HIGH TEMPERATURE EMBRITTLEMENT OF STEELS: THE ROLE OF ALUMINIUM AND SULPHUR

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ABSTRACT

The effect of aluminium and sulphur on the embrittlement in the temperature range from 1000 to 700°C was studied in case of a steel containing 0,2% C, 1,2% Mn and 0,3% Si. The investigation was carried out in the aluminium concentration of the range of 0,005 to 0,22 and sulphur of 0,004 to 0,025 weight percent. A sharp drop of ductility or percent reduction in area was found to occur when the content of aluminium was ~ 0,01%, showing maximum embrittlement in the range from 0,05 to 0,13% of Al. According to Auger spectroscopy deformation by the value of ε =9,5% at 800°C resulted in the average S concentration increase from 0,3 to 2,5 at.% at austenite grain boundaries.

KEYWORDS

Low-alloy steel, high temperature brittleness, ductility trough, grain boundary failure, ductile deformation, aluminium nitride, segregation of sulphur.

INTRODUCTION

It is known[1] that low-alloy Al-deoxidized steels exhibit high temperature embrittlement, i.e. the decrease of ductile properties in the temperature range from 1000 to 700°C. The highest degree of embrittlement corresponds to the interval from 850 to 750°C, which is due to the fracture along austenite grain boundaries. It is ascertained[2,3] that aluminium content affects the ductility trough. The question of sulphur's role in the range given above is disputable since the steels studied contain more than 1% Mn which binds sulphur into sulphides (MnS), which are difficult to dissolve. The aim of this work is to study the role of Al and S as well as their combined effect on the process of embrittlement of low-alloy steels in the temperature range of from 1000 to 700°C.

EXPERIMENTAL PROCEDURES

The experiments were carried out on the steel of high purity of the following composition: 0,2% C, 1,2% Mn, 0,3% Si. The content of Al was varied from 0,004 to 0,025 weight percent. One of the heats contained a small quantity of Ti (0,032%) which was added to prevent grain boundary precipitations of AlN. High temperature tensile testing was carried out in the chamber of IMASH 20-75 plant in the atmosphere of an inert gas on the samples of 3x3x70 mm. The strain rate was minimized at $6,5 \times 10^{-4}$ s^{-1}. The samples were heated by radiation with a tantalum radiator. The mechanical properties of steels were determined by cooling from the temperature of 1350°C. The prior heating to this temperature was used with the aim to dissolve a nonmetallic phase and obtain large austenite grains.

RESULTS AND DISCUSSION

The investigation of sulphur's role was carried out on the samples with two different contents of aluminium: a higher content (0,06-0,07%) and a lower content (0,01%). In the steel with a higher Al content on cooling below 1000°C one could observe a ductility trough with a minimum value of reduction in area at 800°C (Fig.1, curves 1,2). The reduced value of

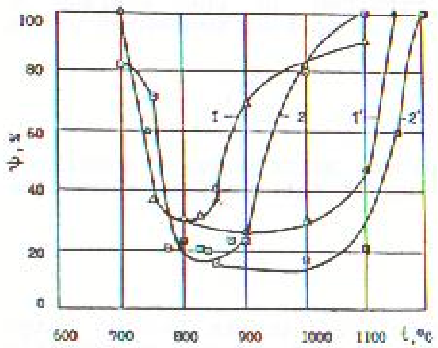

Fig.1. Sulphur effect of ductility of steel with an elevated Al content:
1,1' - 0,005% S,
2,2' - 0,025% S.

ductility was expected, as it is the characteristic for the steel with 0,025% S. Cooling down to the temperature of 800°C widens the range of embrittlement up to 1200°C for the steel with 0,025% S (curve 2'). Further, the ductility in the zone of widening was 10-15% lower for the steel with an increased S content in comparison to the steel with 0,005% S. The mechanism of failure in both cases was of a grain boundary fracture with negligible microdimples indicating brittle failure.

The results of S effect for the steel with a reduced aluminium content (0,01%) are presented in Fig.2. The failure of the samples in this case can referred to as that of ductile grain

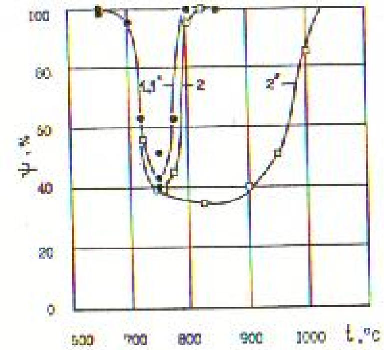

Fig.2. Sulphur effect on ductility of steel with 0,01% Al:
1,1" - 0,004% S,
2,2" - 0,020% S.

boundary fracture. Unlike the previous case (Fig.1), the increase of S content results in the lowering of ductile properties (Fig.2, curves 1,2). The broadening of the ductility trough was not observed after cooling down to the temperature of 750°C in the case of steels with 0,01% Al (compare curves 1 and 1").

