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A Review on Cold Cracking Phenomenon in High Strength Steel Welded Joints (Causes and Cures)

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مراجعة لظاهرة الكسر البارد في مفاصل لحام الفولاذ عالي المقاومة (أسبابها وعلاجها)

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Abstract

Welding engineering becomes essentially important in all fabricating branches, such as; oil pipelines, ship industry, oil platforms, vehicle industry, oil tanks, and more applications. Hydrogen-induced cracking related to welding could be a source of genuine harm to welded structures. In this manner, it may be a common topic in such areas and its avoidance is an imperative issue. Steel weldability, with respect to cold cracking, is relative to steel hardenability, which indicates the forming of hard and fragile martensitic microstructure. The most perfect way to dodge martensite is by abating the cooling rate of the parent metal and warming the heat-affected zone. There are numerous arrangements to avoid the over issue, two of them are: preheating and the utilization of fewer hydrogen consumables. The current paper surveys a few of past and later inquiries that are coordinated towards getting a more coherent understanding of the impact of welding parameters on cold breaking shirking, centering especially on the impact of preheating technique and diffusible hydrogen levels on cold cracks of different steel types. However, one of the foremost vital discoveries of this ponder is that resistance to hydrogen-induced cracks has for the most part progressed in numerous steel types, and the required ways to dodge cold cracks by control of the welding conditions are well set up.

Keywords: *Cold cracking, Diffusible hydrogen, Heat affected zone, Martensite, Preheating temperature.*

الملخص

هندسة اللحام أصبحت مهمة بشكل أساسي في جميع فروع التصنيع، مثل؛ خطوط أنابيب النفط وصناعة السفن، ومنصات النفط، وصناعة المركبات، وخزانات النفط، والمزيد من التطبيقات. يمكن أن يكون الكسر الناجم عن الهيدروجين المرتبط باللحام مصدر ضرر حقيقي للهياكل الملحومة. بهذه الطريقة قد يكون موضوعًا شائعًا في مثل هذه المجالات وتجنبها مسألة حتمية. قابلية اللحام للفولاذ فيما يتعلق بالكسر البارد تتعلق بصلابة الفولاذ، مما يشير إلى تكوين بنية مجهرية صلبة وهشة. الطريقة المثلى لتفادي وجود مارتينسيت هي تقليل معدل التبريد للمعدن الأم وتسخين المنطقة المتأثرة بالحرارة. هناك العديد من الترتيبات لتجنب المشكلة المشار إليها أعلاه اثنان منها: التسخين المسبق واستخدام كميات الكترودات ذات محتوى أقل من الهيدروجين. يقوم البحث الحالي بمسح عدد من الاستفسارات السابقة واللاحقة والتي يتم تنسيقها من أجل الحصول على فهم أكثر تماسكًا لتأثير متغيرات اللحام على الكسر البارد، مع التركيز بشكل خاص على تأثير تقنية التسخين المسبق ومستوى الهيدروجين القابل للانتشار على الشقوق الباردة لفولاذ مختلف الأنواع. ومن الجدير بالذكر، فإن أحد أهم الاكتشافات الحيوية لهذا التأمل هو أن مقاومة الشقوق التي يسببها الهيدروجين قد تطورت في معظمها في العديد من أنواع الصلب والطرق المطلوبة لتفادي الشقوق الباردة من خلال التحكم في ظروف اللحام تم إعدادها بشكل جيد.

الكلمات الدالة: الكسر البارد، الهيدروجين القابل للانتشار، المنطقة المتأثرة بالحرارة، مارتينسيت، درجة حرارة التسخين المسبق.

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1. Introduction

Costs of about £260 million were annually caused as a result of fabricating issues straightforwardly inferable to welding technology. £40 million of this total emerged from the ought to repair cold cracks and adjoining to welds. Despite of the fact that much more is known approximately how to maintain a strategic distance from cold cracks when welding ordinary steels, unused steels and unexpected issues have emerged. Therefore, encourage investigate and guidance has been required. Steel weld-ability with respect to cold cracks, is contrarily corresponding to the hardenability of the steel, which reflects the shaping of martensite. The steel hardenability depends on its chemical composition, with more noteworthy amounts of carbon and other alloying components coming about in higher hardenability and hence a lower weldability. In arrange to be able to judge combinations made of numerous unmistakable materials, a degree known as the equivalent carbon content (CE) is utilized to compare the relative weldabilities of distinctive combinations by comparing their properties to a plain carbon steel (Lincoln Electric, 2010; and Baily *et al*., 1993).

