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Cold Cracking of weldments

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Abstract: This paper will discuss the definition of the cold cracking. By discussing it the reasons, the factors and how to avoid it, and comparison of testing the cold cracking sensitivity, the materials were used (high strength steel, C-Mn steel, and armored steel). Hydrogen cracking may also be called cold cracking or delayed cracking. The principal distinguishing feature of this type of crack is that it occurs in ferritic steels, most often immediately on welding or a short time after welding.
Keywords: Hydrogen; welded joints; cold cracking.

Introduction

Cold cracking (also called hydrogen-induced or heat-affected zone (HAZ) cracking) occurs at temperatures below 600° F (300°C) and does not appear until hours after the weld cools. In some cases, it may not appear for days. Most cold cracking begins in the base material (as opposed to the weld itself) and passes transversely into the weld. It is particularly common in thick materials, which are prone to rapid cooling due to the large heat sink, and results from induced residual stresses in the base material and the presence of diffusible hydrogen in the weld. Cold cracking can also occur in materials with high carbon or alloy content, as these are also higher in strength and can be less ductile [1].

Hydrogen-induced cracking, or hydrogen embrittlement, is a chemical phenomenon that causes metal alloys to fracture due to a build-up of hydrogen molecules within the crystal lattice structure. This is a unique mode of mechanical failure that most commonly affects low alloys and high-hardness

[1] Lucas, B.–Mathers, G.–Abson, D. (2000): *"Defects-hydrogen cracks in steels identification."* Cambridge: TWI.

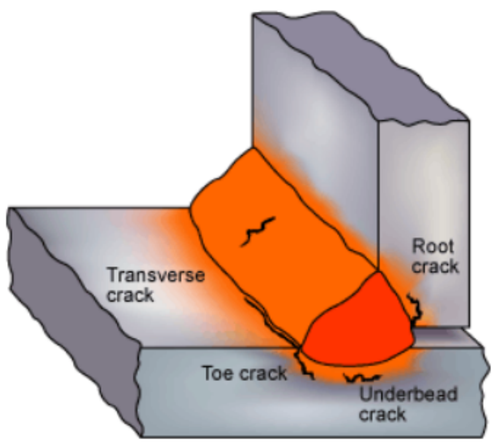
steel grades such as titanium (Ti). Often, components will develop increased susceptibility to hydrogen-induced cracking due to the introduction of excess hydrogen molecules into the metal structure during forming or finishing processes [2].

Identification

Hydrogen cracks can be usually be distinguished due to the following characteristics:

In C-Mn steels, the crack will normally originate in the heat affected zone (HAZ) but may extend into the weld metal *(Fig 1)*. Cracks can also occur in the weld bead, normally transverse to the welding direction at an angle of 45° to the weld surface. They follow a jagged path but may be non-branching. In low alloy steels, the cracks can be transverse to the weld, perpendicular to the weld surface, but are non-branching, and essentially planar [1].

Fig. 1. Hydrogen cracks originating in the HAZ and weld metal. (Note that the type of cracks shown would not be expected to form in the same weldment.



[1] Lucas, B.–Mathers, G.–Abson, D. (2000): *"Defects-hydrogen cracks in steels identification."* Cambridge: TWI.

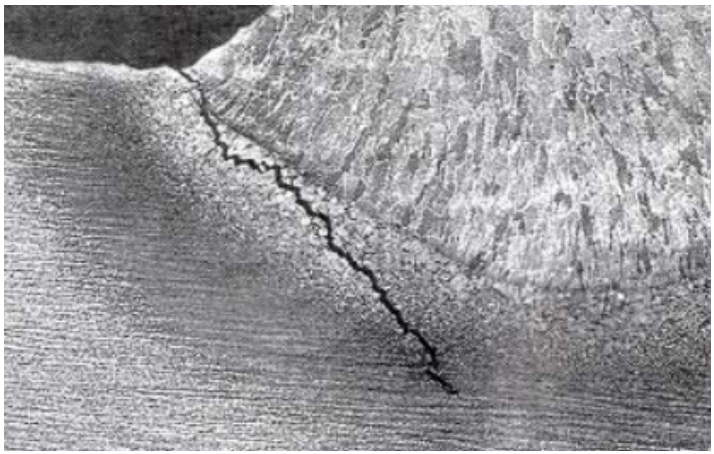
[2] Kou, S. (2003): Welding Metallurgy, second edition, chapter13 *„Difficulties Associated with the Partially Melted Zone"*. Pp. 328–333.

