46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-1234

ULTRASONIC NONDETRUCTIVE TESTING AND INSITE CONTROL OF WELDING RESIDUAL STRESS OF PIPELINE BY HIGH-ENERGY GUIDED WAVE

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ABSTRACT

Unbalance distribution of residual stress importantly result in deformation and breakage of pipeline welding(especially weak stiffness wall with complicated, huge and thin metal structure), injecting high-energy guided acoustic wave into the interior of the pipeline wall to quickly homogenize and reduce residual stress distribution is the very effective way for controlling residual stress in balance state and breakage and deformation for plate-like structure at normal temperature. The physical principle of controlling and dispersing the residual stress concentration by high-energy guided acoustic wave with different frequencies, phases and amplitudes is to use the powerful kinetic energy generated by high-energy elastic waves to change the potential field energy formed by the residual stress throughout the whole weldings of pipeline, so that the residual stress can be reduced and homogenized; Realtime monitoring or detecting of the changes in residual stress using acoustic-elastic principle with the propagation of ultrasonic wave during residual stress being controlled, forming a closed-loop control system and technology for residual stress regulation; The directional acoustical beam can also provide the focusing energy for the stress concentration area inside the pipeline wall, and the local residual stress can be reduced and homogenized without changing the mechanical properties such as the elastic modulus and yield strength of the pipeline material, meanwhile, keep the pipeline shape unchangeable and unbreakable.

Keywords: Residual stress, Pipeline, Ultrasonic Wave, Nondestructive Testing, Stress Control , Guide Wave

1. INTRODUCTION

Residual stress is a type of inherent stress that maintains stress balance in the inner material when the components are unaffected by external strength. The main sources of residual stress are mechanical processes, such as extrusion, rolling, drawing, correction, cutting, grinding, surface rolling, shot peening and hammering, as well as hot working including welding and cutting. Residual stress is usually harmful. For example, resistance to fatigue strength, brittleness fracture, stress corrosion cracking, and the stability of the size and shape of the components are significantly reduced under the combined action of residual stress, working temperature, and working medium Therefore, developing an effective detecting method is important in improving the residual stress state in the components.

Since the introduction of residual stress detecting technology in the 1930s, over 10 types of detection methods have been developed. Damage detection methods can be categorized into three, namely, destructive, half-destructive, and nondestructive methods. Destructive testing methods include the slice and contour methods. Half-destructive methods include the blind hole, ring core, and deep hole methods. Nondestructive testing methods include the X-ray diffraction, neutron diffraction, magnetic measurement, and ultrasonic methods. The destructive and half-destructive testing methods belong to the category of stress release, and they more or less lead to the damage of tested component. The damage in service conditions of mechanical components is fatal and must be avoided. Therefore, nondestructive testing methods are more widely used. However, testing and calibrating the stress gradient in the depth direction of mechanical components using nondestructive testing methods are still difficult at present. For example, MIAO et al[8], measured residual stress in the precipitation-hardening layer of NAK80 steel before and after a shot peening treatment by X-ray diffraction method. The shot peening experiment results show that the depth of residual stress in the precipitation-hardening layer can reach approximately 450μm. However, the X-ray diffraction method can only detect a shallow residual stress field(5–20μm). Hence, the author had to use numerical calculation to obtain a larger depth residual stress field. Neutron diffraction has a strong penetrating power (the maximum depth can reach 30 cm especially for the heavy metal). Thus, WITHERS mapped residual and internal stress in hexagonal polycrystalline materials by neutron diffraction. However, building and running neutron reactors can be costly, thus limiting their practical applications in the industrial field. Magnetic measurement is also called Barkhausen noise method. On the basis of Barkhausen noise effect, DESVAUS, et al, inspected the homogeneity of surface and subsurface (in the first 60μm under the surface) stresses on the bearing rings. Their result shows that magnetic measurement can only test the stress profile in the surface. Ultrasonic method has been rapidly developed. Different types of ultrasonic testing methods have been developed, such as the ultrasonic longitudinal wave, ultrasonic shear wave, combination of shear wave and longitudinal wave, ultrasonic surface wave, ultrasonic guided wave, nonlinear ultrasonic, and ultrasonic critically refracted longitudinal wave(L_{CR} wave) methods.

Regarding the residual stress control of in-service welded components, whether it is the traditional natural aging method, the hammering method, the thermal aging method, or the current spectrum harmonics, electric shock method, magnetic pulse method, etc., have their limitations, can not achieve In-situ regulation or reduction of welding residual stress. Although the ultrasonic shock elimination residual stress technology is a popular technology developed in recent years, the micro-high-strength metal horn impact punch impacts the metal surface to increase the surface compressive residual stress, and the frequency is higher and higher, and the ultrasonic vibration frequency can be achieved. However, this technique produces compressive residual stress on the surface of the aluminum alloy. At the same time, the surface of the mechanical component is affected by the impact of the horn, which will inevitably bring impact damage or even cracks or micro-cracks. These damages will also cause non-metallic surface damage. Inclusive damage affects the safety and reliability of components. Therefore, it is urgent to study a new residual stress reduction technology to meet the needs of on-site reduction of residual stress of aluminum alloy components.

To solve the aforementioned problem, based on the theory of acoustic elasticity, the relationship between ultrasonic and stress is studied. The calibration technique of ultrasonic residual stress detection is discussed. The ultrasonic stress detection and calibration system is applied to the distribution detection of residual stress in aluminum alloy, and good application results are obtained. At the same time, a high-energy ultrasonic reduction technique with residual stress is used to place the mechanical components in the high-energy sound field. The surface energy and the internal residual stress state of the aluminum alloy components are changed by applying high-power acoustic energy, and the local quantitative reduction of the residual stress state is implemented.

2. TESTING METHOD FOR ACOUSTOELASTICITY THEORY

Acoustoelasticity theory is one of the main basis for ultrasonic stress testing. Acoustoelasticity theory is based on the finite deformation of continuum mechanics to study the relationship between the elastic solid stress state and the macroscopic elastic wave velocity.

3. RESIDUAL STRESS CONTROL THEORY

According to theoretical analysis, the essence of residual stress is lattice elastic distortion, and lattice elastic distortion is largely caused by the binding force between lattices. On the basis of experimental phenomena, the existence and existence of residual stress Starting from the dislocation lattice model, the interaction between the binding force field around the dislocation and the elastic fluctuation is analyzed, and the theoretical model of the regulation of residual stress by high-energy ultrasound is given.

4. CONCLUSION

The welded pipeline is placed in a high-energy sound field, and the high-power acoustic energy is used to change the surface and internal residual stress field state of the welded part, and the in-situ local quantitative regulation of the welding residual stress state is well realized.

The experimental application and results analysis show that the residual stress detection and in-situ control technology have good accuracy, practicability and extensive application fields, which can well solve the problem of pipeline welding residual stress detection and elimination, and ensure oil and gas transportation equipment. The overall performance is good.

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