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Analysis of Mechanical Properties of Welds by Magnetic Memory Detection

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Abstract

In order to detecting the mechanical properties of steel weld quality quickly and accurately, the method of detecting the weld quality of low carbon steel by magnetic memory detection technology is studied. Tensile test and magnetic signal measurement of different welding current welding specimens were carried out, and the defect detection analysis were carried out by using ray detection technique. Studying the relationship between the change of magnetic memory signal during tensile process and the yield strength and tensile strength of low carbon steel welds. The results show that the specimens with different welding current have different mechanical properties, and the specimens with different yield strength and tensile strength have different characteristics of magnetic memory signals. It is found that the mechanical properties of low-carbon steel welds can be effectively determined by using the two-parameter information fusion technology based on the basic principle of metal magnetic memory detection technology and the average magnetic signal information and magnetic signal gradient information under different stress. The research results can provide reference for the application of magnetic memory detection technology in the quality evaluation of carbon steel weld quality.

Keywords

Nondestructive Testing, Magnetic Memory Detection, Weld Quality, Average Magnetic Signal, Magnetic Signal Gradient

1. Introduction

Metal magnetic memory testing technology is a new and green non-destructive testing technology, it is through the stress on the ferromagnetic specimen on the characteristics of the dangerous area of the spontaneous leakage magnetic field analysis [1-2], and then the degree of damage to the test specimen for early diagnosis and reliable evaluation, so as to prevent the occurrence of catastrophic accidents. Since the rise of magnetic memory detection technology [3-4], many experts and scholars at home and abroad have done a lot of theoretical research and instrument development, and has made outstanding contributions [5-6]. Among them, the theory of magnetic memory testing for welded components is also studied in theory and experiment [7-8]. Beijing Institute of Technology, Liu Hong-guang, Zhang Wei-min, who through the study of the magnetic memory signal changes on the weld defects, the magnetic dipole model of the weld under geomagnetic field is established, and the weld defect is evaluated [9]. Tianjin University, Qiu Xin-jie, Li Wu-shen, who through the study of the characteristics of the leakage magnetic field, established the neural network system based on the wavelet packet energy of the metal magnetic memory signal of the welding crack, which is used to identify the defects such as cracks in the weld [10-11]. Professor Dubov of Russia applied the magnetic memory detection technique to the initial stage of the welded steel structure of electrical engineering and turbine components [12-14], and the non-uniformity of the stress-strain state of the welded joint before and after the heat treatment was evaluated. Professor Long Fei-fei of the Northeast Petroleum University [15] used the method of heat treatment to evaluate the quality of welds. At present, the research on the magnetic signal detection technology of welds is mainly focused on the detection of weld defects. The theoretical research on the mechanical properties of welds is very few, and the welding technology (welding current, heat treatment process) and other factors Magnetic signal research is more rare. In this paper, combined with the traditional ray detection technology, study on mechanical properties of welding component under tensile condition by Magnetic Memory Testing Method. The influence of welding current on magnetic signal is analyzed according to the law of variation of yield strength and tensile strength, and study the relationship between magnetic memory signal and welding quality. It can provide reference for further research on metal magnetic memory testing technology for low carbon steel weld quality inspection.

2. Test Materials and Methods

2.1. Experiment Material

The tentative uses Q235 hot-rolled steel, which has moderate carbon content and good comprehensive properties. It is well matched with its strength, plasticity and weld-ability. The structure size of the specimen is shown in Figure 1. The length of the specimen is 220mm, the width is 60mm, the center width is 40mm, and the thickness is 2.5mm. For the flat welding joints, the method of argon arc welding is adopted. flat-panel butt welding on a single side, not open groove, and the welding wire diameter THQ-50C is 1.6mm. The welding machine is Shanghai power WSME-315. In the welding voltage and welding speed of the same conditions, welding with different welding current is used to change the welding quality.

