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The Study of a Drop of Plasticity Behavior of the As-Cast Low Carbon Steels in γ → α Transformation Region

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Abstract

Plasticity degradation in the region of γ → α transformation was studied on experimental material comprising 24 commercially produced low carbon steels. Specimens were high frequency heated under protected argon atmosphere and the experiments were realized by tensile tests at constant testing conditions. The main aim of the work was to quantify the plasticity drop evaluation by statistical analyses of the reduction of area values. A considerable influence of the austenite grain size and/or boron on the intensity of plasticity drop was demonstrated. Temperature of the plasticity degradation, which was up to 323°C higher than the theoretical γ → α temperature, increased without the embrittlement effect of the proeutectoid ferrite on the austenite grain boundaries but as well as the increase of the content of trace elements, particularly of arsenic. Attention was also given to study the morphology of fractures formed in the temperature region of plasticity degradation.

Keywords: low carbon steels, as-cast state, hot ductility, γ → α transformation, austenite grain size, effect of trace elements, intensity of R.A. drop

Introduction

Various surface defects can locally occur during low carbon steels casting[1-2]. Defects can subsequently and negatively influence the quality of the final products. A high temperature test, which was focused chiefly on the study of temperature intervals of plasticity degradation is one of the possible methods to contribute to the reduction of the surface defects. The high temperature tests are realized by various methods and using various testing equipments.

A reduction of plasticity took place at high temperature plasticity tests in the as–cast state of low carbon steels in the region of γ → α transformation temperatures. The plasticity degradation is often explained by an embrittlement of the austenite grain boundaries as a consequence of proeutectoid ferrite precipitation on these boundaries[3] Various factors are influencing the decrease of the plasticity temperature, the intensity of its drop and its morphology as well as qualitative properties of ferrite[4-5] in matrix[6] However, in some cases, the plasticity degradation takes place at higher temperatures than the γ → α. transformation temperatures.

Besides a weakening of cohesion strength of the ferrite grain boundaries, the plasticity is negatively influenced also by weakening of the austenite grain boundaries as results of selective diffusion of trace elements [7-8]. In steels containing a relatively higher content of sulphur, the grain boundary weakening can take place also via precipitation of small sulfides on these boundaries [9-10]. The paper deals with fracture morphology studied in the temperature region of γ → α transformation in which plasticity degradation is taking place as well as the quantitative analysis of the intensity of its plasticity drop behavior.

Material and Experimental Procedures

The tests were realized on equipment comprising of a tensile testing machine, high frequency generator with measuring and control elements. Temperature-time heating cycles of specimens were operated by software. Testing was performed in a protecting atmosphere of argon. The specimens used for testing had a diameter from 5 – 6 mm. The test could be realized on the experimental equipments after heating up or after remelting the tested zone. The temperature-time cycles could be changed before testing in a quite wide interval. On tested specimens, strength and reduction of area values were evaluated. The experiments, results of which will be described and analyzed further, were realized under standard heating conditions (Figure 1) and at a deformation velocity of $4.7x10^2.s^1$. For establishing a possibility for mutual comparison of results constant testing conditions were chosen. The experimental material constitutes of 24 commercially-produced low carbon steels with carbon contents from 0.006 to 0.199 % and 5 steels were microalloyed. The testing equipment as well as a detail on the specimen heating technique is documented on Figure 1. The high temperature tests were done in a temperature interval from 800 – 900°C up to the melting temperature of the steel.

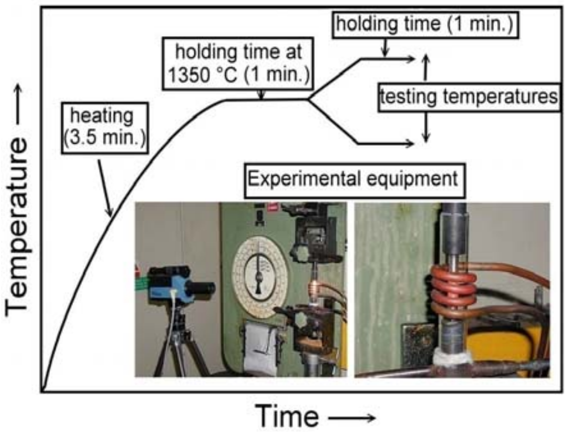

Figure 1. Heating up of specimens and the experimental equipment

Results and Discussion

Fracture morphologies

The decrease of the reduction of area values in the region of lower testing temperatures was evaluated by the temperature tx (Figure 2). From the difference of **tx** temperature and the theoretical transformation temperatures **tx teor**, extrapolated from the Fe – Fe3C diagram, we can see that a drop in reduction of area values was taking place also at noticeably higher temperatures as are the theoretical γ → α transformation temperatures (Figure 3). The tx – tx teor values were in an interval from -60 up to 323°C, with a an average value of 108°C.

