Comprehensive analysis of the progress and application for defect detection technology in welding process

Yijia Gu[1, *]

No.120 Secondary School, Shenyang City, Liaoning Province, 124000, China

* 1911511227@mail.sit.edu.cn

Abstract. Welding defect detection is one of the research hotspots in the field of welding. Some researchers have found that in many welding processes, due to some uncontrollable factors, the weld will have different degrees of defects. These defects often cause great harm to production and life. This makes the welding defect detection technology become one of the current research hotspots. However, the defect detection technology based on heterogeneous sensors applied in welding field still faces certain challenges and limitations in many practical application scenarios. Therefore, the research progress of welding defect detection is deeply analyzed in this paper. Firstly, this paper summarizes the research background and significance of welding technology and welding quality inspection. Secondly, the causes of weld defects and corresponding hazards are analyzed from many aspects. Then, combined with the recent literature, the defect detection technology in welding process is reviewed. Finally, the research status of welding defect detection technology is summarized, and its future development prospect is prospected.

Keywords: welding defects, causes of defect, defect detection

1 Introduction

With the development of industry, welding technology has emerged in many important fields such as automobiles, ships, and aerospace [1]. At present, welding has developed into an independent discipline, which is a processing method with short development time and high efficiency. Some modern large-scale equipment nowadays. Such as large-scale transportation facilities and basic energy equipment, welding techniques are used. The high quality, long lifespan, durability, and other performance that people pursue, require many types of metals for welding. With the expansion of welding application scope, technologies in welding processes, welding equipment, welding materials, welding structure design, and welding quality inspection methods are also constantly improving. At the same time, higher requirements have been put forward for welding quality [2, 3]. During the welding process, defects such as cracks, slag inclusions, incomplete penetration, and incomplete fusion often occur in the weld seam. These defects pose a serious threat to

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safety production and product quality. Therefore, welding defect detection is particularly important [4]. More and more manufacturing enterprises are paying attention to efficient and fast-paced production methods. They are trying to solve many problems such as labor shortage and high labor costs [5]. The progress of welding technology has driven an increase in the number of welding products. The quality of welding has become the key for people to judge the quality of products. Various factories want a simple and more efficient welding defect detection method to effectively reduce production costs. Weld defect detection has great practical significance. The automation and intelligence of robot welding in welding, as well as the automatic tracking system for welding seams, have reached advanced levels. However, there are still many challenges in the automation of welding quality and defect detection.

Therefore, this article conducts research on welding defect detection technology. The subsequent structure of this article is as follows. In Chapter 2, a background technical overview of defect detection technology in the welding process is provided based on sensor type and detection time. Chapter 3 analyzes the typical defect characteristics that are prone to occur during the welding process. Chapter 4 introduces the inspection methods for existing welding defects. Chapter 5 provides a summary and outlook.

2 Related work

2.1 Classification method based on multi-source sensors

2.1.1 Computer vision inspection. Nowadays, research on detection technologies related to initial and precise positioning of welding images, as well as feature matching, has made significant progress. Through effective analysis and experimental research, researchers from various countries have developed detection algorithms that can meet the requirements of identifying defects, and have successfully designed some specific defect detection devices. The accurate image foundation lays a strong foundation for the evaluation of surface defects in welded parts and the calculation of weld size. The welding defect detection method based on machine vision technology has been preliminarily formed. However, the algorithm is too complex to be accurately applied to the production process.

Image enhancement technology can be used to enhance the recognized image, highlight useful feature information in the image, enhance image recognition, and weaken or eliminate other irrelevant feature information. One of the image enhancement methods is segmented linear grayscale enhancement. Segmental linear grayscale enhancement can perform segmented linear expansion on the grayscale of an image, enhance the contrast between foreground and background, and compress images containing unnecessary grayscale.

Visual inspection technology based on digital image correlation methods can be used to measure the three-dimensional dynamic deformation of welds. At present, welding deformation measurement method based on computer vision is mainly achieved through camera systems with different angles. Image matching mainly includes horizontal matching and vertical matching. Horizontal matching refers to the implementation of correlated matching between the left and right cameras at the same time; Vertical matching refers to the correlation matching of image sequences collected by the same camera in the time direction. For the matched image, in order to obtain the 3D coordinates of the points in the overall calculation area, the 3D reconstruction method can be used to achieve dynamic 3D deformation calculation during the welding process [6].