In an earlier publication[4] it was shown that prestrain in the temperature range of 850-750°C resulted in the broadening of the ductility trough towards higher temperatures by more than 100°C. The experiments carried out in this work showed that with the S content of 0,020% the deformation by the value of 6% at the temperature of 750°C resulted in the broadening of the ductility trough upto 1000°C (Fig.2, curve 2"); with a low S content (0,004%) deformation did not affect the character of the dependence of ductile properties on temperature (curve 1").

Thus, from the results presented in Fig.2 it is evident that in this steel with a low Al content (0,01%), a negative role of sulphur is revealed only in the process of hot ductile deformation. The results of the S effect on high temperature ductility of a prestrained steel with a different aluminium content are summarized in Fig.3.

Similar concentration dependence illustrating the Al effect is shown in Fig.4. Curve 1 shows the change of reduction of area (ψ) of the steel with 0,004-0,005% S; curve 2 - 0,018-0,025% S. The samples were not prestrained in this case, i.e. the curves show the change in ψ value in the range of the minimum ductility temperature. Embrittlement is seen to occur when the content of Al is 0,01%; the maximum fall of ductile properties corresponds to a range of 0,05-0,13% of Al.

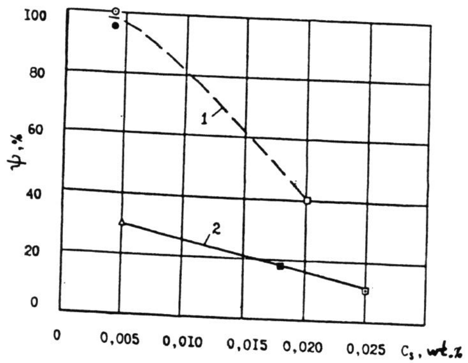

Fig.3. Effect of S content on ductility properties of steel with different Al contents:
1 - 0,01% Al (prestrain temperature - 750°C, temperature of testing - 900°C);
2 - 0,06-0,07% Al (prestrain temperature - 800°C, temperature of testing - 1000°C).

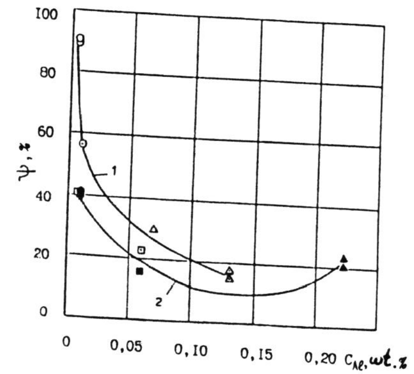

Fig.4. Effect of Al content on ductility properties of steels with two different S contents:
1 - 0,004-0,005% S;
2 - 0,018- 0,025% S.
Temperature of testing - 750-850°C (range of minimum ductility).

Electron microscopic examination accomplished by the method of carbon extraction replicas showed that a deleterian effect of Al was due to the precipitation of AlN on austenite grain boundaries. The quantity of AlN precipitates increases with the Al content. In this connection one can suggest that minimizing the AlN precipitation at grain boundaries should result in complete elimination of embrittlement. The experiments were performed on the steel containing a small quantity of Ti (0,032%) as well as lower contents of Al (0,005%) and S (0,005%). The results of high temperature mechanical testing of this steel showed that the value of exceeded 80% over the whole temperature range studied without grain boundary embrittlement. The data obtained proved that the purity of steel is of principle effect as well as the fact that the probability of AlN precipitation at grain boundaries must be minimized to eliminate high temperature brittleness.

To determine the chemical composition of the grain boundaries and the effect of hot ductile deformation on it, the fracture

surfaces were examined by an Auger analyser. The samples after different deformation at 800°C were cooled down to room temperature, electrolytically saturated with hydrogen, loaded according to the scheme of three-points bending till failure occurred and after that the samples were placed into the Auger microprobe chamber. The investigation was carried out on a model Cr-Ni steel containing 0,17% C, 2% Cr, 4% Ni, 1% Mo, 0,045% Al, 0,006% S, which allowed to obtain brittle failure at grain boundaries after hydrogen saturation.

Fig.5 shows the effect of the extent of deformation on S enrichment at grain boundaries. On increasing the deformation extent upto strain level ε =9,5% the average S concentration at grain boundaries increases from 0,3 to 2,5 at.%; the maximum S content on separate facets being 5,5 at.%.

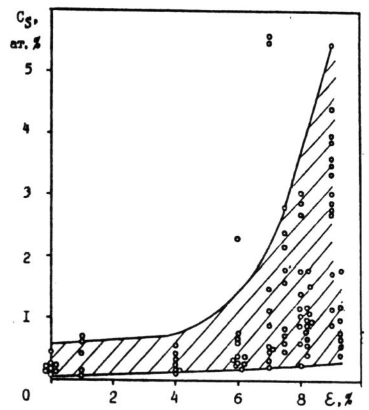

Fig.5. Effect of ductile deformation on S enrichment of grain boundaries of Cr-Ni steel.

CONCLUSION

The phenomenon of high temperature embrittlement of low-alloy steels in the temperature range from 1000 to 700°C can be accounted for by the combined effect of AlN precipitations and the process of formation of S-atoms segregations at austenite grain boundaries.

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