$1^{\#}$ and $2^{\#}$ specimens are flat specimen, $3^{\#}$ and $4^{\#}$, $5^{\#}$ and $6^{\#}$, $7^{\#}$ and $8^{\#}$, $9^{\#}$ and $10^{\#}$, $11^{\#}$ and $12^{\#}$ are welding specimens, the welding current is 70A , 90A, 110A, 130A and 150A. All the specimen after welding were treated by stress annealing to eliminate the residual stress in the process of welding the specimen, and the surface of the specimen is lightly polished with sandpaper.

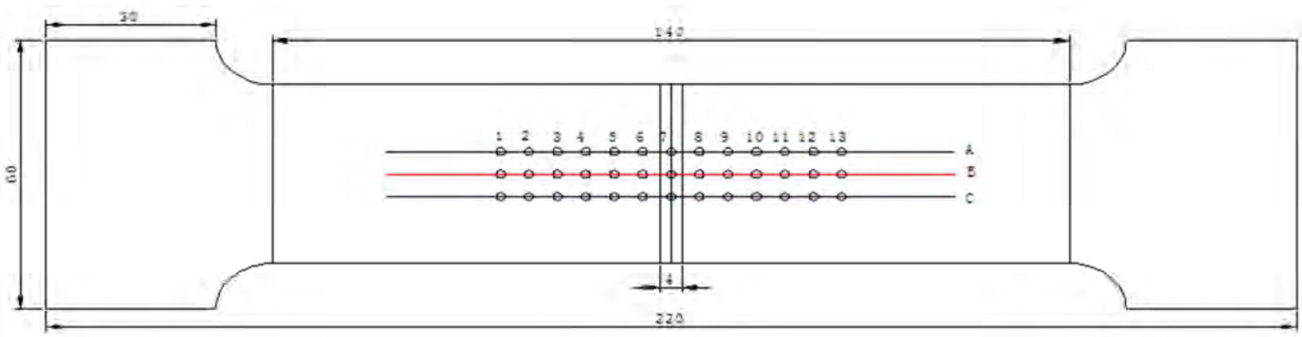


Figure 1. *Q235B structural dimensions of steel butt welds (unit: mm).*

2.2. Experiment Method

2.2.1. Ray Detection Method

Firstly, X2515 ray machine and CR-ray scanner on the 3# ~ 12# weld work piece radiation detection. When tested in X2515 ray machine, using 90kV voltage and 15mA current, exposure time is 90s. The five groups of welding soldering samples with different welding currents were subjected to radiation detection and observed with a CR-ray scanner.

