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TITLE

PREDICTION OF HYDROGEN CRACKING IN MULTIPASS WELDS IN LOW CARBON STEELS

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Prediction of Hydrogen Cracking in Multipass Welds in Low Carbon Steels

by

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ABSTRACT

Enormous advances have been made in recent years to improve the hydrogen cracking resistance of steels during welding by using low carbon levels coupled with thermo-mechanical controlled processing, precipitation hardening, or other strengthening methods. As the resistance to heat affected zone cracking has improved, however, the region of greatest risk of cracking has shifted from the HAZ to the weld metal, or as experienced in pipelines, the reheated HAZ of multipass welds.

Whereas the critical problem with older steels was the determination of a suitable preheat to allow the root pass to be deposited without HAZ cracking, with modern steels the challenge is to determine welding procedures that prevent critical hydrogen levels being reached at any critical location throughout a multipass weld. The initial preheat may be less important than, say, the number and size of passes, the geometry of the weld, or the time/temperature experience between passes. Time between passes is rarely specified in a welding procedure but may have a decisive effect on local hydrogen concentrations and the risk or weld metal cracking.

In the present work, hydrogen distribution is modelled using a simple finite difference approach that accounts for the major factors influencing hydrogen levels. Hydrogen diffusivity is expressed in terms of a trap model allowing calibration of two parameters from simple experiments. Experiments have been performed using bend specimens with various hydrogen removal aging treatments between passes. The deflection to failure of the bend tests was used as an index of sensitivity to hydrogen cracking. The results showed good agreement with the model for room temperature aging but effects of temperature were not accurately predicted. The results suggest, however, that for the purposes of welding procedure development, a simple hydrogen distribution model coupled with a local critical hydrogen concentration cracking criterion is a practical approach.

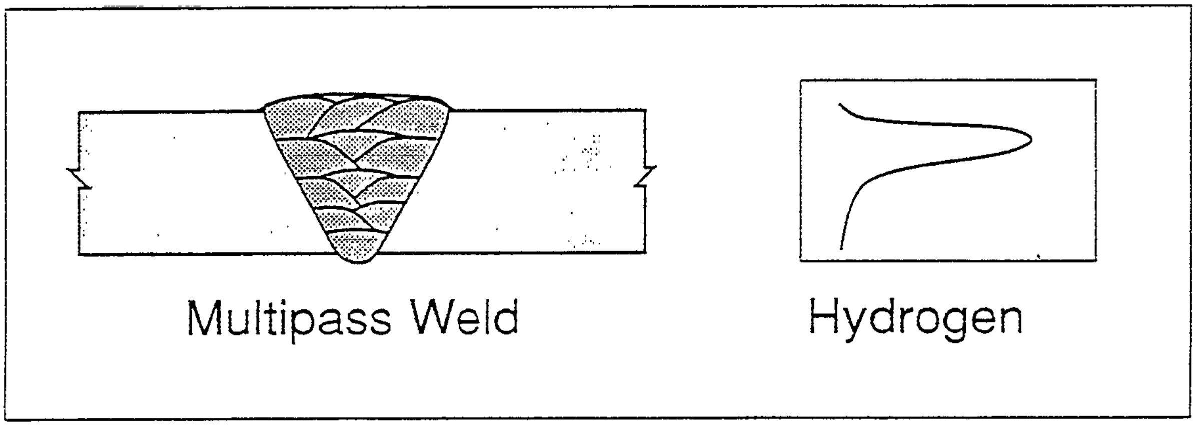
A. BACKGROUND

1. Modern day weldable steels have low carbon and low carbon equivalent. The HAZ thus has high resistance to weld hydrogen induced cold cracking.

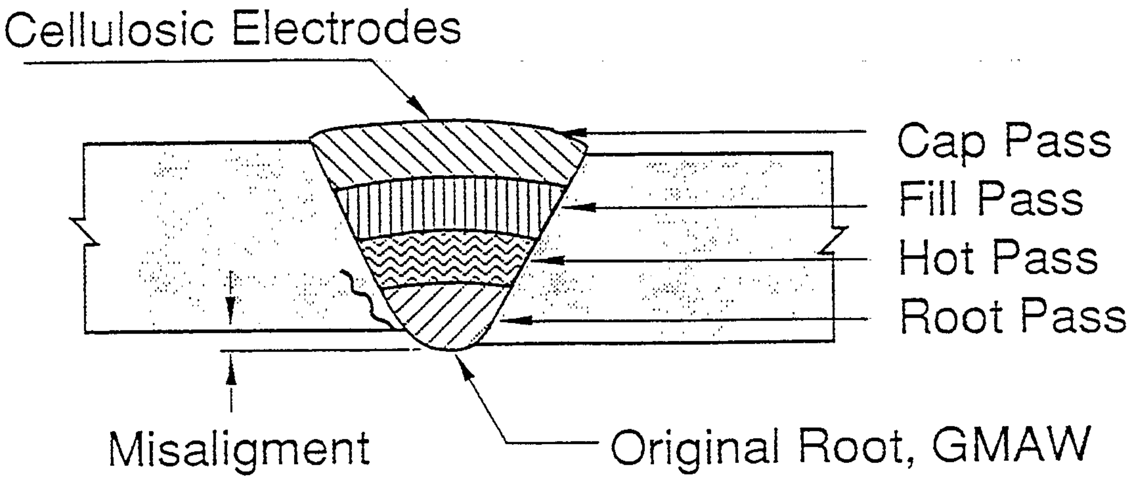
2. However, there is still a risk of cold cracking in weld metal, and in the case of pipelines, in the relatively soft reheated HAZ.

3. Most of the weldability assessment methodologies (CTS test, Tekken test, restraint test etc.) are based on single pass welds and are suitable for preheat or welding procedure determination for root pass or fillet weld without HAZ cracking.