1.1. Defining the cold cracking problem

Cold cracks are additionally alluded as hydrogen induced cracking, postponed cracking or under bead cracking. It could be a mechanical break caused by the entrance and dissemination of nuclear hydrogen into the inside structure of steel, which changes into atomic hydrogen within the inside interface between non-metallic consideration and base fabric. The nearness of hydrogen in fabric could be a potential source of defects and must be recognized some time recently it comes to a basic estimate which can result in extreme harm and costly repairs. Figure (1) demonstrates cold cracks in ASTM 515(60) steel plates. Cracks may happen within the HAZ or weld metal and it may be transverse or longitudinal. Root and Toe cracks as shown in (Figure.2) begin in zones of much stress concentration (SGS Group, 2010; Davis, 1996; and Baily *et al*., 1993).

Figure 1. Hydrogen induced cracks (ASTM 515(60) Steel plate)
(AIT Advanced Inspection Technologies)

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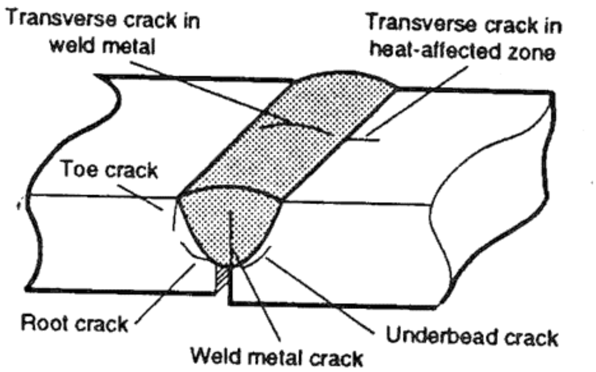

Figure 2. Cold cracks in carbon steel welded joint (Davis, 1996)

A hydrogen induced cracking is for the most part alluded to as unconstrained crack that happens at temperatures less than 200ºC after hardening is total in welding. Cold crack could create hours or even days later after the welds has been done, which is alluded to as (postponed or delayed crack). Hydrogen induced crack is likely to happen in all martensitic and ferritic steels, high and low alloy steels special precautions and, primarily preheating are utilized. Hydrogen induced cracks are caused by the combined impacts of less ductility of the weld, diffusible hydrogen and stresses within the weld, as shown in (Figure 3). A ductility of welds may diminish with a higher cooling speed and higher carbon equivalent and an after hardening. Remaining stress in a weld can be bigger than anticipated on the off chance that it contains weld discontinuities such as porosity, deficient fusion, slag, and inadequate joint penetration. Weld diffusible hydrogen source is primarily moisture within the atmosphere and welding consumables (KOBELCO Welding Today, 2004; and Dinovitzer *et al.*, 2000).

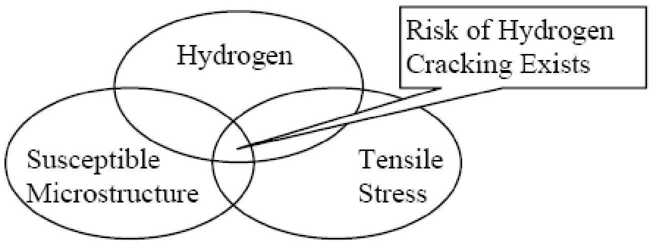

Figure 3. Factors lead to cold cracking (Dinovitzer *et al.*, 2000)

1.2. Effect of hydrogen diffusion on cold cracking

Hydrogen is ingested by the weld pool from the atmosphere during weld. Much of hydrogen get away, from the solified bead during cooling by diffusion but a few of it diffuses into the parent metal and the heat affected zone. The amount, which relies on a few many factors such as; temperature conditions of cooling, the initial absorbed amount, size of weld, the diminishing solubility, and the time temperature conditions. In common, the more hydrogen shows within the metal the more prominent the chance of the cracking. To control hydrogen level may be

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accomplished either by guaranteeing that adequate is permitted to elude by diffusion some time recently the weld cools or by reducing the initially absorbed. Figure (4) illustrates SAW welds and Hcr for a thin plate SMAW as a function of weld metal Pcm. The weld Hcr for lean plate SMAW and other than the seriousness of the MC test example, the test information connected to cracking – no cracking boundary was detailed to comprise of additional high-strength weld metals with RM ≈ 890–1000 MPa. The triangle region in Figure (4) presents the 'no cracking region' of the initial graph characterized agreeing to the results about of the WIC and MC tests.

