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Study on the Effects of Helium-Argon Gas Mixture on the Laser Welding Performance of High Temperature Alloys

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Abstract

In order to solve the problem of porosity in laser deep penetration welding of GH3625 high-temperature alloy plates, five different ratios of high-purity helium gas and high-purity argon gas mixed gases were compared in welding experiments after various process parameter improvements and adjustments failed to achieve Class I welds. The experimental results show that using high-purity helium gas or a mixture of 50% high-purity helium gas and 50% high-purity argon gas can both achieve Class I welds. This indicates that using high-purity helium gas or an appropriate mixed gas instead of pure argon is one of the effective ways to solve the problem of porosity in laser deep penetration welding of high-temperature alloys. The mixture of 50% high-purity argon gas and 50% high-purity helium gas can reduce the consumption of high-purity helium gas, lower production costs, and is more suitable.

Keywords: *high-temperature alloy; laser welding; pores; shielding gas; welding quality*

1 Introduction

With the progress of science and technology and the development of economic construction, the application of high-temperature alloys in aerospace, energy, and chemical industries has become increasingly widespread. A GH3625 high-temperature alloy part whose welding quality is affected by the presence of weld porosity in the weld test plate. Despite measures such as strengthening pre-weld cleaning and optimizing welding process parameters, the porosity problem remains unresolved, and the weld does not meet the requirements of a Class I weld. In order to solve the porosity problem in laser deep penetration welding of GH3625 alloy, comparative welding experiments were conducted on GH3625 alloy plates using helium-argon mixed gas with different ratios.

During laser deep penetration welding, a laser beam with a power density of 10^7 W/cm^2 or higher can vaporize the metal in the heating zone in a very short time, forming a small hole in the liquid molten pool, which is called a keyhole [1]. The mechanism of pore formation is the formation of bubbles in the closed space after the collapse of the keyhole, and the bubbles are not able to escape from the surface of the molten pool and are captured by the solidification interface [2]. Laser deep penetration welding of metal materials such as steel and aluminum alloys is prone to pore formation, and high-temperature alloys with high contents of alloying elements such as Ni and Mo have poor fluidity of the molten pool during laser welding, making it difficult for gases in the molten pool to escape, resulting in a higher tendency for pore formation.

Xiao Rongshi et al. [3-4] applied the method of using a mixture of argon and helium as a protective gas in CO_2 laser deep penetration welding. Through comparative experiments, it was found that when using pure argon as the shielding gas, plasma shielding phenomenon occurs at around 5KW laser power, but the plasma shielding phenomenon disappears after adding helium. Lei Zhenglong et al. [5] found that when pure helium is used as the protective gas in aluminum alloy laser self-melting welding, it has a significant effect on suppressing pores, enhancing pore stability, and reducing the porosity to below 1%. He Shuang [6] found that adding helium to the protective gas during A7N01 aluminum alloy laser-MIG hybrid welding can enhance the stability of the welding process and avoid the instability of the pores, thus preventing the formation of weld porosity. As the proportion of helium in the helium-argon mixed shielding gas increases, the porosity of the weld gradually decreases. After the helium content reaches 50%, the porosity of the weld does not change

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significantly, and it is reduced by about 80% compared with high-purity argon. Su Xiaoyang et al. [7] found that in helium-argon mixed protective gas laser + arc hybrid welding, when the volume fraction of helium in the protective gas increases to 5% and 10%, the arc pressure and electric potential gradient increase, and the weld penetration depth also increases.

Through literature research, it has been found that helium-argon binary shielding gas is superior to pure argon shielding gas in laser welding process in terms of pore suppression, weld penetration depth, joint quality, etc. Moreover, there are already studies proving that a mixed shielding gas of helium (50%) and argon (50%) has the best effect on pore suppression in laser melting welding of aluminum alloys. Currently, there is little research on porosity suppression in laser welding of high-temperature alloys, and the use of helium-argon binary gas as a shielding gas has not been reported. Key parameters such as gas flow rate, mixing ratio, and porosity rate still need to be experimentally verified.

2 The Problem of Pores in Laser Welding of GH3625 Alloy Plate

After laser welding, there are no cracks or pores found in the appearance inspection of GH3625 high-temperature alloy plates with thicknesses of 2 mm and 3 mm. However, when the weld seam is cut open and polished for microscopic examination, internal pores on the cross-section of the weld seam can be easily observed. Figure 1 shows the internal pores on the cross-section of the weld seam of the 2 mm thick welding specimen, located in the lower part of the weld seam.

