FISH EYE FORMATION IN A508.3 AND 18MND5 STEELS AFTER HYDROGEN CHARGING

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The presented paper deals with the study of hydrogen embrittlement of A508.3 (heavy forging) and 18MND5 (thick plate) steels. The effects of hydrogen are investigated by means of tensile tests on hydrogen charged specimens. Both materials seem to be susceptible to hydrogen embrittlement. Hydrogen gives rise to special defects, fish eyes, nucleated on coarse globular non-metallic inclusions. In spite of the fact that both materials do not differ in basic structural characteristics, their behaviour in the presence of hydrogen is different. The differences observed in material behaviour (mechanical properties, fractographic characteristics) are explained by local microstructural characteristics (segregations), by non-metallic inclusion morphology and also by local microstructural changes of the matrix in the vicinity of inclusions due to forging or rolling.

INTRODUCTION

Investigating the various forms of hydrogen embrittlement in steels, we can meet on fracture surfaces, although not too frequently, special defects called fish eyes. The fisheye regions represent circular areas of quasicleavage fracture centred on non-metallic inclusions and provoked by increased hydrogen content in steel. Analysis of literature data shows that there are only few repeated factors which could be considered as decisive for fish eye formation. Fish eyes were found in different steel products, in castings as well as in heavy forgings or in plates. They affect carbon steels but also various kinds of low alloy steels. As to microstructure, fish eyes were found in all basic types of steel structures. Concerning non-metallic inclusions, fish eyes can be observed around nearly all kinds of inclusions in steels. It seems, however, that at least two basic conditions can be defined which are decisive for fish eye formation in steels. According to Sojka (1) it is on the one hand the presence of relatively large non-metallic inclusions, regardless of their type, and on the other hand the testing conditions which must enable a significant interaction hydrogen - plastic deformation.

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The submitted paper describes fish eye formation in A508.3 and 18MND5 steels after hydrogen charging. It shows that their formation can be influenced by particular material characteristics, such as local properties of inclusion - matrix interface or local properties of metallic matrix in the vicinity of non-metallic inclusions.

EXPERIMENT

A heavy forging of A508.3 steel with thickness approx. 200 mm and a thick plate of 18MND5 steel with thickness of 80 mm were used for experimental studies. The chemical composition of steels is given in Table 1.

TABLE 1 - Chemical composition of steels (weight %)

Steel	C	Mn	Si	P	S	Cu	Cr	Ni	Mo
A508.3	0,22	1,35	0,20	0,008	0,003	0,006	0,13	0,78	0,50
18MND5	0,17	1,34	0,23	0,009	0,002	0,017	0,10	0,62	0,49

Both materials were used after conventional heat treatment comprising water quenching and subsequent high temperature tempering. Steels were tested by means of tensile tests on smooth cylindrical specimens at the deformation rate $\dot{\varepsilon}=6.10^{-5}\ s^{-1}$. Specimen orientation was tangential (T) or through thickness (TT) in case of A508.3 steel and longitudinal (L) or through thickness (TT) in case of 18MND5 steel. Hydrogen was introduced into specimens prior to tests by electrolytic charging in 1N HCl solution with 1g/l KSCN. Charging time was 24 hours and a standard current density applied was 50 Am^{-2}. In case of 18MND5 steel, a lower current density was also applied, 5 Am^{-2}. A special attention was given to the detailed metallographic analysis of tested materials by means of light and scanning electron microscopy, including the methods of image analysis, local chemical analysis and quantitative fractography.

RESULTS AND DISCUSSION

High temperature analysis of hydrogen content in steels has ascertained that in initial state both materials contained approx. 0,9 ppm of hydrogen. After hydrogen charging with applied current density 50 Am^{-2} A508.3 steel contained 7,2 ppm of hydrogen while hydrogen content was lower in 18MND5 steel, only 4,8 ppm for the same conditions of charging. When charging with lower current density (5 Am^{-2}), 18MND5 steel contained 3,4 ppm of hydrogen.