In any case, the guideline sources of hydrogen in welding consumables are:

- Dampness within the coating of manual metal-arc terminals, within the flux utilized in submerged-arc welding or in flux-cored wires.
- Any more hydrogenous compound within the flux or coating.
- Grease and dirt, oil, either on the surface or caught within the surface layers of welding wires.
- Rust or hydrogen oxide on the surface of welding wires.

While the vital sources of hydrogen from the fabric to be welded are (Nevasmaa, 2003; and Bailey *et al*., 1993):

- Paint, rust, oil, etc., on the surface and adjoining to the weld planning, these can break down to create hydrogen within the arc atmosphere.
- Degreasing liquids utilized to clean surfaces some time recently welding may moreover break down to deliver hydrogen.
- Hydrogen from the base steel.

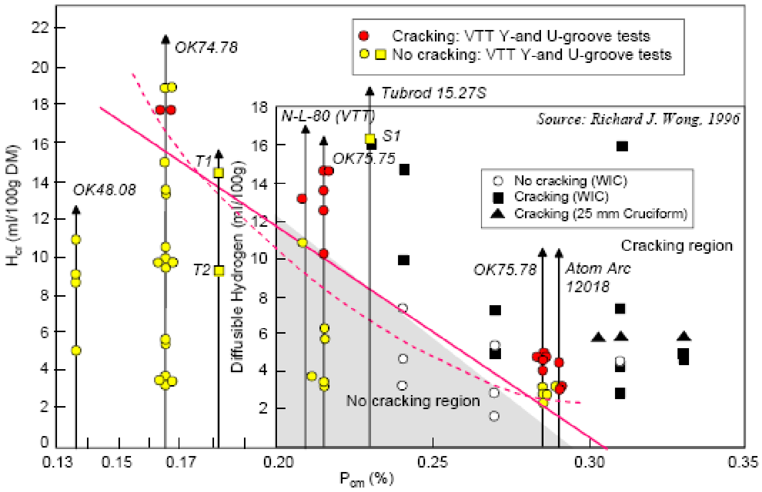

Figure 4. Weld metal (Pcm), critical hydrogen content (H_{cr}) relationship (Nevasmaa, 2003)

1.3. Effect of preheating on cold cracking

Preheating includes warming the base metal, either in its aggregate or fair the locale encompassing the joint, to a particular required temperature, called the preheat temperature, earlier to welding. There are four essential reasons to utilize preheat: where it moderates down

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the cooling rate within the base metal and weld metal, produces a more ductile metallurgical structure with more crack resistance. The slower cooling rate gives an opportunity for hydrogen that will be display to diffuse out innocuously, diminishes the potential for cracking. It decreases the shrinkage stresses within the weld and adjoining base metal, which is particularly critical in exceedingly controlled joints. It moreover raises a few steels over the temperature at which brittle fracture would happen in structure. Also, preheat can be utilized to assist guaranteeing particular mechanical properties, such as weld metal toughness. HAZ. The point Z is the basic point at which the martensite volume division nearly 0% within the HAZ (Funderburk, 2000; and Welding and Joining Technology, 1995).

2. Literature review about hydrogen level and weld preheating effect on cold cracks

2.1. Weld Preheating effect on delayed cracks

Zhai *et al.* (2018) studied (Effect of preheating on welding cold crack sensitivity of China low activation martensitic steel). They found out that the cracking rate of y-groove test reduced with the increase of the PT, and the crack rate maintained at a relative stable stage when the PT exceeded 250 °C. It revealed high welding crack tendency of the CLAM steel. Thus, the preheating before welding should be applied, and a PT at about 250 °C was proposed in order to prevent welding cracking.