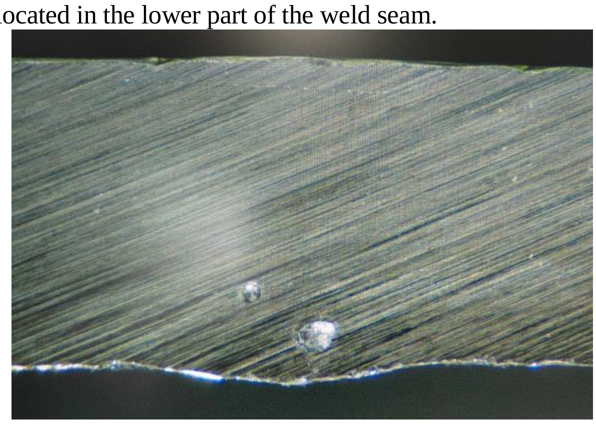

Figure 1 Pores inside the weld seam of the 2 mm specimen (15×)

If X-ray testing is performed on the welded test plate, it can be found that there are many pores in the weld, which does not meet the requirements of the weld grade. When a tensile test is conducted on the sample, the strength of the welded joint does not meet the quality requirements. Figure 2 shows a group of pores on the fracture surface of the unqualified sample with a thickness of 2 mm. The pores are densely distributed in the lower part of the weld.

Figure 2 Group of pores on the fracture surface of the unqualified tensile sample (5×)

In order to solve the problem of porosity in GH 3625 alloy plate laser welding, a lot of work has been done in the pre-weld cleaning and optimization of welding process parameters of the test plate. Although there has been progress, the weld has not been able to meet the quality requirements of Grade I. Therefore, we are looking for solutions to the porosity problem from the aspect of shielding gas.

3 Comparative Experiment of Laser Welding with Different Ratios of Helium-Argon Gas Mixture

In order to gain a deeper understanding of the effects of argon gas, helium gas, and argon-helium gas mixture on laser welding, it was decided to conduct a comparative experiment on laser welding of GH3625 alloy plates using five different gas ratios.

3.1 Pre-welding preparation

3.1.1 Welding equipment

The welding equipment used the 2000W laser welding experimental platform from Changsha Tianchen Laser. It includes a 3-axis precision welding platform, a Chuangxin 2000 laser, a Jizhi Mechanical and Electrical 3000 water cooler, and a Hanwei dual swing laser head.

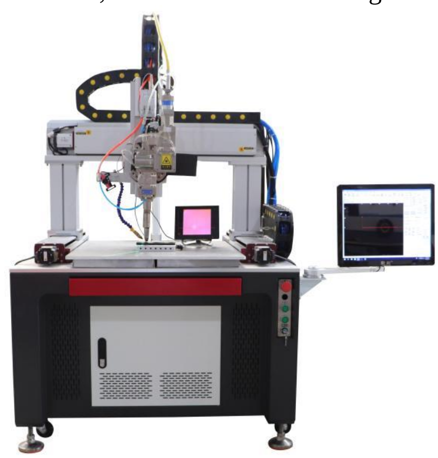

Figure 3 2000W Laser Welding Experimental Platform

3.1.2 Welding test plate

Two pieces of GH3625 high-temperature alloy plates with a thickness of 2 mm were used. Each test plate is approximately 150 mm long and 120 mm wide. The material of the test plate has undergone acceptance inspection, and its chemical composition meets the requirements of GB/T 14992 [8].

3.1.3 Protective gas

Bottled high-purity argon gas and bottled high-purity helium gas were used. Both gases have qualified certificates after inspection.

3.2 Welding experiment

Laser welding was performed using 5 different gas ratios. During welding, only a single test plate was melted, and butt welding was not performed temporarily. The gas ratio was controlled by flow adjustment. Three welds were made for each gas ratio. Before each weld, the welding area was carefully cleaned with alcohol and dried with a hairdryer. A total of 15 welds were made, using up both test plates. The welding sequence, gas ratio, and welding power are shown in Table 1.

