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# Hydrogen Embrittlement of heat treatable steel plates welding

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***Abstract:*** **In the paper, influence of hydrogen on mechanical properties of welded joints from heat-treatable structural steel plates were investigated. The heat treatment of welded plate specimens was performed, and then the specimens were charged with hydrogen electrolytically generated from 1 N H2SO4 solution. The following studies were carried out: static tensile test, hardness investigations, macroscopic metallographic investigations as well as investigations with the use of a scanning microscope. Hydrogen embrittlement of welded joints from steel plates was revealed by a distinct decrease of ductility and a slight decrease of strength. On the basis of metallographic investigations, it was found that in a fracture region there are fine pores created by the presence of hydrogen and its displacement due to formed stresses and plastic deformation. It was shown that welded joints are susceptible to hydrogen cracking in the heat affected zone and in the fusion zone.**

***Key words— Hydrogen Embrittlement, steel, welding.***

## I. INTRODUCTION

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the work pieces to form a bond between them, without melting the work pieces.

Fig 1: Welded Heat treatable steel plates.

## II. HYDROGEN EMBRITTLEMENT

Electrodeposition and electroless deposition and their associated processing steps including acid pickling and electro cleaning can generate hydrogen which can enter substrates in the atomic fonn and cause hydrogen embrittlement. This chapter outlines the factors which cause hydrogen embrittlement, its subsequent effects and failure mechanisms, and then elaborates on methods for reducing or eliminating the problem. Since steels are particularly prone to hydrogen embrittlement, emphasis is placed on these alloys. A section on permeation of hydrogen through various protective coatings is included to show the effectiveness of various barrier layers on minimizing hydrogen egress to substrates. Some excellent materials science investigative work showing how electroless copper deposits are embrittled by hydrogen is also presented along with data on hydrogen pick-up as a result of chemical milling of various steel and titanium alloys.

Hydrogen embrittlement is a generic term used to describe a wide variety of fracture phenomenahaving a common relationshipto the presence of hydrogen in the alloy as a solute element or in the atmosphere as a gas (1). Louthan

(2) lists the following problems as a result of hydrogen embrittlement and/or hydriding: failures of fuel cladding in nuclear reactors, breakage of aircraft components, leakage from gas filled pressure vessels used by NASA, delayed failure in numerous high strength steels, reductions in mechanical properties of nuclear materials, and blisters or fisheyes in copper, aluminum and steel parts. Steels, particularlythose with high strengths of 1240 to 2140 MPa (180,000 to 310,000 psi) are prone to hydrogen embrittlement regardless of temperature However, hydrogen embrittlement is not specific to just high strength steels.

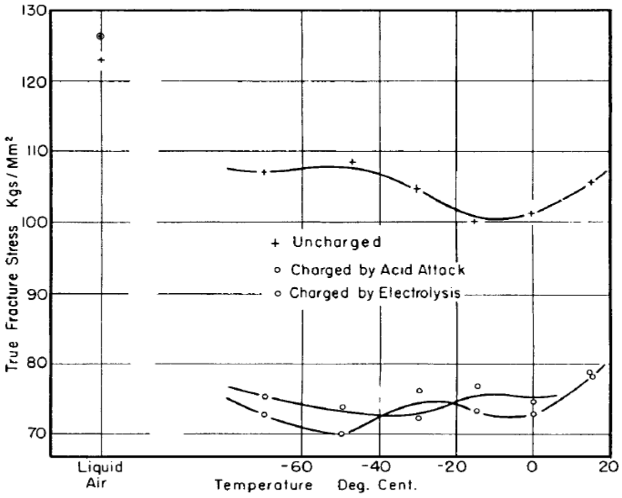


Fig 2: Fracture stress as a function of hydrogen absorption and temperature for 0.08% carbon steel.