4. The weld metal and reheated HAZ cracking in comparison are problems of multipass welds.



Hydrogen in Multipass Welds



Cracking in Reheated HAZ during Repair Welding

5. Instead of the initial preheat, the important variables are number and size of the weld passes, the geometry of the weld, and interpass time and temperature. Interpass time is rarely specified in welding procedure but may have a decisive influence on the incidence or absence of cracking in the welds.

6. The challenge in the case of weld metal and reheated HAZ cracking is therefore to optimize some of the above mentioned variables so as to prevent critical hydrogen levels being reached at any critical location throughout a multipass weld.

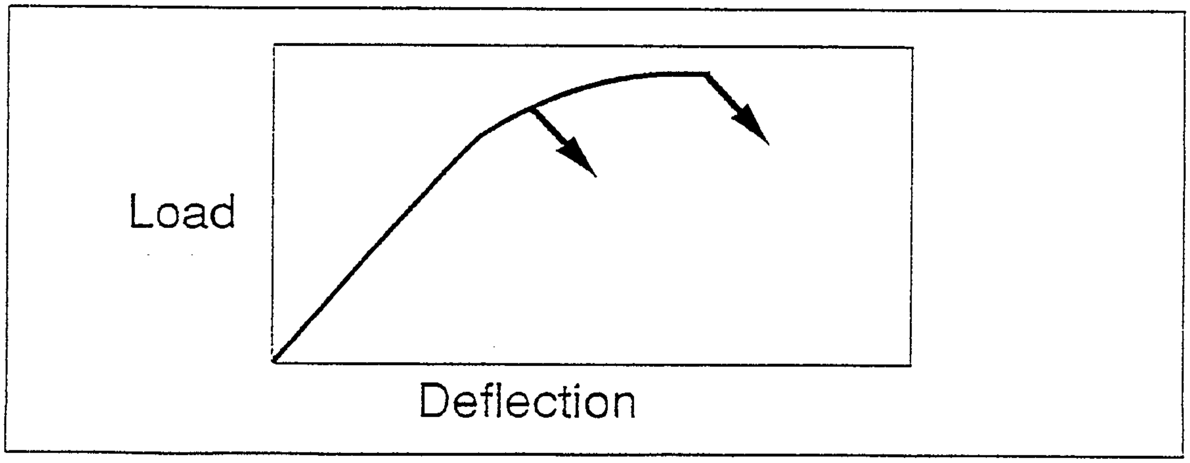
B. OBJECTIVE

To develop a hydrogen distribution model for pipeline girth welds that would account for the effect of major factors influencing hydrogen levels and susceptibility to hydrogen cracking in the reheated HAZ.

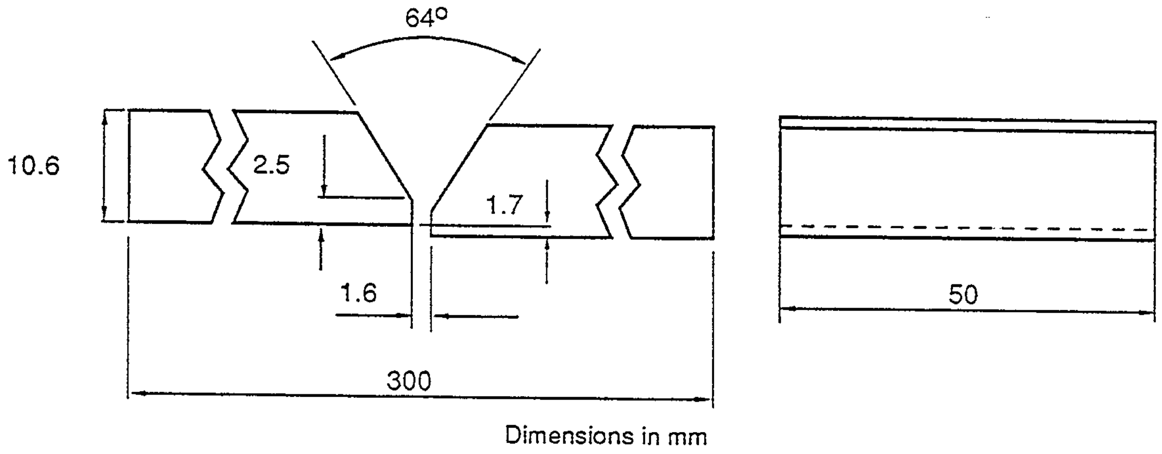
C. APPROACH

- Use a simple finite difference modelling approach;
- Employ simple experiments to estimate diffusivity of hydrogen;
- Experiments involve simple 'slow' bend tests on welds with various intra-pass or post weld aging treatments to create different hydrogen distributions (see **Figures 1 and 2**).

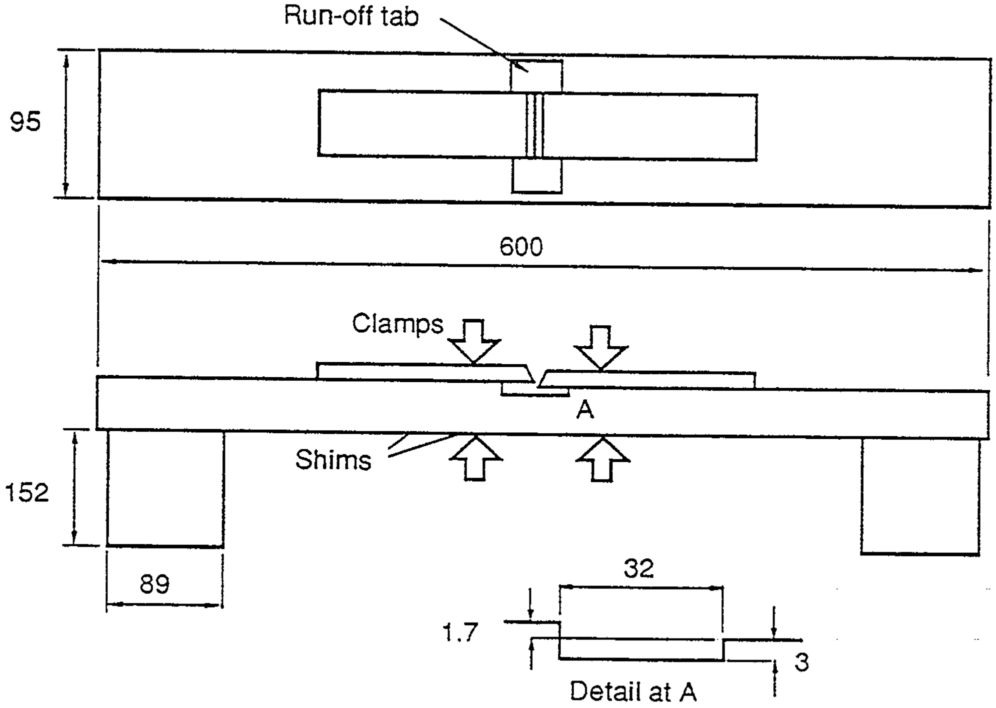
  In these tests, the deflection to failure in the bend tests serves as an index of sensitivity to hydrogen cracking, dependent upon the **local hydrogen concentration in the HAZ** of the root pass near the stress concentration.