Table 1 Gas Composition and Welding Power of Comparative Experiments

Serial Number	Gas Composition and Flow Rate	Weld Seam Number	Welding Power (W)
1	100% High Purity Argon Gas, 25L/min	1	700
		2	760
		3	760
2	75% High Purity Argon Gas, 21L/min +25% High Purity Helium Gas, 7L/min	4	760
		5	760
		6	760
3	50% High Purity Argon Gas, 14L/min +50% High Purity Helium Gas, 14L/min	7	760
		8	760
		9	760
4	25% High Purity Argon Gas, 21L/min +75% High Purity Helium Gas, 7L/min	10	760
		11	760
		12	760
5	100% High Purity Helium Gas, 25L/min	13	760
		14	760
		15	760

3.3 Test results

The results of the above 15 welds, which were subjected to X-ray inspection ratings, are shown in Table 2.

From Table 2, it can be seen that when the helium content reaches 50% or more, it can effectively reduce the quality of pores and improve the weld grade. This is mainly because the basic physical properties of argon gas and helium gas are shown in Table 3. The atomic mass of argon gas is about ten times that of helium gas, and the relative air density is ten times that of helium gas, which means that argon gas has a higher gas density and the low-density helium gas is more likely to escape after entering the molten pool, reducing the porosity of the weld. At the same time, the thermal conductivity of argon gas is small, about one-tenth that of helium gas, which means that helium gas is more capable of conducting heat and has less impact on laser energy, making the welding process more stable compared to argon gas. On the other hand, the first ionization energy of argon gas is 15.75 eV, while the first ionization energy of helium gas is 24.58 eV. Helium gas has the lowest ionization energy and can quickly remove the rising metal vapor generated from the molten pool. Using helium as a protective gas can effectively suppress plasma and reduce the formation of pores. However, due to its higher price, considering cost reduction and the actual welding results, a gas ratio of 50% high-purity argon gas and 50% high-purity helium gas is the most suitable for protection.

Table 2 X-ray detection results of comparative experiments with different gas ratios

Serial Number	Gas ratio for protection	Weld Seam Number	X-ray detection rating
1	100% high-purity argon gas	1	II
		2	II
		3	II
2	75% high-purity argon gas + 25% high-purity helium gas	4	II
		5	II
		6	II
3	50% high-purity argon gas + 50% high-purity helium gas	7	I
		8	I
		9	I
4	25% high-purity argon gas + 75% high-purity helium gas	10	I
		11	I
		12	I
5	100% high-purity helium gas	13	I
		14	I
		15	I

Note: Rating standard NB/T 47013.2-2015 [9].

Table 3 Comparison of Physical Properties of Helium and Argon Gases

Gas	Boiling Point (1.013bar)(℃)	Atomic Mass (Kg/Kmol)	Density (0℃1.013bar)(Kg/m^3)	Relative Density Of Air (0℃1.013bar)	Thermal Conductivity(W/Mk)
Ar	-185.9	39.948	1.784	1.380	0.017
He	-268.9	4.002	0.178	0.138	0.154

4 Production Application

By using improved shielding gas and other methods, the 2mm and 3mm GH3625 alloy butt-welded test plates achieved Class I welds. The test plates were sampled and tested for mechanical properties, which passed the expert evaluation and were applied to the welding production of GH3625 components.

5 Discussion

5.1 Using high-purity helium gas or a suitable mixture of helium and argon gases can significantly reduce the generation of pores

From the comparative test of helium-argon gas in this study, it can be concluded that replacing pure argon with high-purity helium gas or a mixture of 50% high-purity argon gas and 50% high-purity helium gas can significantly reduce the generation of pores. This is one of the ways to solve the problem of porosity in laser deep penetration welding of GH3625 high-temperature alloy.

5.2 The advantages of using a 50% high-purity argon gas + 50% high-purity helium gas mixture

Due to the high cost of high-purity helium gas and the higher production cost, using a 50% high-purity argon gas + 50% high-purity helium gas mixture can achieve the same effect as using high-purity helium gas, while reducing the consumption of high-purity helium gas and lowering the production cost. Therefore, using a 50% high-purity argon gas + 50% high-purity helium gas mixture is more suitable.

6 Conclusion

Replacing pure argon with high-purity helium gas or a 50% high-purity argon gas + 50% high-purity helium gas mixture can significantly reduce the formation of gas pores in laser deep penetration welding of GH 3625 high-temperature alloy plates with thicknesses of 2 mm and 3 mm. It is an effective way to solve the problem of gas pores in laser deep penetration welding of high-temperature alloys.

By using a mixture of 50% high-purity argon gas and 50% high-purity helium gas, the consumption of high-purity helium gas can be reduced, and the production cost can be lowered.

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