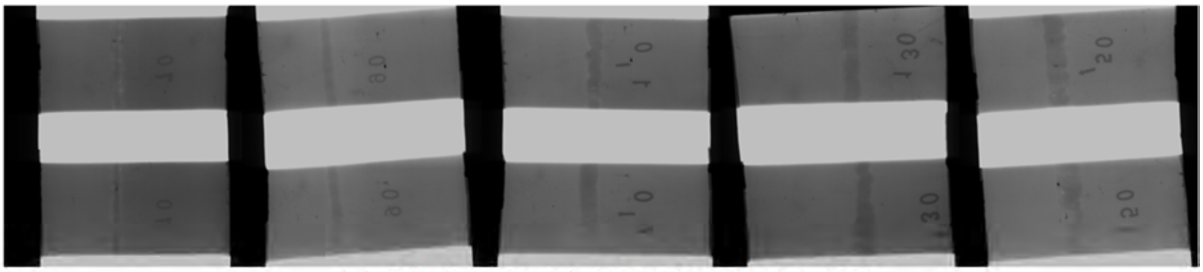
2.2.2. Stress Tensile Test Method

First of all, the specimen $1^{\#}$, $3^{\#}$, $5^{\#}$, $7^{\#}$, $9^{\#}$ and $11^{\#}$ were subjected to static tension, and the stress-strain curve was made to determine the yield strength and tensile strength. Before the test of the tensile test, the initial magnetic field value of the specimen is measured, that is, the specimen is placed in the same direction as the static object away from the ferromagnetic object, the leakage field of 13 points on each path of the test specimen was measured by Lake Shore 421 Weak Magnetic Field Meter (measuring range 0.001Gs ~ 300kGs, measurement error ± 0.2%, resolution 4%). Finally, the test pieces $2^{\#}$, $4^{\#}$, $6^{\#}$, $8^{\#}$, $10^{\#}$ and $12^{\#}$ were placed on the WDW-100 electronic tensile tester for static load tensile test, and the tension machine is loaded at the speed of 2mm/min. In the elastic phase, take a 5kN loading gradient. In the plastic phase, taking a 3kN loading gradient. After loading to a predetermined load, stop, unload to zero, remove the specimen, and measure the leakage field of 13 points on each path of the test piece. The specimen is then replaced on a test machine with a higher predetermined load to repeat the operation until the specimen is broken.

3. Test Results and Discussion

3.1. Radiation Detection and Analysis of Weld Quality Under Different Welding Current Conditions

Figure 2 shows the ray detection picture images under different welding current conditions. When *I* is 90A, 110A and 130A, the weld quality is good; But when *I* is 70A, there is no penetration defect in the weld zone; when *I* is 150A, there is a small amount of tungsten inclusion in the weld zone. It can be seen that when welding current *I* is 90A~130A, weld quality is better, welding current is too high or too low, it is easy to produce defects and reduce welding quality. In other words, when the welding current is in the 90A~130A range, the quality of the welding seam is in the optimum state.



(a) 70A (b) 90A (c) 110A (d) 130A (e) 150A

Figure 2. *Radio graphic inspection images under different welding currents.*

3.2. Effect of Welding Current on Mechanical Properties of Welded Specimens

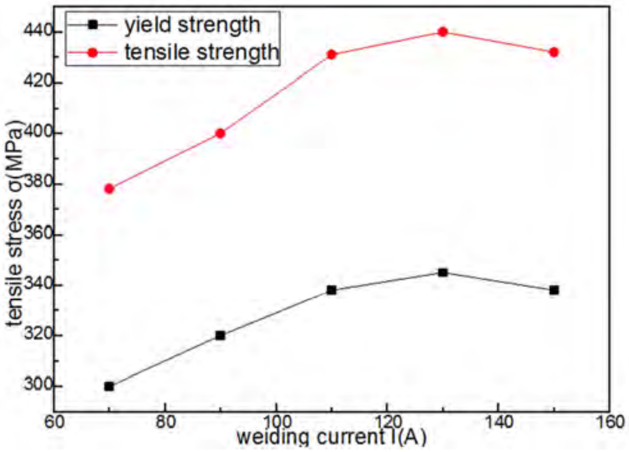
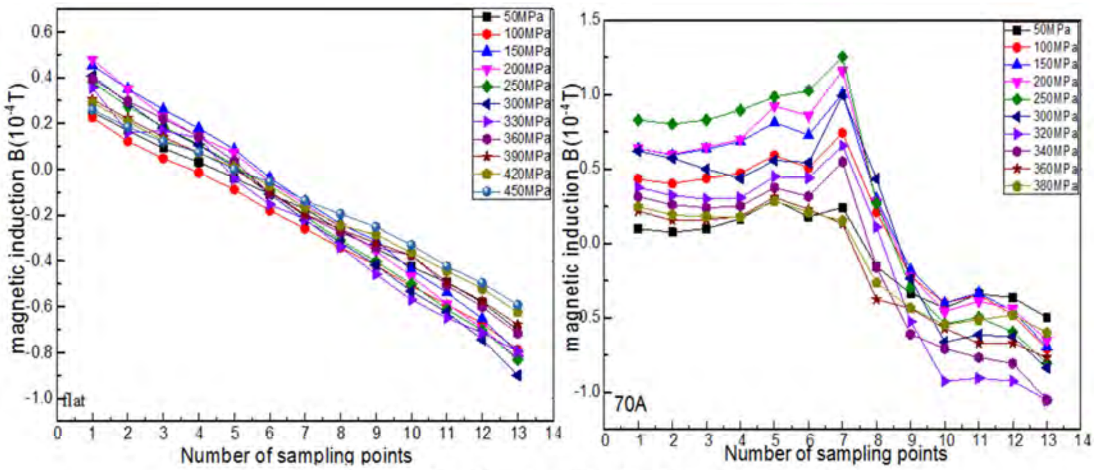


