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Effect of Welding Process on Ultrasonic Testing of 9Ni Steel Weld Joint

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Abstract. In the world, 9Ni steel with the relatively low price, high strength, low temperature toughness and safety reliability has become the principal material of LNG storage tanks. The presence of coarse-grained microstructures in the weld microstructure has a substantial impact on the ultrasonic testing of the weld. Therefore, an excellent 9Ni steel ultrasonic testing technology is realized for a suitable welding process.

1. Introduction

LNG storage tanks are widely used in oil and gas storage and transportation, petrochemical and other industries, and their qualities of manufacture directly could affect the safety of high-pressure storage tanks. In the world, 9Ni steel with the relatively low price, high strength, low temperature toughness and safety reliability has become the main material of LNG storage tanks. However, due to the structural characteristics of 9Ni steel, especially the welding position, it affects ultrasonic flaw detection. Based on the ultrasonic testing in non-destructive testing, this paper systematically reviews the influence of the welding process on the ultrasonic propagation characteristics of 9Ni steel ^[1-4]. The research is useful to the optimization and improvement of the detection process.

2. Influence of welding process on welded structure of 9Ni steel

2.1. Influence of welding process on the microstructure of 9Ni steel weld

The microstructure of 9Ni steel welds is different using different welding processes. Meng Genbagen et al.^[1] studied two different welding methods, manual welding and tungsten argon arc welding, and selected different welding processes. Finally, the microstructure of welded joint were very different. The weld structure of 9Ni steel is mainly composed of γ phase solid solution and precipitation phase. The hand-welded weld dendrites are severely segregated, the columnar crystals are relatively coarse, and the dendrite segregation of the tungsten argon arc welding is not serious, and the columnar crystals are relatively small. The width of the columnar crystal in the tungsten argon arc welding seam is small, and the martensite of the lath in the heat-affected zone is insignificant, which makes the joint low temperature toughness higher than that of the manual welded joint. It could be observed that different welding processes have a profound influence on the microstructure of 9Ni steel weld joints. In the test, we should make a suitable welding process to produce an excellent LNG storage tank.



2.2. Effect of welding process on grain thickness of 9Ni steel weld joint

Different welding process parameters will have a huge impact on the grain size of the weld.

(1) Effect of soldering temperature on grain size

9Ni steel could work at an ultra-low temperature of -196 °C, so the welding materials used must not only ensure the quality of the welded joint, but also ensure the low temperature toughness of the welded joint. In the actual engineering of LNG storage tanks, the welding materials of nickel-based materials for 9Ni steel are usually used. The use of a nickel-based material should be pointed out the nickel-based alloy has poor thermal conductivity and is prone to overheating during welding to cause grain growth.

(2) Effect of cooling rate of weld seam on grain size after welding

The slower the cooling rate after soldering, the more it contributes to grain growth.

(3) Effect of welding line energy on grain size

The heat input during welding is too large, which tends to cause coarse grains in the heat-affected zone, so the welding line energy must be controlled.

3. Effect of 9Ni steel weld on ultrasonic propagation

Different welding processes and microstructures will result in different grain sizes of 9Ni steel, which are the fine and coarse grains, respectively. Different grains have different effects on the acoustic properties of the base metal and the weld. In the industry, LNG storage tanks are used at low temperatures, and 9Ni steel is commonly used, and the weld seams also have a high Ni content. For this reason, in the construction of LNG storage tanks, austenite large particles, that is, coarse crystal structures, usually appear in the weld. Because there are some problems in the ultrasonic testing of coarse-grained materials: (1) the microstructure of the coarse-grained material attenuates the ultrasonic wave greatly, and the appearance of the forest-like echo reduces the signal-to-noise ratio of the defect. (2) the ultrasonic wave passes through the refraction generated at the interface of the dissimilar metal weld will distort the ultrasonic propagation path, and the interface of the dissimilar metal weld will cause false defect signals, causing misjudgment. (3) The coarse grain and anisotropy of the weld easily make the ultrasonic propagation distorted. These factors will cause great difficulties in ultrasonic testing and defect detection, positioning and quantification. And if defects occur in LNG storage tanks, serious consequences will be brought about. In view of the particularity of ultrasonic testing of 9Ni steel welds, those who perform ultrasonic testing of coarse-grained material welds should have certain knowledge of materials and welding. Make correct assessments, judgments, and actions for problems that may arise during testing. Ultrasonic testing of coarse-grained material welds has been a problem in ultrasonic testing^[2]. The following is an analysis of the specific impact.