Slow Bend Test



Joint preparation for the bend test



Welding jig for the bend test.

Figure 1. Details of the bend test preparation.

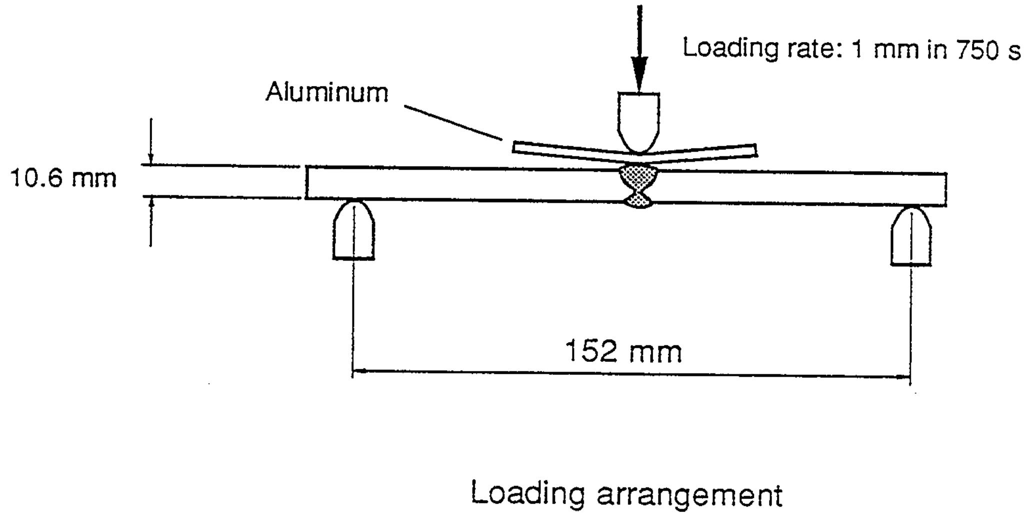


Figure 2. Loading arrangement for the bend test.

D. EXPERIMENTS & RESULTS

D.1 TASK 1

Slow bend specimens welded according to normal procedure. Then aged at 20° or 70°C for various times (0 to 64 hours) prior to slow bend tests. Measure total diffusible hydrogen content on tested samples after tests. From the results so obtained (**Figures 3 and 4**),

$$D(70) = 9.14\ D(20)$$

where D(70) and D(20) are hydrogen diffusion coefficients in the weld zone at 70° and 20°C, respectively. Also, the activation energy for hydrogen diffusion can be calculated to be 37 kJ/mole which is higher than expected.

Figures of deflection versus hydrogen (**Figure 5**) and deflection difference (with respect to zero aging time) vs adjusted time (**Figure 6**) indicate that

$$D(70) = 5\ D(20)$$

and Activation Energy = 27 kJ/mm (expected value)

Prediction of the Model for Total Remaining Hydrogen in the Specimens after Ageing

Figure 7 shows the calculated vs measured global hydrogen.

- Good correlation between the calculated and measured values;
- Discrepancy could be due to the assumed initial hydrogen level (20 ml/100g) or the effect of plastic deformation during the test.
- Ideally, should have measured hydrogen on untested duplicate specimens.

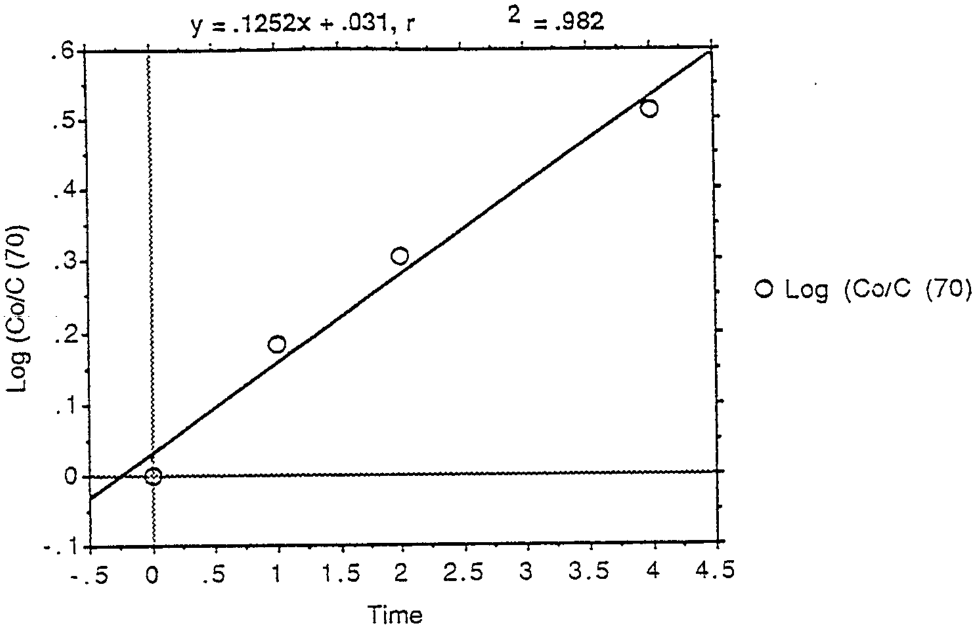


Figure 3. Regression plot for measured hydrogen contents for 70°C ageing.