Figure 3. *The relationship between the yield and tensile strength of welding specimen and welding current.*

Figure 3 shows the relationship between the yield strength and the tensile strength of the weld specimen with the welding current. Figure 3 shows that the yield strength and the tensile strength increase with the increase of the welding current in the range of 70A-130A; In the range of 130A-150A, the yield strength and tensile strength decreases with the increase of welding current. When welding current is 130A, the maximum value is reached. Therefore, when welding current is 130A, the welding seam has the best mechanical performance and welding quality.

3.3. Influence of Welding Current on Force-Magnetic Effects of Welding Specimen

The relationship between yield strength or tensile strength of the welded component and magnetic memory signal was studied by magnetic memory signal measurement. The tensile stress test and magnetic memory signal measurement of the flat specimen 2# and the welded specimens 4#, 6#, 8#, 10# and 12# specimens were carried out respectively. Where the weld area for the sampling point 6 to 8 points area. Because the leakage magnetic field values of the three paths of A, B and C are in the same trend, then the leakage magnetic field on the path B is only analyzed, and the test results are shown in Figure 4. The magnetic memory signal curves under the tensile stress at the elastic-plastic stage all pass through zero point, and the left signal is positive, and the right signal is negative. The magnetic memory signal curve of the flat specimen is approximately a straight line, and the magnetic signal curve of the weld member exhibits a nonlinear change in the weld zone, that is, under the action of tensile stress, the "sine wave" jump phenomenon occurs. So it can be through the magnetic memory signal "sine wave" graphics to initially determine the location of the weld.