3.1. Effect of grain size of weld on ultrasonic waves - scattering and attenuation

Ultrasonic scattering is related to the average grain size of the material. When the ratio of the average diameter d of the grain to the wavelength λ is less than 0.1, the scattering phenomenon is weakened and does not have a large effect on the ultrasonic detection. when the ratio is greater than 0.1, the scattering phenomenon will significantly enhance. The signal-to-noise ratio of ultrasonic testing is reduced, and the sensitivity is decreased. In addition, the scattering of ultrasonic wave is also related to factors such as the degree of material anisotropy and ultrasonic frequency. In the Rayleigh scattering region, the scattering coefficient and the average grain diameter, the degree of anisotropy, and the ultrasonic frequency f . The quantitative relationship between them is given by:

$$\alpha_s = c_2 \bar{d}^{-3} f^4$$

Where: (s is the scattering coefficient. c_2 is a constant related to the degree of material anisotropy \bar{d} . It is the average diameter of the crystal grains. It could be seen that the coarser the crystal grains, the more intense the anisotropy of the material, and the higher the ultrasonic frequency, the stronger the scattering.

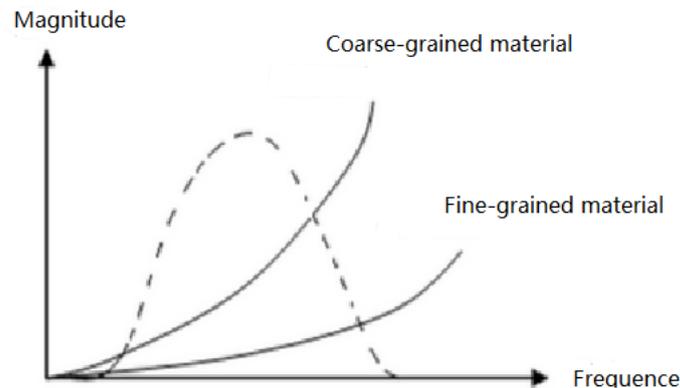


Figure 1. Boundary conditions Schematic diagram of grain scattering amplitude and transducer frequency response curve.

Figure 1 is a schematic representation of the relative positional relationship between the scattering amplitude curves of different grain size materials and the ultrasonic transducer frequency response curve. Generally, the scattering amplitude curve of the fine-grained material overlaps with the transducer band range, and the scattering phenomenon is weak. Therefore, the signal-to-noise ratio and sensitivity of the ultrasonic detection are high. However, for coarse-grained materials, the average amplitude of the crystal grains increases, the scattering amplitude curve shifts toward the low-frequency direction, and the transducer band overlaps greatly, the scattering phenomenon is obvious, the signal-to-noise ratio is low, and conventional ultrasonic detection is performed. Procedures are often not implemented, and ultrasound's ability to detect defects is severely degraded.

Scattering can cause severe material noise, while attenuation leads to weakening of structural characteristics of materials such as defects and bottom wave signals, which is another important cause of the decline in ultrasonic detection capability. In the process of diffusion, scattering and absorption of sound waves, the extreme attenuation caused by coarse grains could seriously degrade the sensitivity of ultrasonic detection. In summary, material grain size is an important consideration in the sensitivity of ultrasonic testing.

The attenuation of ultrasonic waves during the propagation process mainly has scattering attenuation. Due to the large grain size and anisotropy of the 9Ni steel weld, severe scattering is seriously caused. When the diameter of the weld bead is close to 1/10 of the wavelength of the ultrasonic wave, there will be significant acoustic scattering^[2]. The intensity of the scattering and the angle between the ultrasonic beam and the axis are related. When the scattered ultrasonic waves propagate along the complicated path to the probe, grassy echoes are caused on the display screen, causing the signal-to-noise ratio to decrease and the sensitivity to decrease. When the grass echo is more serious, the noise signal will flood the defect signal.

3.2. Effect of weld anisotropy on ultrasonic waves-changing the direction of propagation

The anisotropy of the metal structure causes the propagation direction of the ultrasonic wave to change, and the sound attenuation value and the sound velocity are affected by the angle between the beam direction and the crystal axis. due to the anisotropy of the base metal and the weld material, ultrasonic waves produce deflection of the sound beam during the propagation process. the weld fusion surface of the nickel-based alloy and the interfacial microstructure between the weld grains are significantly different, and the ultrasonic beam is incident on the heterogeneous surface, which may cause reflection, refraction, and waveform conversion or Reflected echo superposition is prone to false signals^[3].

3.3. Influence of the coarse-grained microstructure of the weld on the ultrasonic wave-Probe

When the probe receives the ultrasonic wave returning from the defect, the frequency of the received signal is usually lower than the ultrasonic frequency at the time of transmission, which is the influence of the material on the low-pass filtering of the ultrasonic wave. When the crystal grain is coarse, the

low-pass filtering effect becomes large. .At the same time, considering the higher the frequency of ultrasonic detection, the greater the attenuation, the lower the penetrating power, the 0.5-2.5MHz narrow pulse longitudinal wave double crystal oblique probe is usually recommended ^[3-4].However, NB/T4730.3-2015 Appendix N does not give the specific wafer size and specifications of the probe. At the same time, in actual detection, it is necessary to select a suitable probe according to the characteristics of the test material.

4 Conclusions

In summary, the presence of coarse-grained microstructures in the weld microstructure has a large impact on the ultrasonic testing of the weld. Therefore, an excellent 9Ni steel ultrasonic testing technology is realized for a suitable welding process.

Acknowledgments

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