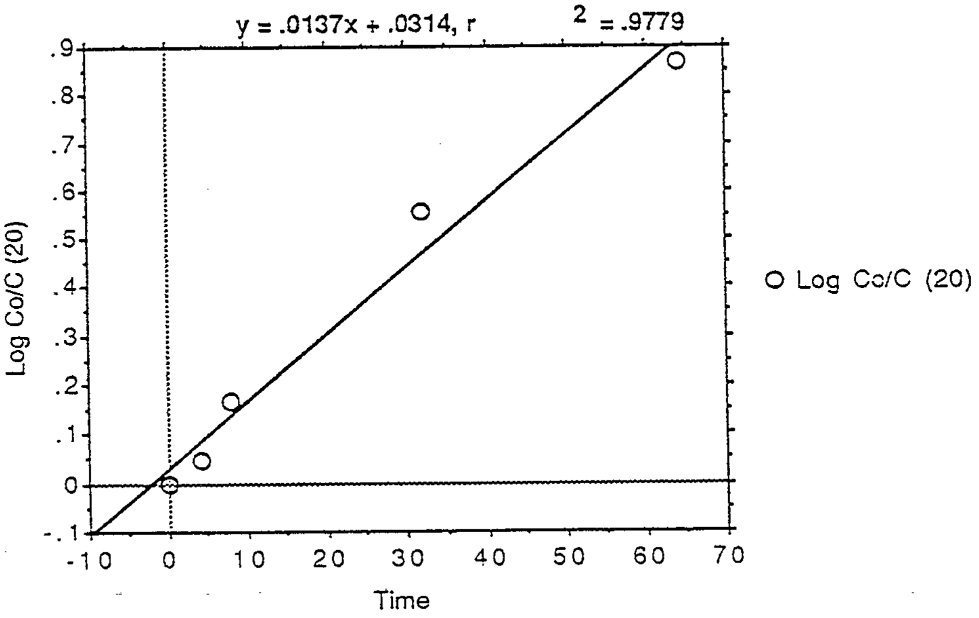


Figure 4. Regression plot measured hydrogen for 20°C ageing. Time in hours.

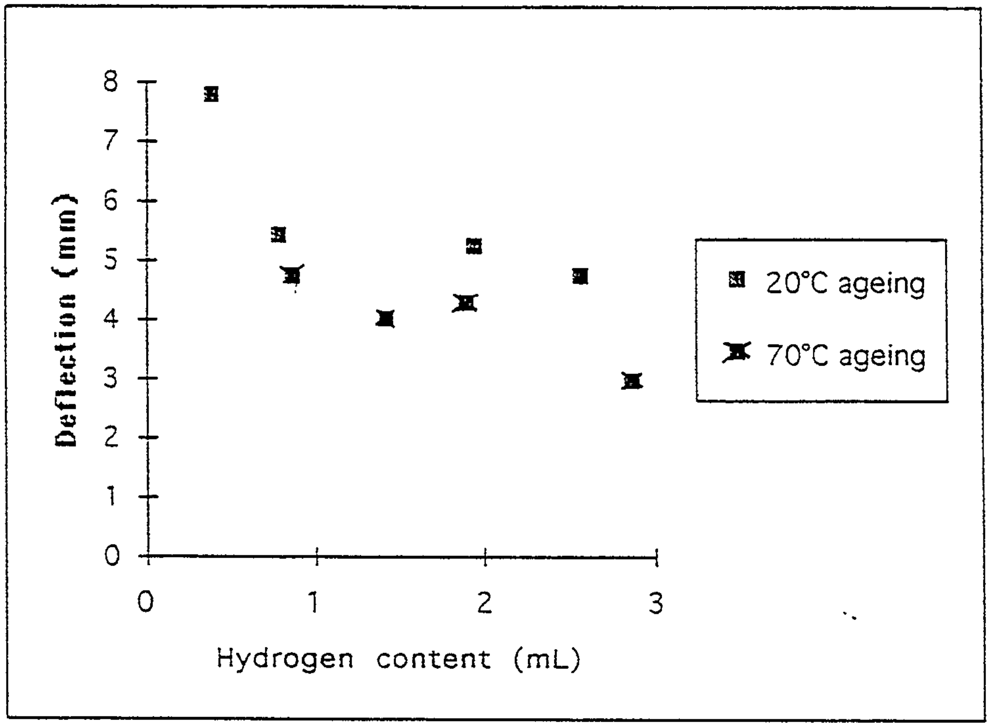


Figure 5. Deflection against measured hydrogen content for two aging temperatures. Measurements from Task 1 fractured bend specimens.

