Comprehensive Performance of Stainless Steel Weld in Aviation Kerosene Pipelines

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ABSTRACT : *Taking the stainless steel aviation kerosene pipeline weld seam as the object, TIG welding was used to prepare samples, and their comprehensive performance was tested and analyzed. The friction and wear test showed that pressure was the key influencing factor. At 60N pressure, there was no damage or sudden change in the weld seam. The maximum wear amount in the long-term test was 39.2mg, indicating good wear resistance. In the corrosion test, the weld seam showed no significant damage after electrochemical and acidic corrosion. An increase in the Ni element content could enhance corrosion resistance, but it is necessary to avoid a similar content of Ni and Cr. In terms of mechanical properties, the hardness of the heat-affected zone was the highest, while the weld seam area had better toughness and plasticity. When the heat flux density was 20-30 kJ/cm, the comprehensive mechanical properties of the weld seam were the best. The weld seam prepared by this process had excellent performance. Controlling this range of heat flux density could ensure the safe operation of the pipeline and reduce maintenance costs.*

KEYWORDS - *kerosene pipeline; mechanical properties; wear resistance; corrosion resistance; friction and wear*

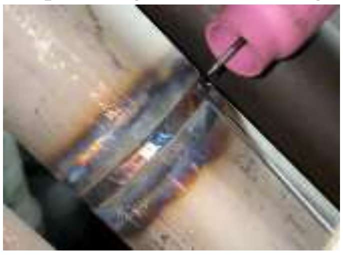
I. INTRODUCTION

In recent years, as the main fuel for aircraft, the demand for aviation kerosene has surged sharply. The traditional tanker truck transportation method can hardly meet the needs of the rapid development of the aviation field, and both its transport capacity and safety performance lag behind the operational requirements of airports. To improve the economic and social benefits of aviation kerosene utilization, the development and application of aviation kerosene pipelines have become a trend [1,2]. Compared with vehicle transportation, pipeline transportation has the advantages of lower losses, less labor input, higher transportation efficiency and safety; at the same time, it also puts forward higher technical requirements for pipeline engineering. Welding is one of the most common methods in pipeline processing, and the quality and performance of welded joints directly determine the reliability of medium transportation [3,4]. Pipeline welds themselves should meet comprehensive performance requirements such as corrosion resistance, high pressure resistance and wear resistance, and medium leakage is strictly prohibited [5,6]. Taking the welds of stainless steel aviation kerosene pipelines as an example, this paper tests and studies the characteristics of welded joints, including friction and wear morphology, corrosion resistance, microstructure, impact response, hardness and temperature response, so as to ensure that the welds have high comprehensive performance and reduce the cost of pipeline repair and maintenance.

II. TESTING AND ANALYSIS OF WEAR RESISTANCE AND CORROSION RESISTANCE PERFORMANCE

2.1 Sample preparation method

Two stainless steel pipes are accurately butted to ensure a uniform butt gap. A V-groove is adopted with a size of 2 mm, and spot welding is used for positioning. The spot welds have a length of 5 mm and a spacing of 50 mm. During spot welding, the quality of the spot welds must be ensured to avoid cracks at the spot welds during formal welding. Welding speed affects the formation and quality of the weld. Too high a speed will lead to defects such as insufficient weld penetration and incomplete fusion; too low a speed will result in an excessively wide weld and excessive deposited metal, increasing the possibility of welding deformation. TIG welding is used, with the welding speed set to 100 mm/min. The flow rate of the shielding gas directly affects the shielding effect of the weld. If the flow rate is too low, it cannot effectively prevent air from invading the weld, leading to oxidation of the weld metal and defects such as pores; if the flow rate is too high, it will cause waste and may disrupt the stability of the arc. Based on TIG welding, the argon flow rate is set to 15 L/min. The weld of the welded pipe is as shown in Figure 1(a). Wire electrical discharge machining (WEDM) is used to process a structure suitable for mounting. Finally, the weld specimen is prepared through processes such as mounting, grinding, and polishing, as shown in Figure 1(b).