2.1.2 Ultrasonic testing. The basic principle of ultrasonic testing is the endpoint reflection echo method. The ultrasonic wave incident on the crack generates reflection at its interface, with a portion reflecting along the original path, known as the endpoint reflection echo. The ultrasonic wave incident on the crack generates reflection at its interface, with a portion reflecting along the original path, known as the endpoint reflection echo.

The combination of variable angle probes and straight probes is used for sample scanning and identification of defect types. Comprehensive upper level scanning, including front and rear scanning, left and right scanning, rotating scanning, surround scanning, etc. By comprehensively evaluating the static and dynamic ultrasonic information obtained, defect types can be identified [7].

2.1.3 Temperature sensor. Welding sensors utilize the continuous advancement and changes of heat sources, as well as the temperature differences at various points on the welding material at any time, and the changes in this heat source are regular and traceable. At a certain moment, the distribution status of the welding temperature field can be displayed through a curve or cloud graph. The welding temperature field describes a complex welding process. This process can determine the melting, crystallization, deformation, and other conditions of welding. By using virtual instruments, welding temperature field detection can be achieved, and the detection results can be plotted into graphical curves, enabling the transmission, analysis, processing, and storage of welding temperature field data, forming text or graphical reports, and accurately detecting defects in welding [8].

2.1.4 Infrared sensor. Due to factors such as welding current and arc voltage, passive infrared thermal imaging non-destructive testing technology can be used to detect defects in the weld seam. This method does not require heating of the weld seam and can identify defects in the weld seam. Using deep learning neural networks for online classification and detection of offset, hump, and flow defects during the deposition process. Based on the test results, on-site testing is carried out to facilitate subsequent milling, repair welding, and optimization of process parameters, ultimately ensuring the quality of the product [9].

2.2 Classification method based on detection time

There are various advanced technologies for welding defect detection, and in terms of time classification, the methods used to detect welding defects mainly include two categories:

Offline detection: after the welding process is completed, defect detection is carried out on the weld seam. This method can ensure safety while detecting the weld seam with high accuracy.

Online detection: during the welding process, welding defects are detected and the results are fed back to the welding robot, which can then repair the defects. This method can improve the efficiency of detection, but it is often subject to external environmental interference and is prone to deviation when used.

3 Weld defect

3.1 Weld crack

Weld cracks are caused by excessive pressure and temperature during welding, which makes some welds relatively fragile, causing the atoms around the weld to receive tension and produce cracks. Cracks are very dangerous and pose a safety hazard, and they can continue to expand.

3.2 Welding holes

The gas in the welding hole mainly comes from two aspects.One is dissolved gases such as hydrogen and nitrogen introduced from the outside; one type is the metal elements such as carbon monoxide and water vapor generated during the molten pool process. When the high-temperature metal molten pool cools down, the temperature of the molten pool drops and enters a saturation stage, which is then rapidly released and wrapped by the metal layer of the weld, ultimately forming pores. However, in the actual welding process, the pores formed due to the shrinkage of the material in the molten pool during solidification are called "shrinkage pores". Porosity can cause the working section of welded joints to become thinner, generate greater stress, and reduce their plasticity and strength, especially fatigue and impact toughness, and even lead to cracks.

3.3 Welding solid inclusions

The inclusions in the weld seam are formed during the welding and smelting process, mainly due to residual oxides, nitrides, sulfides, etc. during the melting process. Due to the influence of inclusions, the plasticity, brittleness, toughness, and fatigue properties of alloy materials will decrease. At the same time, during the stress process, inclusions can also cause stress accumulation. Therefore, this type of inclusion is often referred to as the source of cracks, thereby increasing the probability of hot cracking occurring.

3.4 Arc scratch

Arc scratch is a localized damage that occurs on the surface of the base metal during arc striking outside the weld groove. The majority of the reasons for this are due to the operator's lack of proficiency. For example, when the arc is pulled too long during welding, or when the current is too high during welding, the electrode does not swing properly, and the arc is extinguished too quickly. Arc abrasion can reduce the effective cross-section of the weld and weaken the strength of the weld.