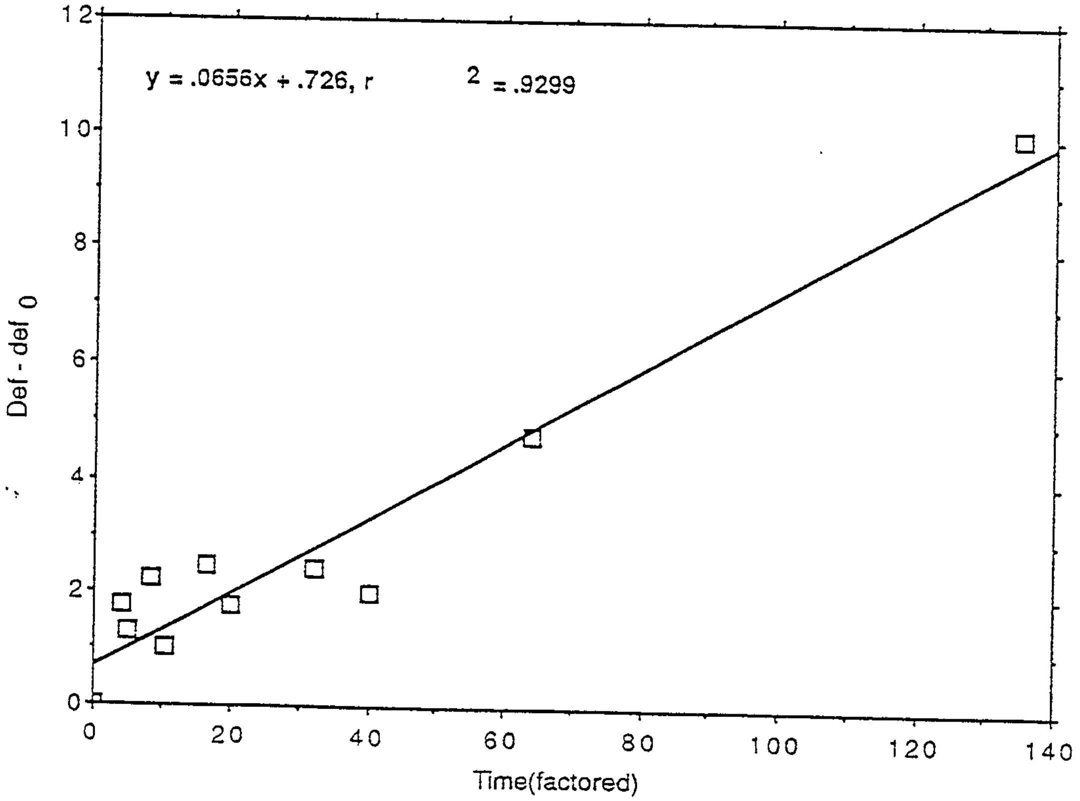


Figure 6. Results of fitting deflection data. Deflection is def - def at zero time. Time for 70°C data is multiplied by factor 5. This factor was found by trial and regression analysis to give best fit of data. This is used to find the activation energy.

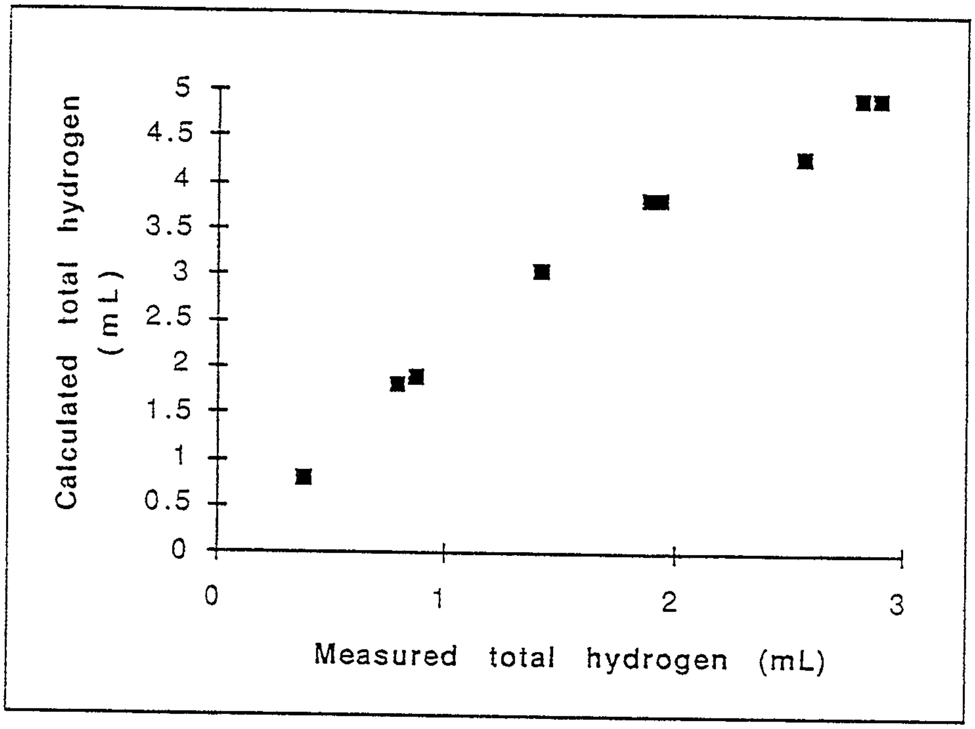


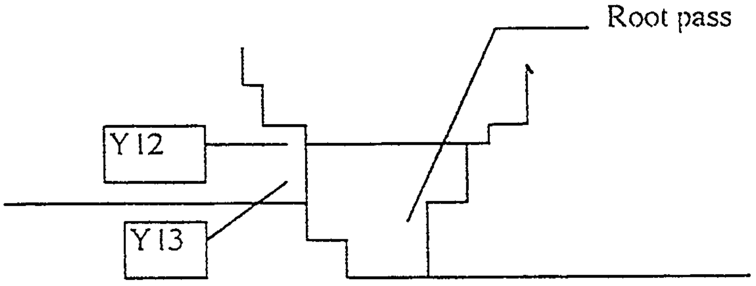
Figure 7. Total hydrogen content calculated from the model versus the measured values from fractured bend specimens. Data from Task 1 tests. The calculated values assumed a weld metal hydrogen content of 20 mL /100g of fused metal.

D.2 TASK 2

- Explore the effect of hydrogen diffusion distance.
- Welding procedure incorporated an ageing treatment (**up to 8 days at 20°C**) after the root pass (Series 1, smaller diffusion distance) or after the root and hot pass (series 2, larger diffusion distance). Then age after weld completion.
- The slow bend test results are shown in table below.

Table 7. Results of Task 2 bend tests.

