  
Effect of equivalent carbon on the ductility trough in zone III.



#### 4. Conclusions

Through the results of experiments, we can reach the following conclusions:

The presence of titanium in medium carbon steels provides an improvement on hot ductility in zone III. This behavior can be attributed to TiN formation that inhibits the AlN formation. The steels

with Ti/N above 3 showed better results.

The titanium alloyed steels present austenitic grain sizes at least three times lower than those without this element in the composition. It improves the ductility in zone III due to the increased amount of triple points.

The carbon evaluated in isolation has no influence on ductility trough temperature. However, the CE showed a correlation of approximately 60% with the ductility trough in zone III, indicating the importance of considering the presence of alloying on the primary ferrite formation.

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