(a) flat (b) 70A

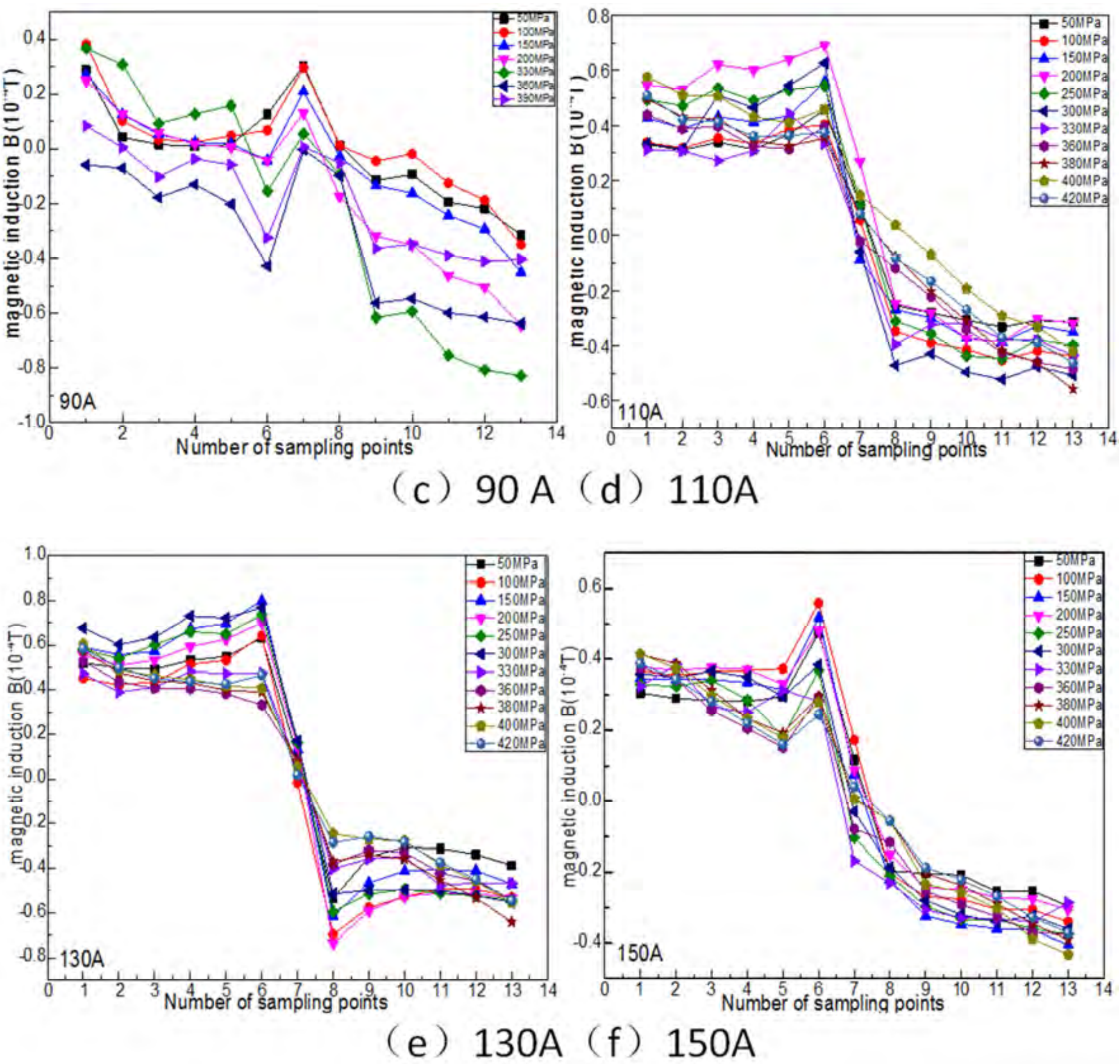


Figure 4. *Magnetic memory signal distribution curves for different welding currents.*

In the initial stage of the stress effect, the ferromagnetic material first undergoes elastic deformation, and the atoms in the internal structure lattice point move, deviating from the equilibrium position, and the lattice distortion occurs. But the relative displacement distance of the atoms is usually less than the balance of the two atoms at no external force until a new equilibrium is reached. With the increase of the tensile stress, the direction of the magnetic field intensity vector is turned to the direction of the tension, so that the initial leakage magnetic field signal with large fluctuation before the loading of the specimen tends to be consistent, and the curve fluctuation becomes gentle. When the ferromagnetic material into the plastic deformation stage, the atomic dislocation distance continues to increase, and the deformation begins to focus on a certain position.

The magnetic signal characteristics of all weld specimens under tensile stress are calculated. The variation of maximum magnetic signal at peak and trough of weld zone $\Delta B_{\max}$ is magnetic characteristic parameter, and the eigenvalue D is the average value of the maximum magnetic signal variation difference $\Delta B_{\max}$ under different tensile stresses, that is, $D=\sum_{\sigma_1}^{\sigma_N}\Delta B_{i\max}/N$, the unit is 1×10^{-4} T, the result is shown in table 1. It can be seen from the X-ray inspection picture of Figure 2 that the 4# sample has the defects of incomplete penetration, which results in the sudden increase of the leakage magnetic field and the great influence on the magnetic signal, but the 12# specimen clamping tungsten phenomenon influence on magnetic signal is minimal, so it can be neglected. Therefore, in order to better reflect the influence of the welding current on the magnetic characteristics of the weld zone, not to consider the 4# specimen, then the relationship between the welding current and the magnetic field characteristic value D is shown in Figure 5. It can be seen from Figure 5 that the magnetic characteristic value D gradually increases with the increase of the welding current, reaches the maximum at I=130A, and then begins to decrease, corresponding to the yield and tensile strength as reflected in Figure 3. Therefore, the magnetic characteristics D can be used to characterize the welding strength, When D is the maximum, the welding strength is the highest, and the welding quality is the best.