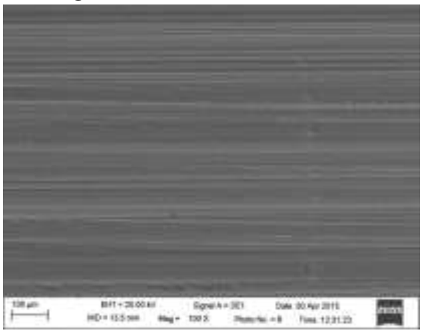
(a) Weld seam of kerosene pipeline

(b) Treated sample

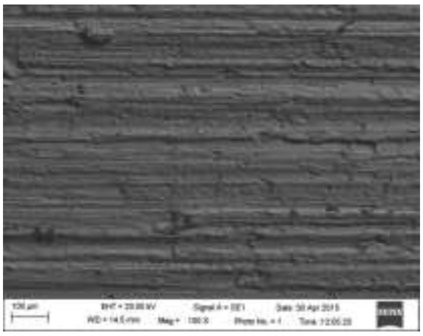
Figure 1 Preparation of weld seam specimens

2.2 Analysis of friction and wear characteristics

The main causes of friction and wear on the weld seam of the pipeline are attributed to the pressure of the coal oil and the mechanical force of impurity particles. Under extreme and long-term working conditions, the internal wear of the pipeline cannot be ignored. In a constant-speed friction testing machine, high-frequency reciprocating friction tests were conducted at pressures of 20N and 60N respectively, and the friction and wear morphologies of the weld seam samples are shown in Figure 2. It can be seen that different pressures have a significant impact on the morphology of the worn surface. At a pressure of 20N, no obvious plastic flow problem occurred. When the pressure reached 60N, the grooves on the surface of the weld seam sample became more obvious, but the scratches were still relatively regular, and no sudden damage occurred, indicating that the weld seam material has good plasticity and toughness. In addition, when different reciprocating friction frequencies were adjusted, it was found that the frequency had no significant effect on the wear morphology. In contrast, pressure was the key factor determining the surface ploughing phenomenon. To further obtain the quantitative properties of wear, long-term timed friction and wear tests were conducted at pressures of 20N, 40N and 60N respectively, with the test cycle set at 50,000 to 250,000 reciprocating cycles. After the long-term friction and wear tests were completed, the wear mass needed to be measured. To ensure the accuracy of the test, the tested samples were placed in an ultrasonic cleaning machine for treatment, and the water was removed before comparison based on a mass analyzer. The research shows that there is a nearly linear relationship between the friction cycle and the wear amount. As the friction cycle continues, the influence of high pressure on wear becomes more prominent, which is consistent with the test results of the worn surface. According to the quantitative analysis results, the maximum wear amount was 39.2mg, indicating that the weld seam material has good wear resistance.



(a) 20N



(b) 60N

Figure 2 High-frequency wear morphologies under different pressures

2.3 Corrosion characteristic analysis

The environment where aviation kerosene pipelines are located is poor, and the probability of acidic corrosion and electrochemical corrosion is relatively high. To simulate the effect of electrochemical corrosion, the surface of the weld sample was set as the working surface of the electrode, and epoxy resin was added to the electrolyte to reduce the internal impedance and the loss of the electrochemical reaction process. The sample was kept for 48 hours under an effective voltage of 0.5 volts, and the metallographic results of the corroded surface are shown in Figure 3. It can be seen that there are no significant defects or corrosion damages in the metallographic structure of the corroded weld sample, indicating that the weld under this process condition has excellent resistance to electrochemical corrosion. In addition, through the tests of welds with different elements, it is known that the ratio of Ni and Cr elements in the weld has a significant impact on the electrochemical corrosion effect. The results show that more Ni elements can significantly reduce current fluctuations and have a lower potential deviation. If the proportions of the two elements are similar, electrochemical corrosion will be significantly enhanced. Therefore, when choosing the composition of the welding wire, the content of Ni and Cr should be avoided from being similar.

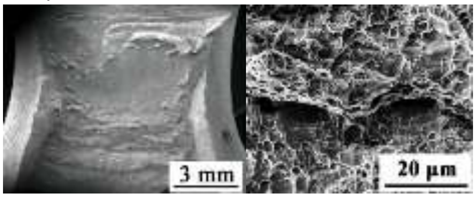
Figure 3 Metallographic structure after electrochemical corrosion

III. MECHANICAL PROPERTY TESTING AND ANALYSIS

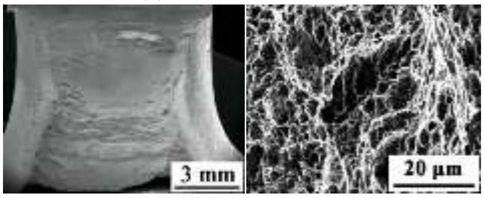
3.1 Analysis of impact toughness characteristics