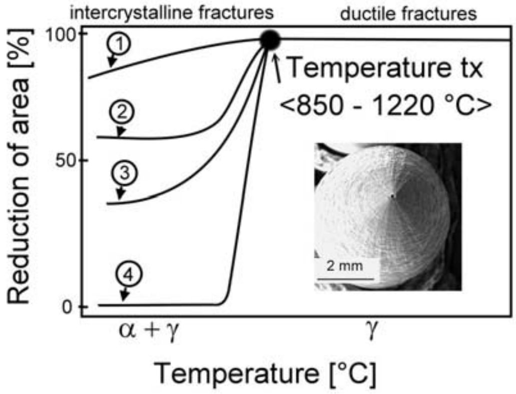

Figure 2. Scheme of a decrease of the reduction of area values and its classification

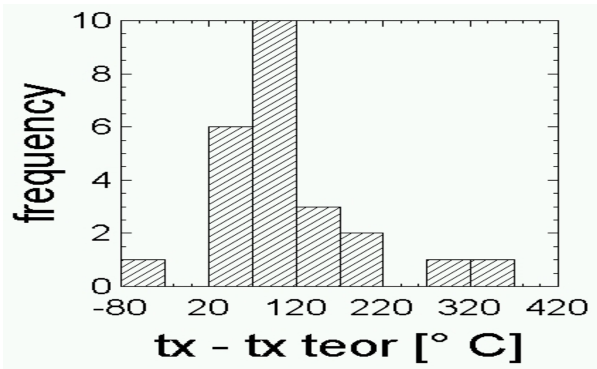

Figure 3. Frequency of tx – tx teor values

The character of the reduction of area values drop can be classified by grades from “1” to “4” (Figure 2). The criteria for classification was the level of reduction of area at testing temperatures 800 – 900°C. The course “1” represents a slight drop of the reduction of area on the level higher than 80 %. The reduction of area decrease and assessed as grade “2” representing its decrease on about 60 % and grade “3” on about 30 – 40 %. The grade “4” was chosen for an extremely high plasticity drop with a very low, sometimes non-measurable value. The character of the reduction of area decrease was assessed for all 24 tested steels with accuracy of one decimal place. The number of occurrence of such a way specified values (mode of R.A. drop) is documented on (Figure 4). the mean value was 2.2. The above defined character of the reduction of area drop will be further signed as M.

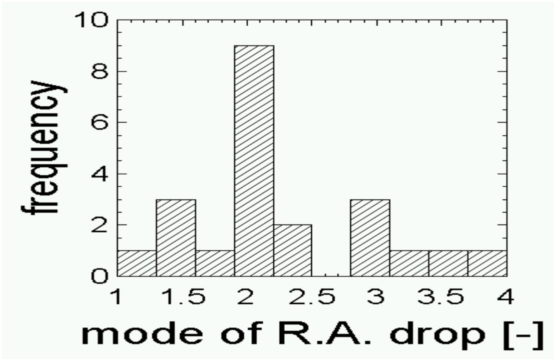

Figure 4. Frequency of M values

The dominance of transcrystalline ductile fracture was observed in steels classified as No. 1 even at the lowest testing temperatures. Plasticity degradation in other steels occurred through by the mechanism of intercrystalline failure Fractures of the steel qualified as 1.5 grade were formed from a mixture of transcrystalline ductile failure and intercrystalline ductile failure with sporadic occurrence of intercrystalline decohesion facets (Figure 5). Steels classified as grade 2 had a higher portion of intercrystalline failure constituent on the fracture surface (Figure 6). Intercrystalline fracture prevails in steels classified as grade 3 (Figure 7a), the ductile constituents were present almost solely on the intercrystalline facets (Figure 7b). Analogous fracture morphology as in steels classified as grade 3 was observed also in steel of grade 4 (Figure 8). Only one steel belonged to this group, with content of C – 0,034 % and an increased content of B on 0,006 %. An occurrence of secondary phases was observed on the fracture surfaces only sporadically and, according to the EDX analyses, they were common phases presented in the tested steel types. Any relevant information concerning to the enrichment of the fracture surfaces by some elements was not found.