Table 1. *Average value D of maximum magnetic signal variation under different tensile stress (unit: 10^{-4}T).*

Specimen Magnetic characteristics	$6^{\#}$ specimen 90 A	$8^{\#}$ specimen 110 A	$10^{\#}$ specimen 130 A	$12^{\#}$ specimen 150 A
$D = \sum_{\sigma_1}^{\sigma_N} \Delta B_{i\,\max} / N$	0.44302	0.7634	1.046	0.625

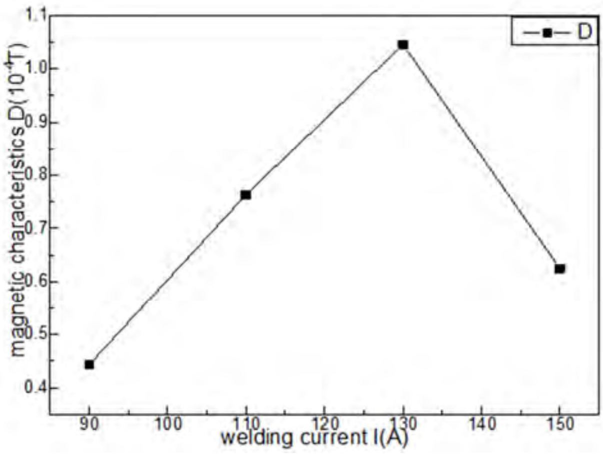


Figure 5. *Relationship between welding current and magnetic characteristic value D.*

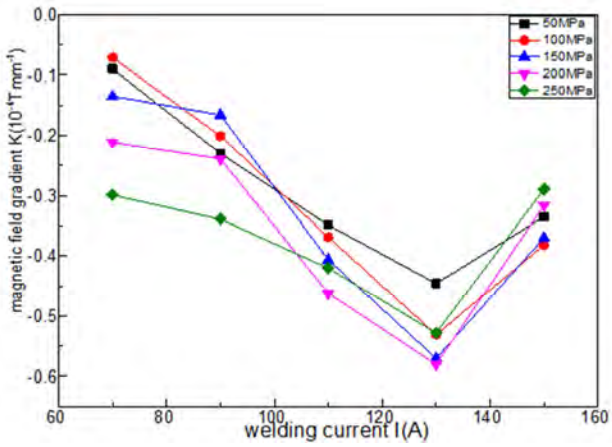


Figure 6. *Relationship between magnetic signal slope and welding current under different tensile stresses.*

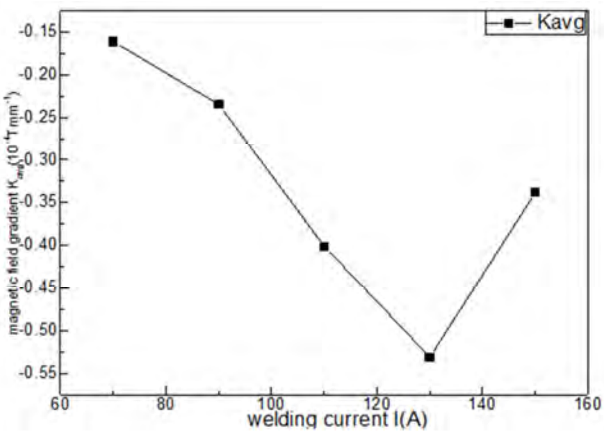


Figure 7. *Average of the magnetic field gradient at different welding currents in the elastic phase.*