For metallic materials, hardness is one of the most important indicators for evaluating comprehensive mechanical properties, which can reflect wear resistance and mechanical strength. According to the hardness analysis, the hardness curve of the weld seam shows a trend of increasing first and then decreasing from the base metal zone to the weld zone, and the hardness boundaries of different zones are very distinct. The heat-affected zone near the fusion line has the highest hardness value of 218.2 HV and is highly fluctuating. The wire material in the weld zone has less impurities and the grain formation is relatively uniform, with an average hardness of approximately 202.4 HV. The strength and hardness of the material are relatively stable and significantly better than those of the base metal. The microstructure of the heat-affected zone is more complex due to the influence of the temperature gradient. In the area close to the base metal, the grains are refined under the action of a smaller thermal load, so the hardness shows a certain decreasing trend compared to the base metal. However, in the area close to the weld zone, the thermal load is larger and the temperature exceeds the normalizing limit. During the recrystallization process, affected by the alloy composition, hard compounds and martensite structures are prone to occur. To improve the overall residual stress and thermal deformation, post-weld heat treatment can be carried out on the heat-affected zone.

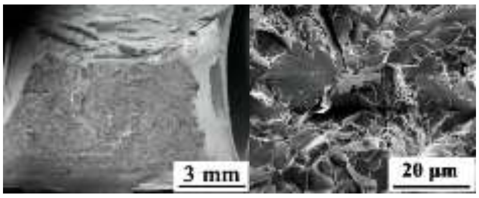
Impact toughness can reflect a material's ability to resist sudden loads and is an important component of comprehensive mechanical performance indicators. According to the testing standards, impact fracture tests were conducted on weld samples from different regions. The notch positions were placed under an electron microscope, and the microstructure is shown in Figure 4. Based on the fracture morphology, it can be known that the samples from different regions all belong to ductile fracture. Compared with the heat-affected zone, the average size of the dimples in the base metal is larger and the state is more uniform. In the weld zone, the ductile tear ridges and dimples coexist but are isolated from each other, thus, the toughness and plasticity are better.



(a) Base metal zone



(b) Heat-affected zone

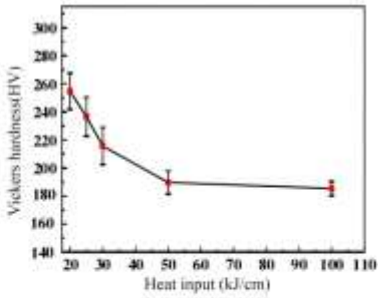


(c) Weld zone

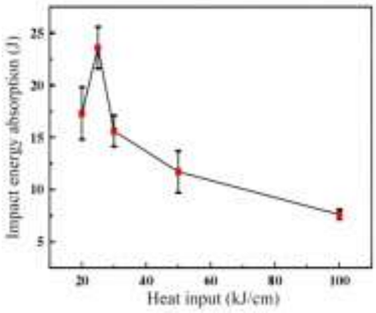
Figure 4 Impact fracture surface morphology of different weld zones

3.2 The influence of welding heat flow on mechanical properties

As is known from the pipe welding process, the heat flux density directly corresponds to the heat output and temperature response, which is also a key process parameter affecting the mechanical properties of the weld seam. To study the specific influence of heat flux density on the weld seam of stainless steel pipes, weld seam samples were prepared under different heat fluxes and hardness and impact tests were conducted. The results are shown in Figure 5. It can be seen that when the heat flux density is in the range of 20 to 50 kJ/cm, the average hardness at the center of the weld seam decreases with the increase of the heat flux density. When the heat flux density exceeds 50 kJ/cm, the microhardness remains basically constant. For the impact absorption energy, it shows a trend of first increasing and then decreasing with the increase of the heat flux density. The impact absorption energy can represent the material's ability to resist plastic deformation and fracture under impact loading. Combined with the hardness analysis results, it can be known that when the heat flux density is controlled within the range of 20 to 30 kJ/cm, good comprehensive mechanical properties can be obtained.



(a) The influence of heat flow on hardness



(b) The influence of heat flux on impact absorption energy

Figure 5 Mechanical performance responses under different heat flux densities

IV. CONCLUSION

The comprehensive performance of welding is the key to ensuring the reliability and safety of aviation kerosene pipelines. Good wear resistance, corrosion resistance and mechanical properties not only can avoid safety failures, but also effectively reduce the cost of equipment maintenance and repair. Different types of weld specimens were prepared by experimental methods, and the level of resistance to friction force under this welding process and weld material conditions was analyzed, verifying that the material has good plasticity and toughness. When the content of Ni and Cr elements is similar, electrochemical corrosion is more likely to occur, while increasing the proportion of Ni element can enhance the resistance to acid corrosion. Affected by the welding heat source, the heat-affected zone has higher hardness, while the weld zone has better impact toughness. For the welding process of aviation kerosene pipelines, it is advisable to control the heat flow density within the range of 20-30 kJ/cm to achieve better comprehensive performance.

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