3.5 Weld Spatter

Welding spatter is the phenomenon of partially liquefied metal splashing around the molten pool due to the action of arc force during the fusion process between the welding rod or wire and the welded part during welding. Welding spatter may burn the operator, cause a fire, affect the surface quality of the weld base metal, and affect the load-bearing capacity of the welded component [10].

4 Inspection methods for welding defects

4.1 Welding appearance and dimensional inspection

The appearance inspection of the weld seam is completed through visual inspection. By using a human magnifying glass, the appearance of welds can be inspected for shape defects such as splashes, arc scratches, and undercuts. The welding inspection ruler can be used to detect items such as weld reinforcement, width, and misalignment. Subsequent inspections can only be carried out after passing the appearance and size inspection according to the standard requirements.

4.2 Welding surface defect inspection

Surface detection technology can be used to detect defects on the surface of welds and near the surface. At present, the common surface defects detected mainly include magnetic particle testing, penetration testing, and eddy current testing. The basic principle of magnetic particle detection is that when a metal magnet is magnetized, due to its structural discontinuity or defects, the magnetic field lines near it may deform locally, causing leakage and absorbing it. Under appropriate light irradiation and certain light conditions, obvious magnetic traces will appear, showing the position, size, shape, and severity of the discontinuity. The magnetic particle method can effectively detect defects on the welding surface, but it is only applicable to the surface and proximal defects of metal magnetic materials. Penetrant testing is the process of penetrating the surface of the weld seam through a penetrant containing fluorescent or red dyes without damaging the weld seam. Under capillary action, the penetrant is penetrated into the open cracks on the weld surface for a certain period of time. After the penetration work is completed, the excess penetrant on the surface needs to be removed, and then a layer of imaging agent is added to the surface of the workpiece to reattach the penetrant from the defect to the surface, to form traces of defects, a method of evaluating defects by directly observing the color or fluorescence image of the defect traces through visual inspection or special lighting fixtures. Penetrant testing can detect both ferromagnetic and non-ferromagnetic materials, and can also be used for the detection of non-metallic materials. However, porous materials are not suitable for penetrant testing [11].

4.3 Inspection of internal defects in welding

Defects present inside the weld seam can be detected through ultrasonic testing and radiographic testing. Ultrasonic testing is a technology that studies the reflection, transmission, and scattering of waves through the interaction between ultrasonic waves and specimens. It monitors macroscopic defects, measures geometric characteristics, detects and characterizes changes in organizational structure and mechanical properties of specimens, and evaluates their specific applicability. Ultrasonic waves have strong penetration and high sensitivity, and can detect small defects inside the workpiece. However, the detection results are not intuitive enough, and it is still difficult to qualitatively and quantitatively identify defects. Radiographic testing is mainly carried out through X-ray or γ. The degree of attenuation of light intensity when a ray passes through the object being tested is used to detect defects inside the object. X-ray radiographic testing can directly reflect the size and morphology of internal defects in parts, thereby determining the essence of defects. However, the equipment required for this method, such as X-ray film, is expensive and the inspection progress is slow. It only checks for volumetric holes, slag inclusions, shrinkage holes, loose defects, etc., and cannot detect defects such as cracks and lack of fusion with very small gaps, such as the inner layer layering of forged parts and profiles such as pipes and rods. In addition, radiation poses a threat to human health and should be protected. X-ray photography technology has been widely used in welding and casting, such as pressure vessels, boilers, ship hulls, oil and gas pipelines, various cast steel valves, pump bodies, drilling and chemical engineering, oil refining equipment, precision cast turbines, and various aluminum magnesium alloy castings used in the aerospace and automotive industries [12].

5 Conclusion

This article provides a comprehensive overview and analysis of the progress and application of defect detection technology in the welding process, and presents different welding defects and detection techniques in a more specific manner. Firstly, the importance of detecting welding techniques and welding defects is analyzed and discussed. Secondly, provide a background technical overview of defect detection techniques in the welding process based on sensor type and detection time. Finally, typical defect characteristics that are prone to occur during the welding process were analyzed and inspection methods for existing welding defects were introduced.

The author believes that welding defect detection technology still has great potential for development in the future. In terms of improving defect detection algorithms, further research is needed for some relatively rare defects, and further improvements can be made to the algorithm, such as using deep neural network technology for generalization analysis to make the algorithm more robust. In addition, the quality of obtained images can be improved by constructing a specific environment, thereby ensuring the efficiency of welding defect detection.

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