Metallography

Cracks which originate in the HAZ are usually associated with the coarse grain region, *(Fig 2)*. The cracks can be intergranular, transgranular or a mixture. Intergranular cracks are more likely to occur in the harder HAZ structures formed in low alloy and high carbon steels. Transgranular cracking is more often found in C-Mn steel structures.

In fillet welds, cracks in the HAZ are usually associated with the weld root and parallel to the weld. In butt welds, the HAZ cracks are normally oriented parallel to the weld bead.

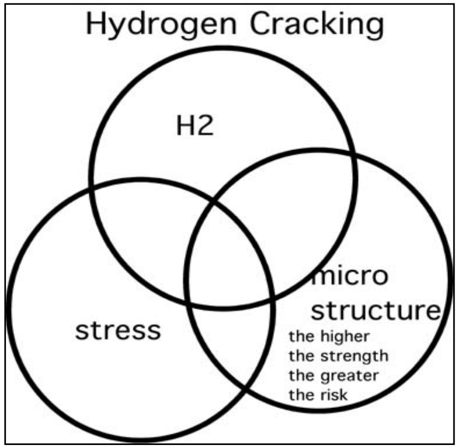
Fig. 2. Crack along the coarse grain structure in the HAZ



Causes

There are three factors which combine to cause cracking:
1. hydrogen generated by the welding process,
2. a hard-brittle structure which is susceptible to cracking,
3. tensile stresses acting on the welded joint.

Fig. 3. Welding triangle



Hydrogen-induced cracking occurs when the crystal lattice of an alloy becomes saturated with diffuse hydrogen atoms. This typically occurs at higher rates in extreme temperatures, given the proportional relationship between the solubility and temperature of hydrogen. These atoms diffuse through the metal and may recombine to form larger hydrogen molecules, which can accumulate in minuscule pockets of space within the metal structure.

Cracking usually occurs at temperatures at or near normal ambient. It is caused by the diffusion of hydrogen to the highly stressed, hardened part of the weldment.

In C-Mn steels, because there is a greater risk of forming a brittle microstructure in the HAZ, most of the hydrogen cracks are to be found in the parent metal. With the correct choice of electrodes, the weld metal will have a lower carbon content than the parent metal and, hence, a lower carbon equivalent (CE). However, transverse weld metal cracks can occur, especially when welding thick section components; the risk of cracking is increased if the weld metal carbon content exceeds that of the parent steel.

In low alloy steels, as the weld metal structure is more susceptible than the HAZ, cracking may be found in the weld bead.

The main factors which influence the risk of cracking are:

– *weld metal hydrogen:*
The source of the hydrogen is moisture contain in the flux, (the coating of the electrodes, the cored wires and the flux used in the submerge arc welding). Hydrogen may also be derived from the surface of the material or the consumable. and there can be other sources of hydrogen for instant (from the material and moisture from the atmosphere).
Sources of hydrogen will include: (oil, grease and dirt, rust, paint and coatings, cleaning fluids).

– *parent material composition:*
This will have a major influence on hardenability and, with high cooling rates, the risk of forming a hard-brittle structure in the HAZ. The hardenability of a material is usually expressed in terms of its carbon content or, when other elements are taken into account, its carbon equivalent (CE) value.

$$IIW\ CE = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

The higher the CE value, the greater the risk of hydrogen cracking. Generally, steels with a CE value of <0.4 are not susceptible to HAZ hydrogen cracking, as long as low hydrogen welding consumables or processes are used.

– *parent material thickness:*
Material thickness will influence the cooling rate, with increasing job thickness.

– *Stresses acting on the weld during welding or imposed (shortly) after welding:*
Cracks are more likely to initiate at regions of stress concentration, particularly at the toe & root of the weld.

– *heat input:*
The heat input to the material from the welding process, together with the material thickness and pre-heat temperature, will determine the thermal cycle and the resulting microstructure and hardness of both the HAZ and the weld metal.