Hu *et al*. (2011) found out in their study that cold cracking can be decreased by selecting appropriate preheating temperature which relies on thickness of base metal., carbon equivalent, welding heat input, joint restriction, weld metal yield strength and hydrogen diffusion content.

Merchant (2015) published a study where base metal and heat affected zone (HAZ) were examined in arrange to allow superior understanding into the cold cracking propensity. They found out that the impact of application of preheating and heat input expanding through the amperage on the hardness and microstructure conveyance along the weld metal.

Hassan (2017) concluded that the preheating temperatures of up to 100 ℃ are favorable in diminishing the cold cracking defenselessness due to a relative fine microstructure and moo M-A constituent sum in coarse grained heat influenced zone, a moo hardenability, and low-level residual stress and strain. Intemperate preheating temperatures of 150 ℃ and 200 ℃ lead to grain coarsening, higher M-A constituent sum, higher residual stress level and expanding strain level within the Tekken specimens. However, preheating temperature over 150 ℃ isn't favorable for diminishing the cold cracking susceptibility of X100 steel.

Chunyan *et al.* (2019) found out that the application of preheating temperature of 1500C come about in a vanishing of cracks. Moreover, expanding the heat input from 0.89 kJ/mm to 1.34 kJ/mm essentially diminishing the cracking record. Expanding the drying temperature of covered electrode encompasses a noteworthy impact on diminishing the diffusible hydrogen content.

Morsy *et al.* (2014) in their study showed that application of preheating temperature of 1500C resulted in a disappearance of cracks. Also, increasing the heat input from 0.89 kJ/mm

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to 1.34 kJ/mm significantly decreasing the cracking index. Increasing the drying temperature of covered electrode has a significant effect on decreasing the diffusible hydrogen content.

El-Batahgy (1994). concluded that the reliance of least preheating temperature on diffusible hydrogen contents in weld metal was clarified.

2.2. Diffusible hydrogen effect on delayed cracks

Seo & Bang (2012) found out that the diffusible hydrogen contents were impacted by welding parameters such as the voltage and contact tip-to-work separate (CTWD). The diffusible hydrogen content expanded with an increment in voltage. It was diminished with an increment in CTWD. CTWD moreover affected the weld metal hardness, particularly when the wire utilized had a higher strength than the base metal. This appeared that weld metal hardness had a more capable impact on weld metal cold cracking than the diffusible hydrogen content in this test.

Klett *et al*. (2021) revealed in their study results that the welding in direct contact with water includes various challenges. A subject centered by numerous considers is the hazard of hydrogen-induced cracking in wet weldments due to hardness values of up to 500 HV 0.2 within the heat-affected zone (HAZ) and tall levels of diffusible hydrogen within the weld metal. Hence, high-strength steels are particularly inclined to hydrogen-induced cracking and are considered risky for underwater repair weldments.

Pandey *et al.* (2016) revealed that hydrogen-assisted cracking (HAC) may be a genuine issue in P91 steel welds since of undesirable martensitic metallurgical-transformation within the heat affected zone (HAZ). They concluded that P91 steel welded by the electrode having higher defilement (high hydrogen level) is more susceptible to HAC.

Mukai *et al*. (2019) included that the result of cold cracking interference by the novel welding method for reducing diffusible hydrogen was confirmed and regarding 50°C preheating chilling result was incontestable.

Leonard *et al*. (2000) found out that weld metal cracking was found to occur solely at high ferrite contents and hydrogen levels. Also they included that the possibility of occurring hydrogen cracking in practice is expected to be low, given adoption of normal welding procedure guidelines.

3. Conclusion

The ponder of the literature review surveys that preheating is essential in welding a few steel sorts to dodge hydrogen induced cold cracks. However, in a few other cases, it still conceivable to weld at room temperature. However, few researchers recommended that the helplessness towards the delayed cracks might be disposed of by utilizing less hydrogen welding methods and consumables. Additionally, examinations appeared that cracks were continuously related with hard martensitic areas adjoining to the fusion boundary. In any case other authors emphasized that heat affected zone hardness, less hydrogen level, and less combination boundary, are very critical components to anticipate delayed cracks. Finally, it is evident that

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reducing the probability of having cold cracks is highly progress in the welded joints of numerous types of high strength steels. More over required welding conditions and procedures are well built up to reduce the initiation of delayed cold cracks.

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