Mechanical properties of both steels are shown in Table 2, always for both orientations of testing specimens. The values of mechanical properties after hydrogen charging correspond to the current density of 50 Am^{-2}, the values obtained for 18MND5 steel with lower current density are given in the brackets. Hydrogen has manifested itself namely by the loss of plastic properties expressed here by the reduction of area for all orientations excepting L orientation of 18MND5 steel. Parameter F represents hydrogen embrittlement index expressed as a relative loss in reduction of area after hydrogen charging with respect to the initial state. None of the evaluated materials shows in its initial state a significant anisotropy of mechanical properties. For A508.3 steel it is valid also after hydrogen charging. In case of 18MND5 steel we observed, in presence of hydrogen, a significant anisotropy of mechanical, or more precisely, of plastic properties.

While in L direction the hydrogen embrittlement index is low, its value increases considerably for tests in TT direction.

TABLE 2 - Mechanical properties of A508.3 and 18MND5 steels

Steel	R_{eL} (MPa)		R_m (MPa)		Z (%)		F (%)
	0	H	0	H	0	H	H
A508.3 T	546	554	670	654	71	35	51
A508.3 TT	543	560	664	657	70	25	65
18MND5 L	489	532	615	638	75	67	11
18MND5 TT	500	474 (507)	637	500 (617)	69	18 (27)	74 (61)

0= initial state;
H= state after hydrogen charging

Qualitative fractographic analysis has shown that the failure mode in initial state was exclusively transgranular ductile. After hydrogen charging, we have observed fish eyes on fracture surfaces for both steels and always for both orientations of tensile specimens (Fig. 1-4). The remaining part of fracture surfaces was transgranular ductile. In case of A508.3 steel there was no significant difference in the area occupied by fish eyes, in their size or in their number for the two orientations studied. On the contrary, in case of 18MND5 steel the character of fracture surfaces was different in dependence on orientation. In L direction the number of fish eyes on fracture surfaces was only limited and the fracture had predominantly a ductile character. As to TT orientation, fish eyes were numerous and they covered a significant part of fracture surface. Furthermore, for this orientation (only for the higher current density) we have also observed on fracture surfaces other areas of quasicleavage fracture which were not initiated by the presence of non-metallic inclusions. These areas, which were rather large, contained small, relatively smooth facets. Figure 5 summarises the results of quantitative fractographic measurements where the number of fish eyes per unit of fracture area was measured. This figure gives also the values of hydrogen embrittlement index.

The following part of our investigation was focused on the problem of a different behaviour of two steels studied in the presence of hydrogen and particularly to the significant anisotropy of 18MND5 steel properties. It can be seen from the data given in the part describing experiment that both chemical composition of steels and their heat treatment were very similar. Metallographic analysis has revealed that microstructure of both steels was also identical corresponding mostly to tempered granular bainite, in segregation bands to tempered lower bainite. Local chemical analysis has shown that segregation bands in 18MND5 steel were more enriched in C, Ni and Mo which was accompanied by increased microhardness. Metallographic analysis of tensile specimens of 18MND5 steel performed after hydrogen charging with current density of 50 Am^{-2} but without any loading has revealed that in this case hydrogen provoked irreversible damage during charging. As it can be seen from Figure 5, high level of hydrogen embrittlement was observed also for the lower current density when no internal cracks were formed during hydrogen charging. Nevertheless, the frequency of fish eyes in TT direction is even higher for the lower current density.

Due to the fact that fish eye formation is closely related to the presence of non-metallic inclusions in steel, their analysis was performed, both on metallographic samples and on fracture surfaces. For both steels, inclusions were identified in most cases as complex oxides containing to variable quantities namely Al, Mg, Si and Ca, the outer shell being formed by (Ca, Mn)S. Inclusion content in steels was evaluated by means of image analysis (1). The results obtained have shown that inclusion content and their geometric characteristics were identical for both steels. It is very important that even in case of 18MND5 steel inclusions could be considered as spherical. It means that shape of inclusions gives no reason for the observed anisotropy of steel properties in the presence of hydrogen. As there is no relation between inclusion distribution and the occurrence of segregation bands in steel, the presence of segregation bands itself cannot explain the high amount of fish eyes found on fracture surfaces in TT direction.