Sample ID	Age temp (°C)	Age time (hours)	Deflection (mm)	Max load (kN)	Test duration (min)
Series 1					
2-1	19	0	2.90	27.7	44
2-2	19	4	2.80	26.1	42
2-3	19	24	5.24	31.0	78
2-4	19	96.5	7.78	34.1	115
Series 2					
3-3	19	0	4.92	31.6	70
3-1	19	16	4.29	30.7	64
3-4	19	96	8.41	35.7	125*
3-2	19	193	9.05	35.4	134**



Model Predictions

Figures 8 and 9 show changes in hydrogen concentration with time in the HAZ at location Y12 adjacent to hot pass boundary. In Figure 8, the local hydrogen concentration decreases steadily with time as expected. When aging is done after the hot pass, the hydrogen concentration is initially zero at Y12 but rises as hydrogen diffuses from fill and cap passes. After reaching a peak at about 8 hours, the level starts to decline and follow a path similar to that in Figure 8. Thus in the second set of experiments, there is a period of a few hours after welding where the specimen hydrogen is decreasing but the local hydrogen in the root region is increasing.

This can also be in seen in the 2-D hydrogen distributions seen in **Figures 10 and 11.** Figure 10 shows the distribution immediately after depositing the cap pass when the total hydrogen content is at its maximum. Figure 11 shows the distribution after the weld has cooled to 50°C prior to aging. Total hydrogen content has increased but hydrogen has spread through to the root pass. **These are the conditions symptomatic of delayed cracking.**

In **Figure 12**, the measured deflection to first load drop in the bend tests is plotted against the local HAZ concentration at Y12 for all tests involving aging at 20°C. An acceptably good correlation is observed. This result should be compared with that shown in **Figure 13** where the deflection is plotted against the total (or average) hydrogen concentration and the resulting correlation is poorer.

E. CONCLUSIONS

- A simple model can provide a reasonable prediction of the local hydrogen concentration which can predict the cracking behavior in bend tests welded with different procedures.

- With suitable experimental/joint simulation calibration, the model can be used to predict cracking behavior in other multipass welds.

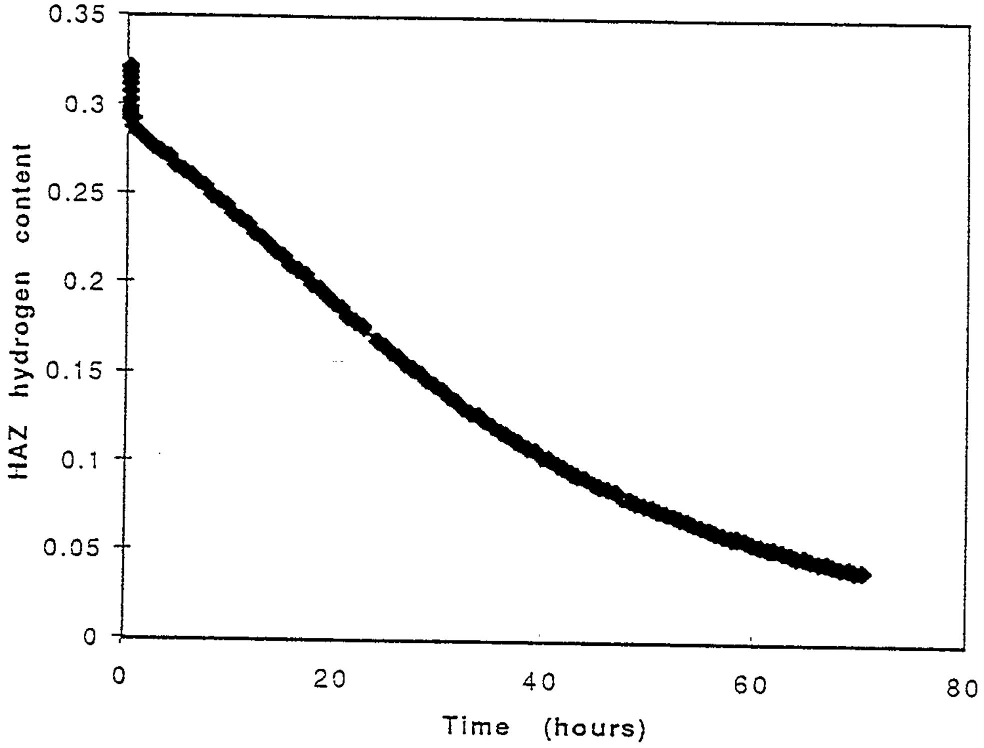


Figure 8

Ageing after Root Pass
H_2 decline starts
immediately.