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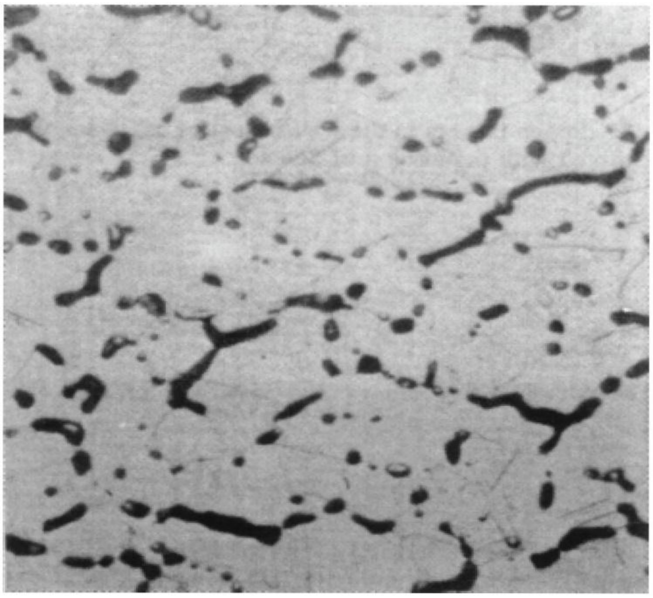

Fig 2: Structure of commercial copper after heating in hydrogen for 3 hours at 750°C (about 250 X).

**Fig 3:** Hydrogen blisters in the wall of a steel container.

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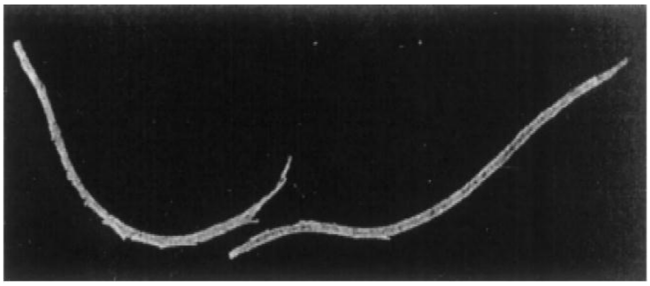

Fig 4 Vanadium wire shattered by cathodic charging with hydrogen.

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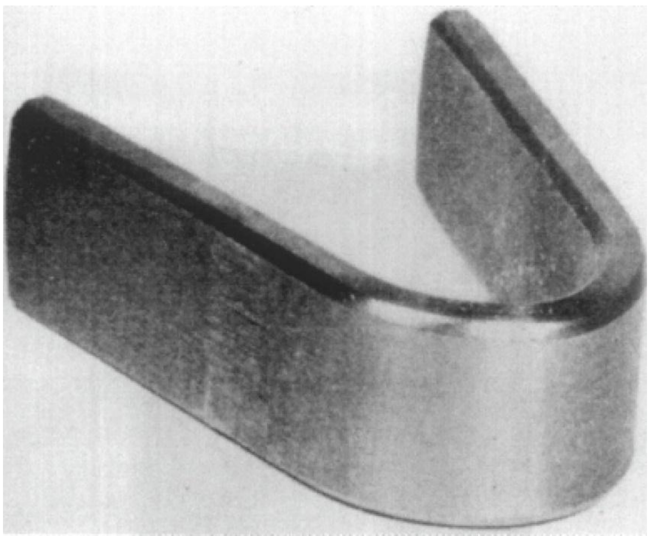

Fig 5: Steel sample with no cathodic treatment (x 1).