From the microscopic point of view, the weld mainly includes weld zone and heat affected zone. Since the distance between the base heat affected zone on the base metal is different from that of the weld [15], the welding heat cycle experienced by each point is different, there will be different performance. According to the different heat-affected zone can be divided into four regions: the weld zone, overheating zone, phase change recrystallization zone and incomplete phase transition zone. In the vicinity of the fusion zone, due to the irregular combination of the weld and the base material will form an interface, non-spontaneous crystal nucleus in the form of columnar crystals and attached to the surface of the weld to the center of growth, thus forming a columnar area; In the overheated area, the metal will be in a state of overheating, the austenite grain grows after cooling will get coarse tissue, resulting in decreased hardness. And the metal of the phase change of the recrystallization zone due to the occurrence of recrystallization, so after cooling in the air will form a uniform fine ferrite and pearlite structure, so the area of plasticity and toughness are better; In the incomplete recrystallization zone, only part of the organization undergoes phase change recrystallization, so the organization of the region is not uniform, grain size varies, and thus mechanical properties are not uniform. So the overall mechanical properties of the weld is not uniform. However, under the welding speed and voltage are certain circumstances, with the welding current increases, the arc, stability, slagging of the welding and weld forming will gradually become better, and with the welding current increases, the grain size of the weld zone, the fusion zone and the heat affected zone is gradually roughened, and the ferrite and pearlite are transformed into coarse martensite and granular bainite, but the welding current is too easy to form undercut or severe splash, So the welding plate should be appropriate to reduce the size of the current. Based on the analysis, the test results are consistent with the microscopic theory, the welding quality is the best when the welding current is 130A.

3.4. Influence of Welding Current on the Gradient Distribution of Magnetic Signals Under Different Stresses

In order to further analyze the variation law of the magnetic memory signal in the weld zone, and find out the characteristics of weld quality. The slope of the magnetic memory signal k under different welding currents (between wave crest and wave trough) in the elastic stage is analyzed and discussed. In the elastic phase (tensile stress σ<300MPa), the relationship between the slope of the magnetic signal and the welding current under different tensile stresses is shown in Figure 6. In the elastic phase, when I<130A, the slope of the magnetic memory signal decreases with the increase of the welding current I under the same tensile stress; when I is 130A, the slope k is the minimum value; When I>130A, the magnetic memory signal slope increases inversely as the welding current I increases. Therefore, it can be explained that the magnetic memory signal curve is the most stable when the welding current I is 130A , which corresponds to the tensile and yield strength in Figure 3, and the welding quality is the best. In Figure 6, the average value of the curve under different tensile stress in the elastic stage under the same welding current is calculated , defined as $K_{avg} = \sum_{\sigma_1}^{\sigma_N} k_i / N$, N=5, and the results are shown in Figure 7. It can be seen from the Figure 7 that when the welding current I is 130A, the magnetic field gradient K_{avg} is the minimum value. When I<130A, K_{avg} decreases with the increase of the welding current I, and when I>130A, K_{avg} increases with the welding current I increased. Therefore, the average value K_{avg} of the magnetic field gradient in the elastic phase can be used as the magnetic characteristics to evaluate the weld quality. When K_{avg} is the smallest, the welding strength is the largest and the welding quality is the best.

4. Conclusion

Through welding specimens of different welding current tensile test, magnetic signal measurement and the defect detection analysis of the ray detection technology, the method of detecting the weld quality of low carbon steel by magnetic memory detection technology is explored, and the relationship between the variation of magnetic memory signal and the yield strength and tensile strength of low carbon steel weld during the process of tension is studied. The conclusions are as follows:

(1) Through the analysis of the ray detection technology and the analysis of the mechanical tensile curve, it is found that the specimens with different welding currents have different mechanical properties, and have different yield strength and tensile strength. For this test, 130A corresponds to the maximum yield strength and tensile strength.

(2) The experimental data show that the variation of the magnetic memory signal is closely related to the yield strength and tensile strength of the low carbon steel welded component during the tensile process. When the yield strength and tensile strength are maximum, the magnetic characteristic value D is the maximum, and the magnetic signal gradient signal K_{avg} is the minimum value.

(3) According to the basic principle of metal magnetic memory detection technology, using the average magnetic signal information and magnetic signal gradient information under different stress, the two-parameter information fusion technology can effectively determine the mechanical properties of low-carbon steel welds. The research results can provide reference for the application of magnetic memory detection technology in the quality evaluation of carbon steel weld quality.

Acknowledgements

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