[3] Takayuki, S. et al. (2020): „Evaluation of hydrogen-induced cracking in high-strength steel welded joints by acoustic emission technique." *Materials & Design.* 190., 108573.

Mechanism of Hydrogen Cracking

- H2 can be absorb in the welding arc from many sources including moisture on members, from air, from welding consumables covering, long or unstable arc,
- When weld metal is relatively hot (> 200 Deg. Cent.) H2 atoms can diffuse through the weld & HAZ quite rapidly & escape into the atmosphere.
- As the weld metal cools below Lower critical temperature (LCT) the weld metal transforms in to α ferrite / Pearlite that has far less solubility for H2. At this point H2 will tend to move in to HAZ where Austenitic phase is still retained.
- If the HAZ has high hardenability, then transformation of HAZ from Austinite to Martensite structure takes place which offers less solubility for H2.
- If the cooling rate is rapid this H2 atoms get trapped in the HAZ. This will result in expulsion of H2 in Hard & Brittle microstructure.
- Cracks may occur from the areas of high stress concentration such as weld toes & generally move through hardened HAZ.

Basic tips for preventing the cold cracking

Pre-heating the base material prior to welding can also prevent cold cracking by slowing the cooling rate and helping maintain the ductility of the weld and base material. Post-weld heat treating (PWHT) helps, too, by driving diffusible hydrogen out of the weldment and stress relieving the material. Other defences against cold cracking include:

(1) Using filler metals with a low hydrogen designator, such as H2 ≤ 4 ml/100g.

(2) Using filler metals with a basic slag system (these have high hydrogen scavengers).

(3) Storing filler metals in a clean, dry area and keeping them in the original package until ready for use.

(4) Storing filler metals in an area that has a temperature within -12C° of the welding environment. Or, allowing several hours for the filler metal to acclimate to the temperature of the welding environment prior to welding (to prevent condensation).

(5) Cleaning the base material free of oil, lubricants, and primers prior to welding [3].

Testing of cold cracking sensitivity

According to the literature [5] where used the SSRT tests were conducted with AE measurements to detect crack initiation, the y-groove weld cracking test which is widely used to investigate the necessary preheat temperature to avoid cold cracking, and the numerical method. To evaluate the distribution of steels, strain and hydrogen content in the y-groove weld cracking test, Finite element analysis was performed using Sysweld and Abaquas. In the condition without hydrogen -charged, the specimen with a cooling rate 30 C˚/s showed higher notch strength. In the hydrogen-charged specimens, it was confirmed that both crack initiation stress and notch tensile strength decrease with increasing the diffusible hydrogen content. The cracking ratio decrease with increasing the preheat temperature and decreasing the initial hydrogen concentration. No cracks were observed at a preheat temperature of 100ºc or higher. The amount of cold cracking in high strength steels could be estimated from the total AE energy. It was suggested that a numerical analysis considering a more detailed geometry is necessary to predict the cracking behavior under partially cracked conditions *(Fig 4) (Fig 5).*

[5] Nunes, Aline Raquel Vieira–Zeemann, Annelise –Henrique de Almeida, Luiz (2019): „The contribution of impurities to unexpected cold cracks in a thick C-Mn steel plate". *Journal of Materials Research and Technology.* (8.), Pp. 4364–4373.

Fig. 4. (a) Dimensions (in mm) of circumferentially notched round bar specimen for slow strain rate tensile (SSRT) test, and (b)experimental photo of SSRT test with AE measurement [5]