Table 1.
Chemical composition of XABO 960 steel and binding agents

| Material | Mass contents, % | | | |
|---|---|---|---|---|
| | C | Mn | Si | P |
| steel | 0.18 | 1.60 | 0.50 | 0.020 |
| | S | Cr | Mo | Ni |
| | 0.010 | 0.80 | 0.60 | 2.00 |
| | C | Mn | Si | P |
| binding | 0.11 | 1.92 | 0.80 | 0.010 |
| | S | Cr | Mo | Ni |
| | 0.013 | 0.48 | 0.53 | 2.41 |

Table 2.
Parameters of a welding with the use of an electrode of 1.2 mm diameter and direct current DC(+)

| Welding sequence | Current intensity, A | Voltage, V | Wire speed, cm/min | Heat input, kJ/cm |
|---|---|---|---|---|
| 1 | 110 - 140 | 18 - 20 | 11 - 14 | 12 - 16 |
| 2 - 10 | 250 - 260 | 27 - 28 | 26 - 32 | 12 - 16 |

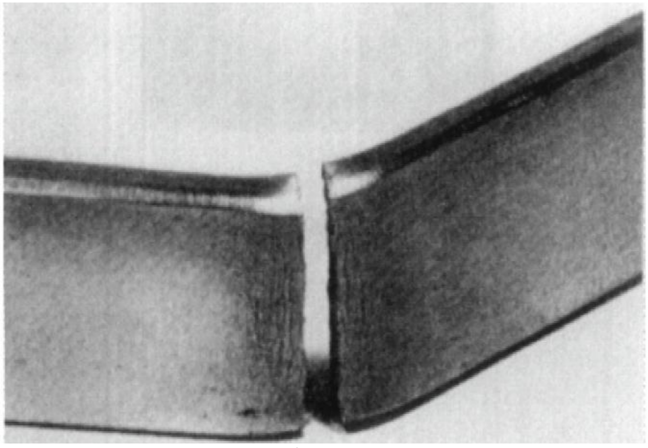

Fig 6: Steel sample after cathodic treatment (x 1).