It seems that the cause of different behaviour of A508.3 and 18MND5 steel in the presence of hydrogen can be connected with local characteristics of inclusion-matrix interface or with local characteristics of metallic matrix in the vicinity of inclusions. In case of forging, where the degree of deformation during forging is relatively low and does not differ significantly for different directions, the characteristics of inclusion-matrix interface can be considered as more or less isotropic. In case of plate, according to Klevebring et al. (2), in those parts of inclusion-matrix interface normal of which is rather parallel to the rolled surface a high density of microdefects (microcavities or even microcracks) is observed in adjacent matrix. On the contrary, in those parts of inclusion-matrix interface normal of which is rather perpendicular to the rolled surface the density of microdefects in adjacent matrix is considerably lower. In our case, this difference does not manifest itself in initial state, but after hydrogen charging the local differences in matrix properties around inclusions can give rise to numerous fish eyes when performing tensile tests in TT direction. This situation is shown schematically in Figure 6.

CONCLUSIONS

This work has examined effects of hydrogen on behaviour of A508.3 (heavy forging) and 18MND5 (thick plate) steels. Both materials seem to be rather susceptible to hydrogen embrittlement. Increased hydrogen content gives rise to special defects called fish eyes nucleated on coarse spherical non-metallic inclusions. While the behaviour of A508.3 steel is isotropic, even in the presence of hydrogen, 18MND5 steel shows a strong anisotropy of its properties. The results obtained indicate that fish eye formation can be affected by anisotropy of local properties of metallic matrix in the vicinity of non-metallic inclusions as a result of different conditions of material forming.

REFERENCES

(1) J. Sojka, "Hydrogen Embrittlement of Low Alloy Steels Used in Nuclear Industry-Role of the Microstructure and Cleanliness", PhD. Thesis, Ecole Centrale Paris, 1997, p. 184.

(2) Klevebring B., Bogren E., Mahrs R., Met. trans., 6A, (1975), p. 319.