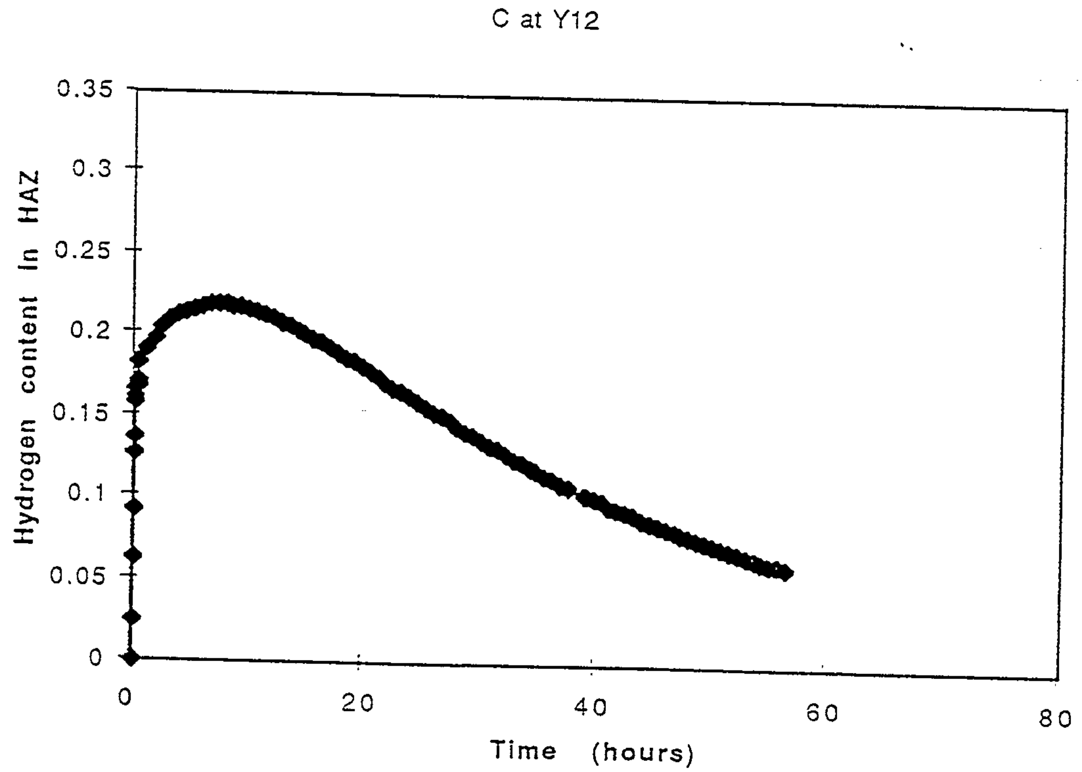


Figure 9
Ageing after Hot Pass
H_2 builds up first,
then declines.

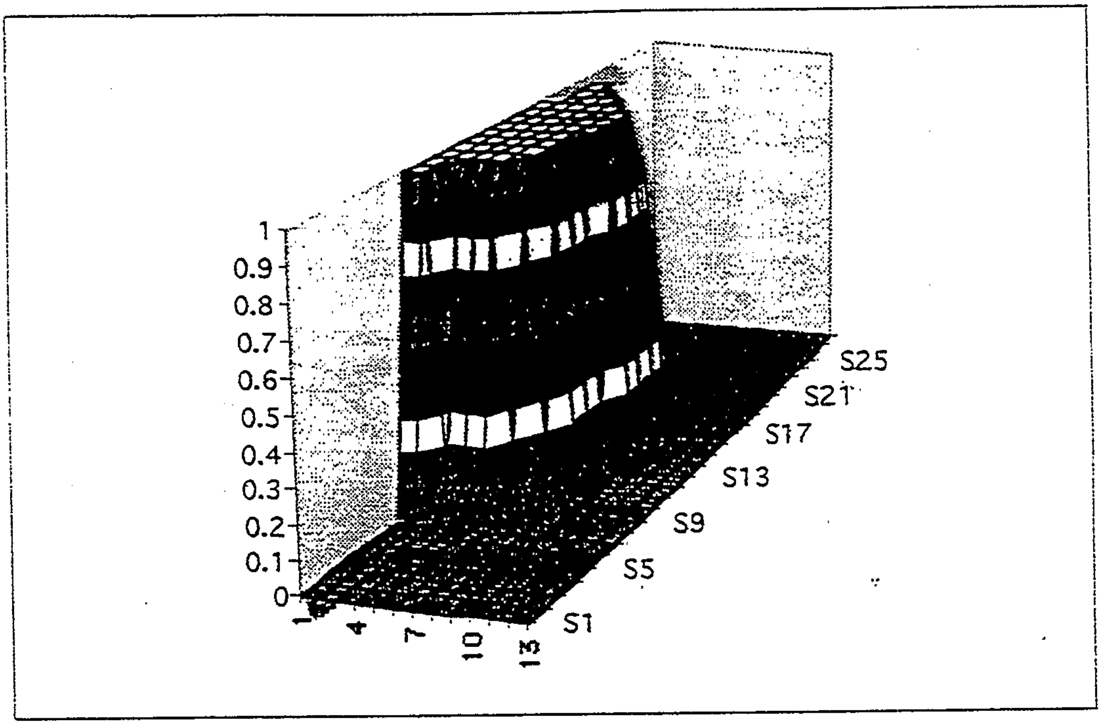


Figure 10. Task 2 series 2. Hydrogen distribution immediately after depositing the cap pass.

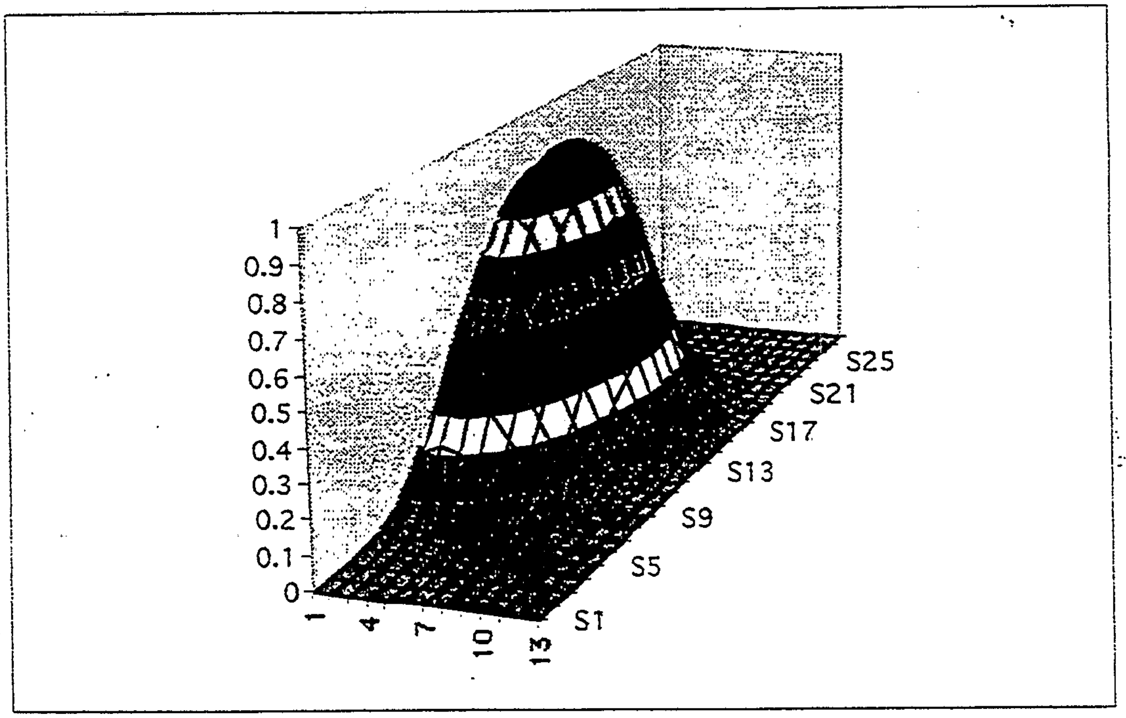


Figure 11. Task 2 series 2. Hydrogen distribution after weld has cooled to 50°C at beginning of ageing time.