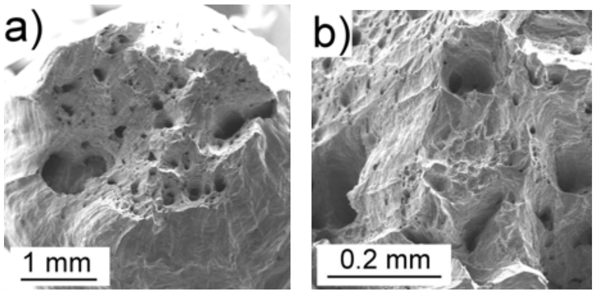

Figure 5. High temperature fracture, intensity of the reduction of area drop 1.5

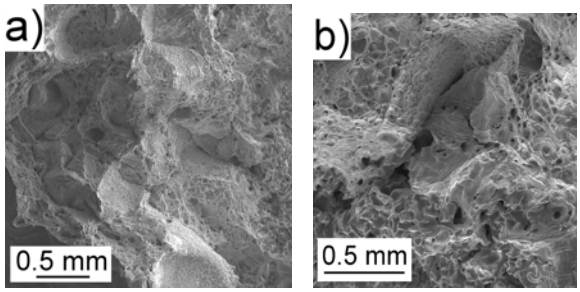

Figure 6. High temperature fracture, intensity of the reduction of area drop 2

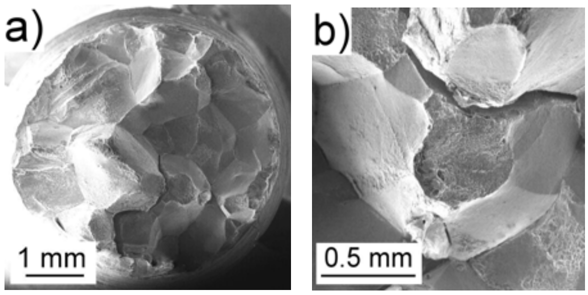

Figure 7. High temperature fracture, intensity of the reduction of area drop 3

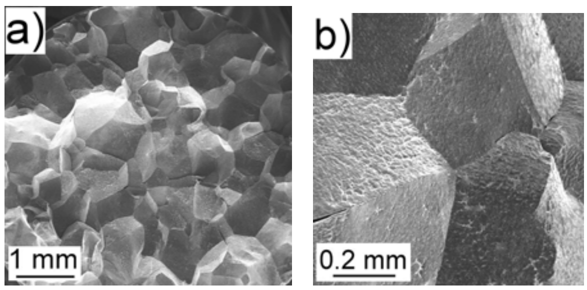

Figure 8. High temperature fractures, intensity of the reduction of area drop 4

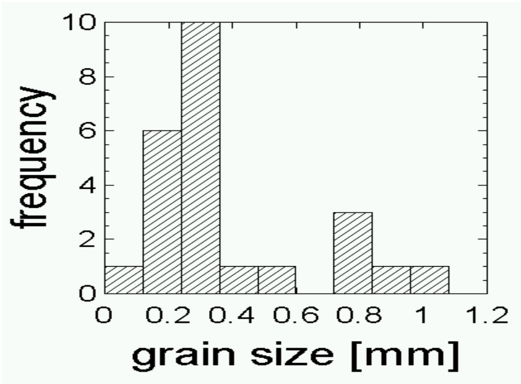

Figure 9. Frequency of the estimated austenite grain size

Statistical analyses of the results

The temperature range in which the reduction of area value, tx, ranged from 850 up to 1220°C. At lower tx temperatures, ductile elements were observed on the intercrystalline facets, their morphology was account for fracturing in the region of proeutectoide ferrite, e.g., (Figure 8b). Appearance of ferrite on the austenite grain boundaries at the temperatures above 930°C is not probable. The tx temperature, and the difference of temperatures tx teor - tx, resp. was statistically analyzed by help of the chemical composition and austenite grain size dF. The dF values were assessed through observations of fractures by SEM and metallographic cross-section by light microscopy.

The chemical analyses of C, Mn, Si, P, S, Al, N, V, Ti, Nb, Cu, Cr, Ni, As, Sn, and Sb were available. The dF values were in an interval from 0.12 to 1.0 mm, the mean value was 0.39 mm. From the previous work, it followed that the tx temperature unambiguously depends on the content of As, which was in an interval from 0.0024 to 0.014 %, and on the grain size dF.

The tx temperature is influenced also by contents of B and probably some others elements. Therefors, it can be possible to assumed that the tx temperature not only affected by the proeutectoide ferrite but also by the austenite grain boundary weakening as a consequence of a selective diffusion of trace elements, particularly As.

We used an analogous statistical access for the evaluation of the character of reduction of area values drop, M. From the results of statistical analyses, it is clear that the character of reduction of area drop M depends chiefly on the grain size dF:

M = 1.27+2.32 . dF   r = 0.7937   M [-], dF [mm]   (1)

Statistically significant relationship between M and dF is at the 99 % confidence level.