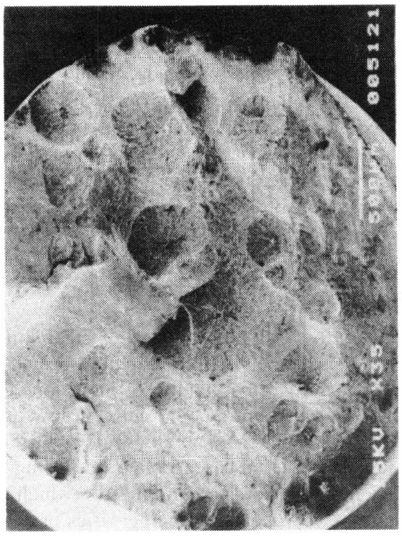

Figure 1 Fractography of A508.3 steel, tangential direction

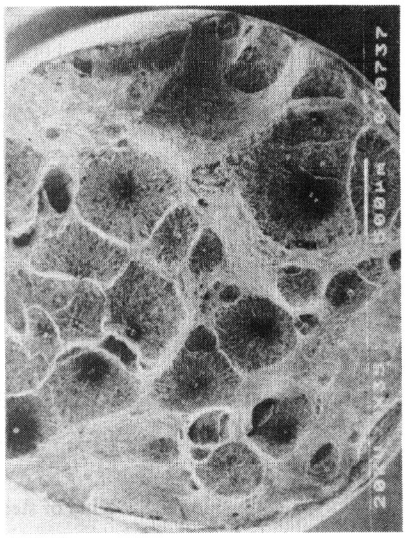

Figure 2 Fractography of A508.3 steel, through thickness direction

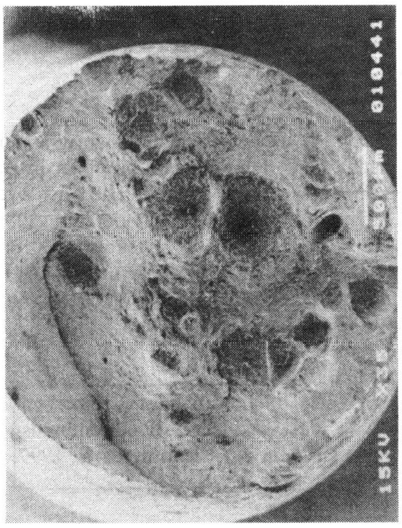

Figure 3 Fractography of 18MND5 steel, longitudinal direction

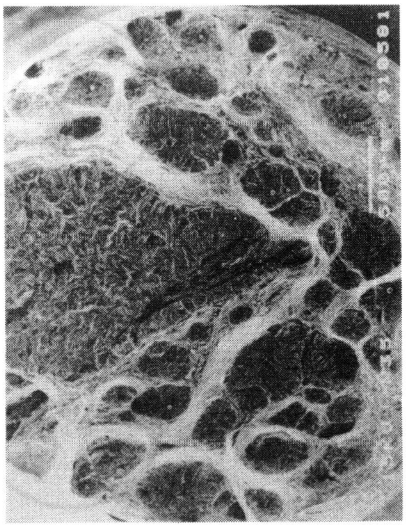

Figure 4 Fractography of 18MND5 steel, through thickness direction

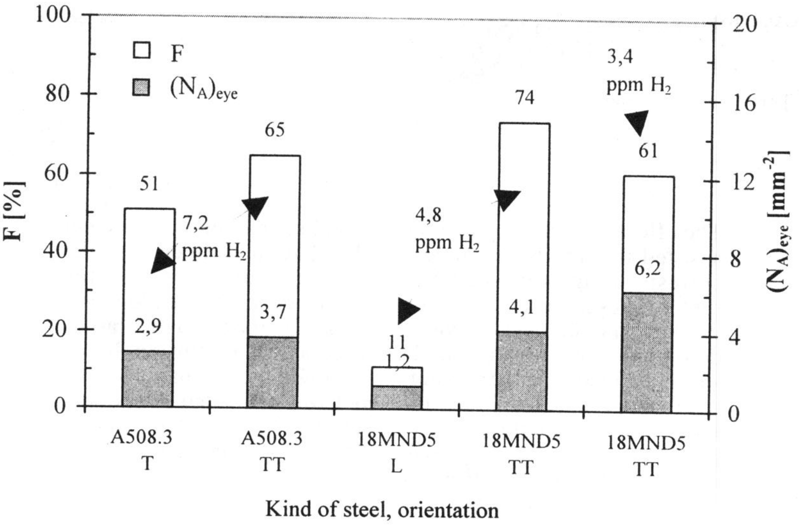

Figure 5 Hydrogen embrittlement index F, number of fish eyes per unit of fracture area $(N_A)_{eye}$ as a function of specimen orientation for A508.3 and 18MND5 steels

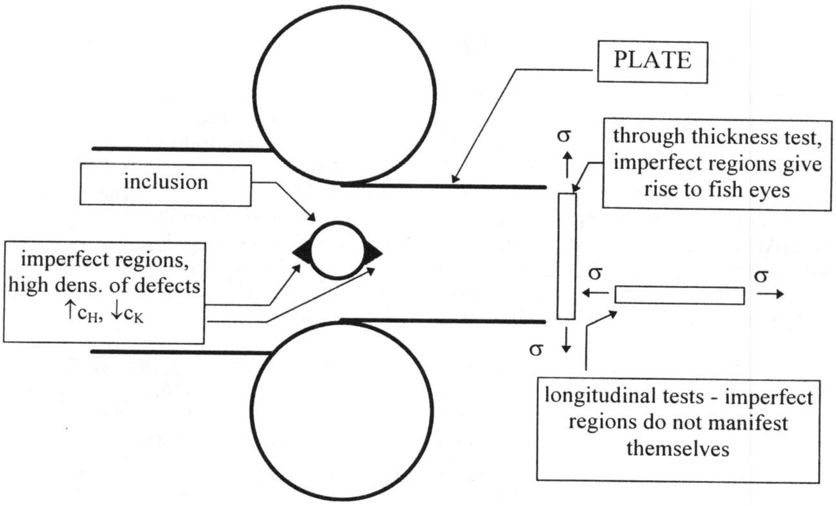

Figure 6 Schematic depiction of occurrence of imperfect regions during rolling in some parts of metallic matrix surrounding non-metallic inclusion