## III. DESIGNED IN PTC CREO AND ANSYS OF HARDENED STEEL GEOMETRY

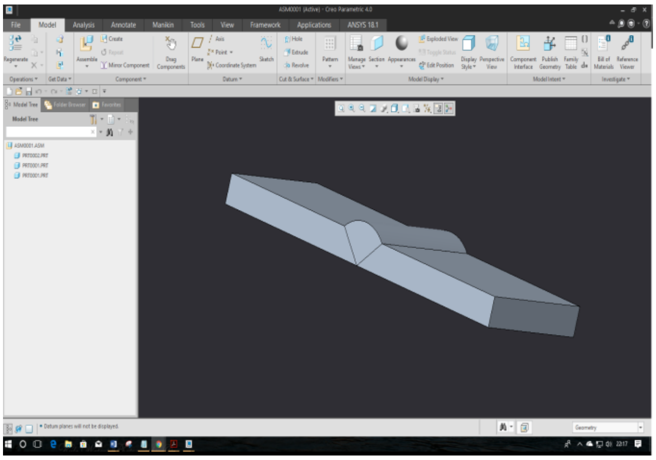

Fig.7 Designed in PTC CREO

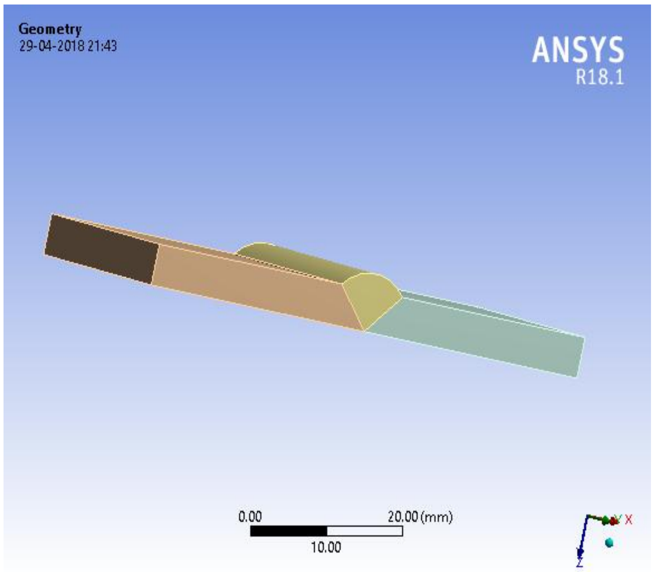


Fig.8 Ansys of Hardened Steel Geometry

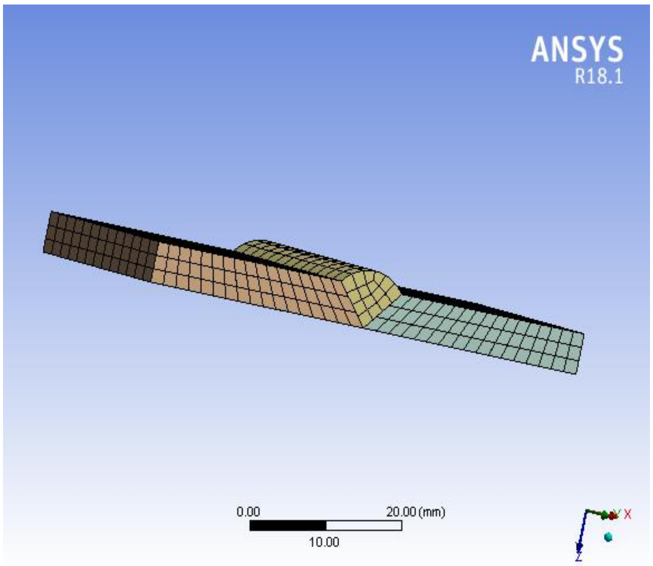


Fig.9 Mesh

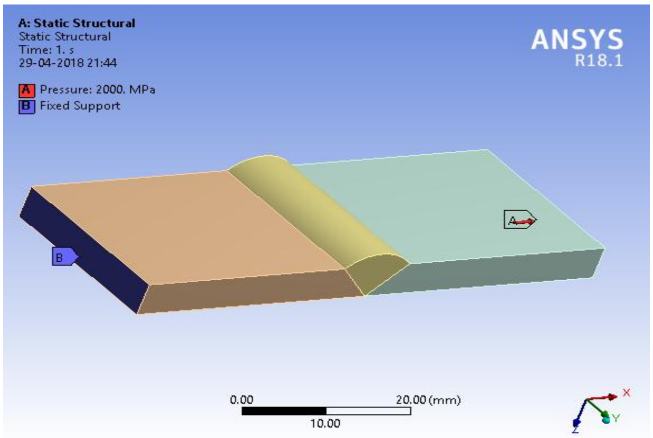


Fig.10 Loads and Constraints

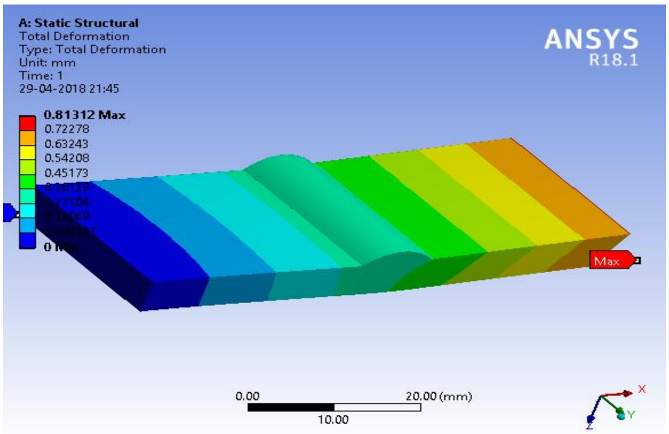


Fig.11 Total deformation

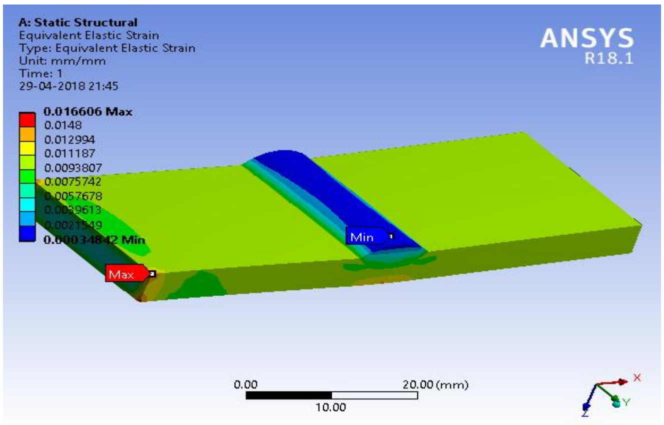


Fig.12 Elastic Strain

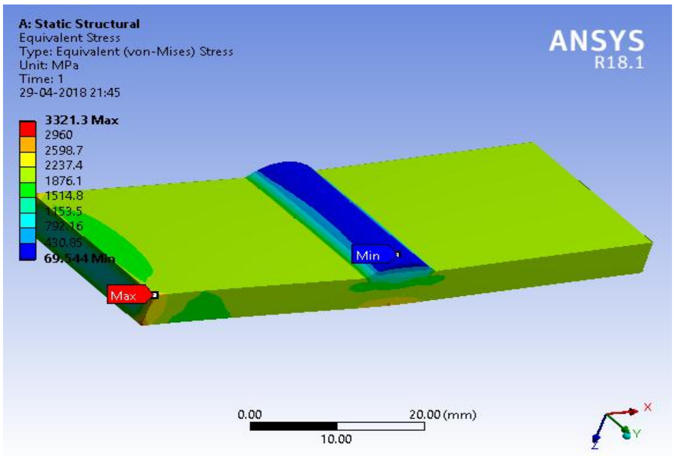


Fig.13 Von misses Stress

IV. ANSYS OF BRITTLE STEEL

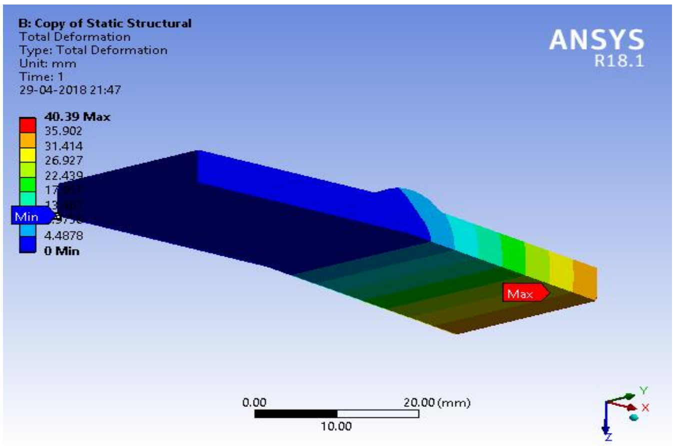


Fig.14 Total Deformation

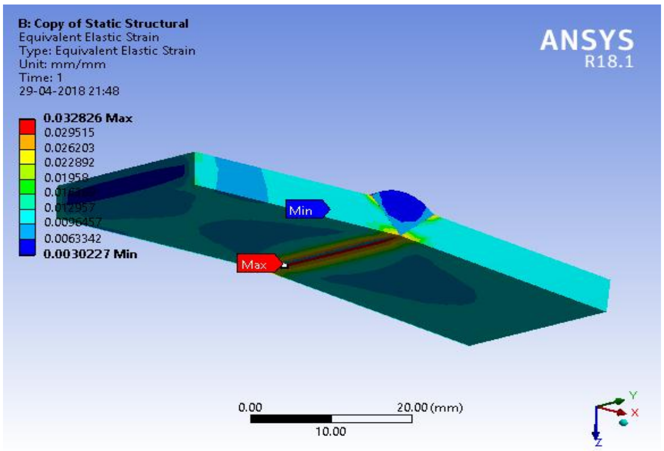


Fig.15 Elastic strain

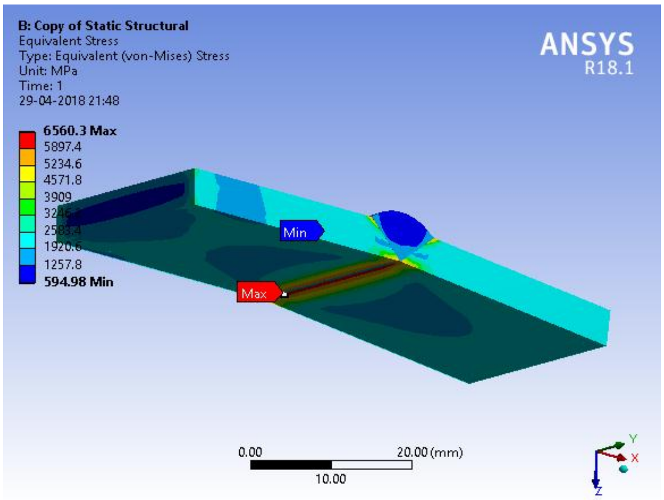


Fig.16 Von misses Stress

## V. RESULTS AND DISCUSSION

The results of static tensile tests (Table 4) indicate that hydrogen embrittlement of welded joints in investigated steel plates manifests itself with a distinct decrease of ductility and a slight decrease of strength. The highest decrease of ductility occurs after hydriding of sample that was not subjected to tempering. In this case, elongation of test pieces decreased from 10 to 6%, for the state before and after hydriding, respectively. The highest strength was noted for samples tempered at the temperature of 350°C. Non-hydrided