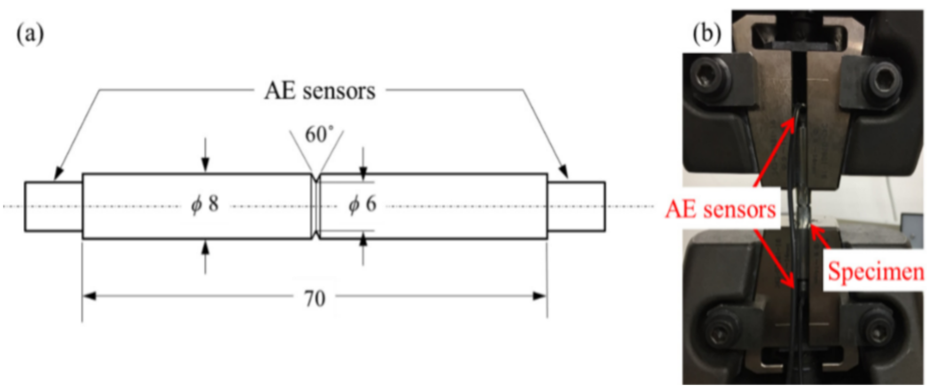
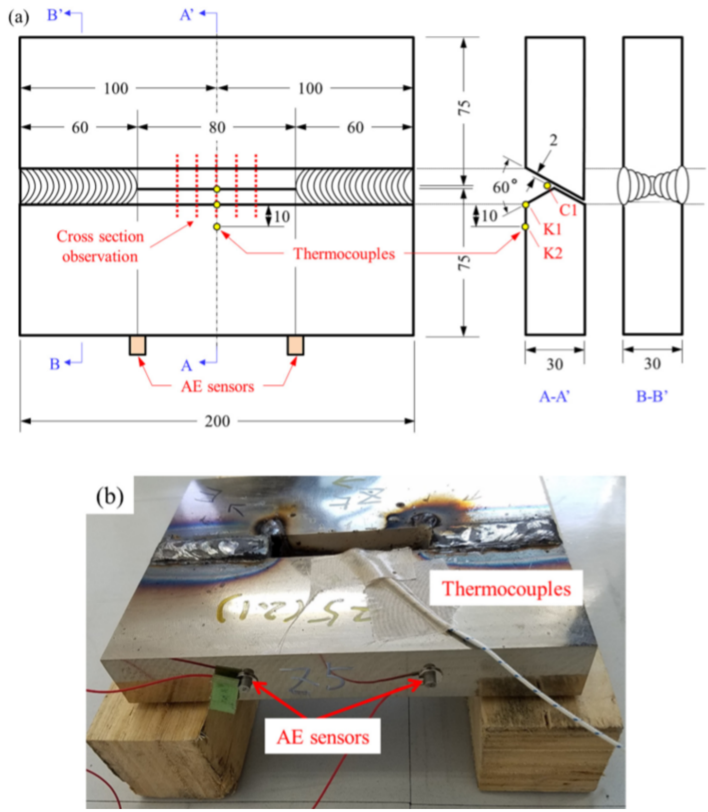


Fig. 5. (a) Dimension (in mm) of y-groove weld cracking test joint, and (b) experimental photo of AE measurement [5]