In case of including the content of B:

M = 1.13+2.06 . dF + 0,20 . B   r = 0.8158   M [-], dF [mm], B [0.001 %]   (2)

The relationship between M and B is at the 95 % confidence level. The observed and predicted M values are documented on (Figure 10). Other statistically notable independent variables concerning chemical composition were not found. The relationship between the characters of the M drop with the temperature tx was not statistically significant. The relationship between dF and the chemical composition was found in the form of:

dF = 0.46+0.0057. Al + 0.091. B - 6.04. P-1 + 0.02. S - 0.0087. Si   (3)

r =0.7661, dF [mm], Al, B, P [0.001 %], Si [0.01 %]

The correlation coefficient r has a lower value, but there is a statistically significant relationship between the variables at the 99 % confidence level.

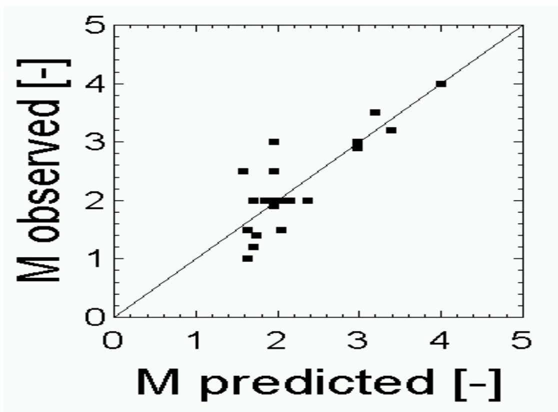

Figure 10 Observed and predicted austenite grain size values M, equation (2)

Low carbon steels represent from the point of view of chemical composition a multicomponent system. Their high temperature properties depend on the content elements which are present in these steels. It can be assumed that the influence of chemical compositions on the microstructure and properties is temperature dependent and that various interaction phenomena took place. The experimental material consisted of steels with different chemical compositions. Statistical analyses are giving integral information about the main influences on the studied parameters. More detailed study of this problem is performed at present. It is obvious from our analyses that the grain size and content of the trace elements, particularly As provide a net influence on the high temperature plasticity of the low carbon steels in the as-cast state.

Conclusion

Plasticity degradation of the low carbon steels in the as cast state in $\gamma \rightarrow \alpha$ temperature region arise by mechanism of intercrystalline fracture of austenite.

The classified and statistically analysed intensity of the reduction of area drop in this region increases with the austenite grain size grow.

The highest decrease of reduction of area amongst studied steels was observed for the steel with an increased content of boron, 0.006 %.

The austenite grain size dF at temperatures about 900 oC was estimated from fractures on SEM and on metallographic cross-section by light microscopy. According to statistical analyses, the dF value depends on contents of Al, B, P, S and Si.

The temperature of plasticity degradation is markedly influenced by the austenite grain size and by the content of trace elements. This temperature is intensively influenced by the effect of proeutectoide ferrite as well as the austenite grain boundary weakening through selective diffusion of trace elements, chiefly As.

Acknowledgements

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References

(1) Mintz, B. 2000. *Ironmaking and Steelmaking.* 27 : 343 – 347.

(2) Kato,T., et al. 2003. Prevention of slab surface transverse cracking by *ISIJ International.* 43 : 1742 – 1750.

(3) Chimani, C.M. and Morwald, K. 1999. Micromechanical investigation of the hot ductility *ISIJ International.* 39 : 1194 – 1197.

(4) Yin, H. et al. 1998. Determination of free energy of delta-ferrite/gamma-austenite interphase boundary of low carbon steels by in-situ observation *ISIJ International.* 38 : 794 – 801.

(5) Takeuchi, H. and Brimacombe, J.K. 1985. *Met. Trans. B.* 16B : 605 – 614

(6) Fujda, M. 2003, *J. Met. Mater. Miner.* 12 : 27 – 31.

(7) Abe,T. et al. 1990, *ISIJ International*. 30 : 444 – 450.

(8) Nagasaki, C. and Kihara, J. 1997. Effect of copper and tin on hot ductility of ultra-low *ISIJ International.* 37 : 523 – 530

(9) Nagasaki, C. and Kihara, J. 1999. Evaluation of intergranular embrittlement of a low carbon steel in austenite temperature range *ISIJ International.* 39 : 75 – 83.

(10) Suzuki, H. G., Nishimura, S. and Yamaguchi, S. 1982. *Transactions ISIJ.* 22 : 48 – 54.