specimen tempered at such temperature presents yield stress value YS0.2 equal approximately 903 MPa and ultimate tensile strength value UTS of about 1035 MPa, whereas values noted for hydrided sample were as follows: YS0.2 of approximately 854 MPa and ultimate tensile strength UTS equal around 970 MPa. Moreover, the elongation of test pieces tempered in a temperature range from 350 to 600°C changes from 8 to 6%.

Table 4. Results of the static tensile test

| Tempering temperature, °C | Specimen condition | YS0.2, MPa | UTS, MPa | A, % |
|---|---|---|---|---|
| Raw Condition | Non-hybrid | 865 | 1053 | 10 |
| | Hydrided | 534 | 1017 | 6 |
| 350 | Non-hydrided | 903 | 1035 | 8 |
| | Hydrided | 856 | 970 | 6 |
| 600 | Non hydride | 850 | 993 | 8 |
| | Hydride | 833 | 974 | 6 |

***ANSYS RESULTS:***

| **Property** | **Steel** | **Brittle Steel** |
|---|---|---|
| Total Deformation | 0.82 mm | 40.39 mm |
| Von Misses Stress | 3321.3 MPa | 6560.3 MPa |
| Elastic Strain | 0.0166 mm/mm | 0.032 mm/mm |
| Loads | 2000 Mpa | 2000 Mpa |

## VI. CONCLUSION

Performed metallographic examinations of samples subjected to prior electrolytic hydriding in 1N solution of $H_2SO_4$ revealed an accumulation of hydrogen on fronts of non-metallic inclusions, micro cracks and on other crystal defects, where powerful exothermal reaction of recombination of hydrogen atoms into hydrogen molecules takes place. It leads to hydrogen embrittlement of welded joints. In such processes, the state of stress and plastic strain formed during propagation of the micro cracks plays an essential role. It was found that hydrogen embrittlement of welded joints in steel plates was revealed by a distinct decrease of plastic properties and a slight decrease of strength. The highest decrease of plasticity occurs after hydriding of sample not subjected subsequently to tempering. Elongation of specimens submitted to hydriding is almost twice lower when comparing to the state before their hydriding. It was pointed out that welded joints are susceptible to hydrogen cracking in both, heat affected and fused zone. Macroscopic metallographic observations of areas located in the vicinity of the fracture region revealed the presence of fine pores created by hydrogen and its displacement due to occurring stresses and plastic strain. Moreover, it was found that the tempering temperature does not influence on the process of formation of pores connected with the migration of hydrogen. In order to obtain optimal mechanical properties of welded joints in investigated steel plates, tempering at the temperature of 350°C should be applied.

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