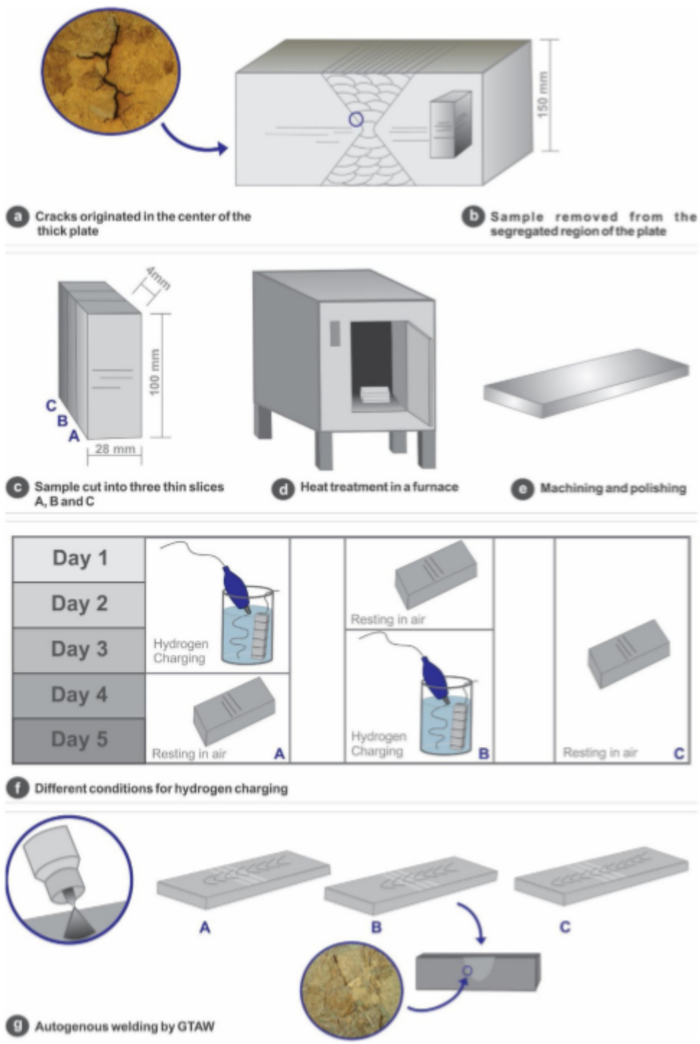


In literature [6] the material used was removed from a cracked region from C-Mn carbon steel thick plate was welded from both sides, in a full penetration double V groove, thick plates with high impurity contents may suffer HIC independently of the steel cold cracking susceptibility predicted by their carbon contents and CE, due to their hydrogen entrapment potential. The thickness of the plate could be an additional barrier foe hydrogen diffusion out of the base metal *(Fig 6).*

[5] Nunes, Aline Raquel Vieira–Zeemann, Annelise –Henrique de Almeida, Luiz (2019): „The contribution of impurities to unexpected cold cracks in a thick C-Mn steel plate”. *Journal of Materials Research and Technology.* (8.), Pp. 4364–4373.

[6] Cabrilo, A.–Geric, K. (2018): *Structural Integrity Procedia "Fracture mechanic and charpy impact properties of a crack in weld metal, HAZ and base metal of welded armor steel".* (13.), Pp. 2059–2064.

Fig 6, Scheme of the experimental procedure adopted [6]



[6] Cabrilo, A.–Geric, K. (2018): *Structural Integrity Procedia "Fracture mechanic and charpy impact properties of a crack in weld metal, HAZ and base metal of welded armor steel".* (13.), Pp. 2059–2064.

[7] Atabaki, M. Mazar, et al. (2014): “Hybrid laser/arc welding of advanced high strength steel in different butt joint configurations.” *Materials & Design 64.* Pp. 573-587.

– In literature [7] the material was used welded armor steel, the welding process was Gas Metal Arc Welding (GMAW) and AWS ER307 solid wire is used, there were the tensile , the hardness and the fracture mechanic test applied to this material, so the results for this research are : solid wire with a preheat temperature of 150 C° and inter-pass temperature of 160 C° can provide a low content of diffusible and residual hydrogen in the weld joint. Tensile strength of weld metal in the specimen welded with austenitic filler metal reached 833 MPa, which is greater than results published for the same filler metal in researches of manual welding. Fracture toughness value of 86 MPa*m1/2 is slightly lower than in the Class 500 of armored steel. Results of calculation show that HAZ has triple fracture toughness in comparison to the base metal. The highest fracture toughness is in the weld metal, four times higher than in the base metal.

– By comparing I found out that the base material has essential role for any failure that’s why we can see in those literatures they tried to predict the cold cracking and avoid it as well by talking about the avoiding the only method that it was in that three research the preheating even though sometimes it effects the properties. and those three literatures are best example for what I mentioned in the identification, and what can influence the cold cracking. Increasing the heat input will reduce the hardness level, and therefore reduce the risk of HAZ cracking. However, as the diffusion distance for the escape of hydrogen from a weld bead increases with increasing heat input, the risk of weld metal cracking is increased. Material thickness will influence the cooling rate, with increasing job thickness.

Conclusion

It is known that welded joints are very heterogeneous, since they include weld metal, heat affected zone and base metal, currently the practical technique to prevent hydrogen-induced cracking in welded joints is preheating. By preheating steel plates before welding, hydrogen diffusion is promoted during the welding, and the locally accumulated diffusion hydrogen is reduced. However, excessive preheating is not preferable from the viewpoint of production cost and undesirable effects on the microstructure. Therefor, it is required to estimate the minimum preheat temperature necessary to prevent hydrogen-induced cracking.