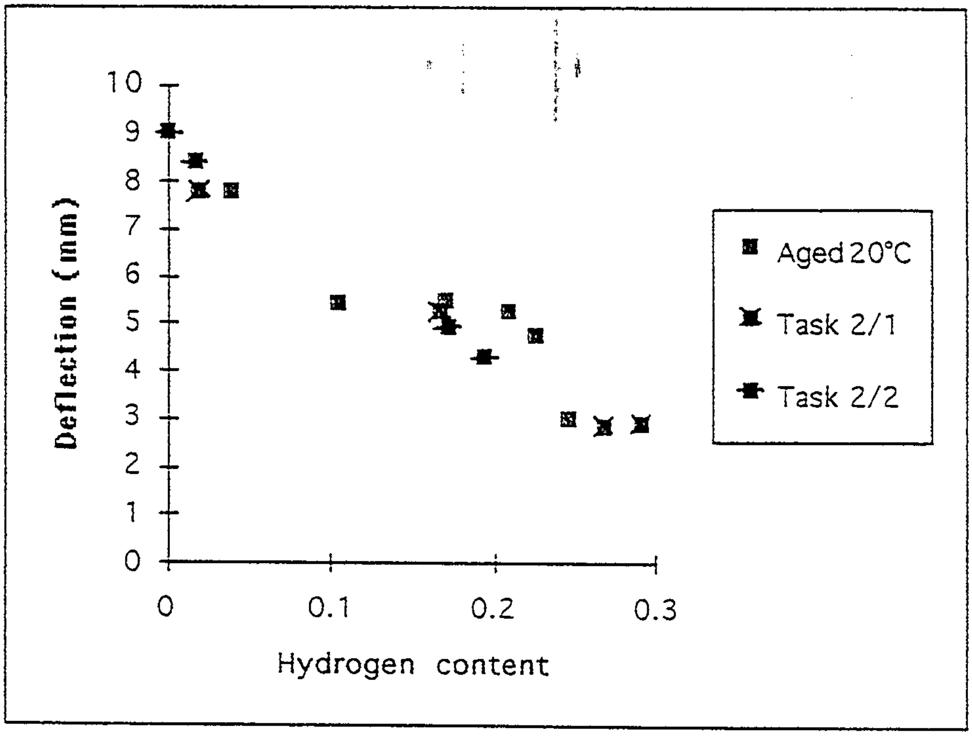


Figure 12. All data for tests aged at 19 or 20°C. Shows good relation between deflection and local HAZ hydrogen content for Tasks 1 and 2.

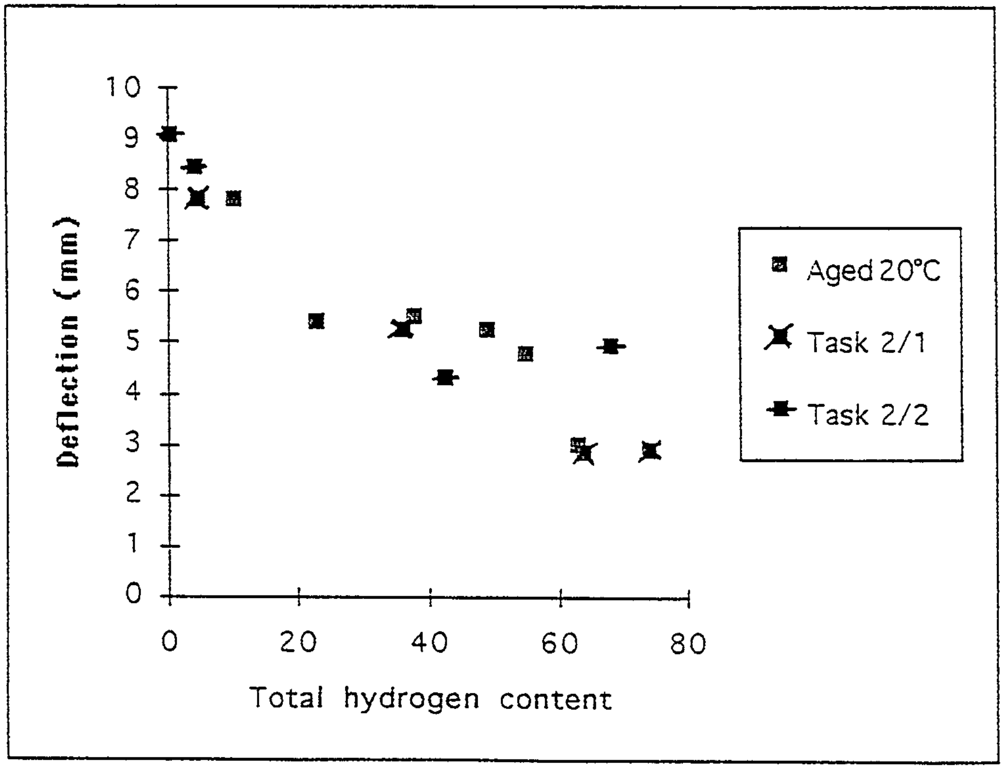


Figure 13. All data for 19 or 20°C ageing plotted against total hydrogen content. Agreement is less good especially for the Tasks 2/2 data.