The relationship between the super plasticity of laser welding joint of titanium alloy and hydrogen treatment

Zean Cao, Donghai Cheng*, XunyanJiang, Dean Hu, Yiping Chen

Nanchang Hang Kong University, Nanchang, China

*Corresponding author e-mail: 1250985008@qq.com

Abstract. The superplastic deformation uniformity of laser welded joint of TC4 titanium alloy is improved by hydrogen treatment. The non-uniform deformation coefficient K was introduced to quantification ally characterize the non-uniform deformation. The results show when the content of hydrogen exceeds 0.29%, the super plasticity of the titanium alloy welded plate decreases with the increase of the hydrogen content. The decrease of the shrinkage of the base material is larger than that of the weld section with the increase of hydrogen content. The K can be used to describe the non-uniform deformation of the weld and the base material during the superplastic deformation of laser welded joint of the TC4. The K value increases with increaseing hydrogen content, increaseing deformation temperature and decreaseing strain rate.The K value reaches the maximum of 0.84 with hydrogen content of 1.299%, deformation temperature of 920 ℃, strain rate of $10^{-4}S^{-1}$.

1. Preface

The welding / super plasticizing technique is a processing method that combines welding with superplastic forming. The welding / superplastic forming technology of titanium alloy can not only overcome the shortcomings of poor processing performance of titanium alloy, but also produce multi-layer hollow lightweight and complex structure, which has unique technical prospects in the aviation and aerospace. However, laser welding technology is very suitable for combination with superplastic forming process because of its characteristics of fast processing speed, easy automatic welding, and small welding deformation.

The domestic and foreign scholars carry out a series of researches on the laser welding / superplastic forming technology of titanium alloy [1-6]. However, the research shows that there are obvious deformation inhomogeneity in the laser welded plate of titanium alloy after superplastic deformation. Up to now, the study on the improvement of superplastic deformation uniformity of titanium alloy laser welded joint is not reported.

Hydrogen treatment is a commonly used method for titanium alloy processing. When the amount of hydrogen in the titanium alloy welded plate is low [7-8], hydrogen can reduce the α+β/β transition temperature, improve the amount of βpromote superplastic deformation and improve the superplastic deformation capacity. When the titanium alloy welding plate in the high hydrogen, the microstructure of the joint can be adjusted by the hydrogen element to improve the uniformity of the TC4 laser welding joint. The machining hardening leads to the differences in microstructure and mechanical properties between the weld and the base metal during laser welding. It make the welded joint has uneven deformation in the superplastic deformation process, which directly affects the mechanical properties, reliability and the service life after forming. Adding excessive hydrogen to welding parts can improve the superplastic deformation uniformity of laser welding joints TC4 to meet the requirements. Therefore, the method of hydrogen treatment is adopted to improve the uniformity of superplastic deformation of titanium alloy laser welded joints.

2. Experimental materials and methods

The material used for the test was 0.8 mm thick TC4 titanium alloy sheet, and the welded joint was in the form of a butt joint. Before welding, the oil of plate is washed by 5% to 10% NaOH ethanol solution. Oxides of surface is removed by 5% HF + 30% HNO3 aqueous solution pickling. And then the plate is rinsed by water, dried and stored in a clean dish.

The welding test uses a CO2 axial-flow laser with a power range of 100-4000W and TEM01 mode. Test parameters is off-focus △ f of -0.5 mm, laser power P of 900 W, welding speed V of 3.0 m/min.

The hydrogen test is carried out in a tubular hydrogen furnace with a temperature of 700℃. The hydrogen content of the sample after hydrogen deposition is measured by weighing method with high precision physical balance. The mass fraction is 0,092%, 0.869%, 1.073%, 1.299%

The high temperature tensile test is carried out on a CMT4104 tensile tester. Before drawing, the Ti-5 glass protective coating is coated on the surface of the sample. The coating has good protection effect at 800 ~ 1000 ℃. The test range is initial strain rate of $10^{-3}S^{-1}$, 10^{-4} S^{-1}, deformation temperature of 900 ℃, 920℃. The plate is cooled in furnace. The tensile specimen size is shown in Figure 1.

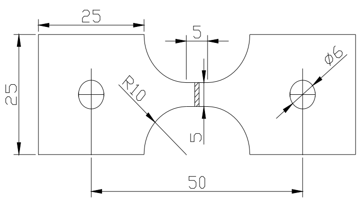

Fig.1 Dimension of hot tensile specimens

3. Experimental results and discussion

3.1 Effect of hydrogen on the mechanical properties of superplastic deformation

Fig.2 shows the effect of hydrogen production on the peak flow stress of superplastic deformation of joints. It can be seen from the figure that the peak flow stress of the non-hydrogen welded joint is less than 10MPa, and the peak flow stress of the joint after hydrogen treatment is more than 10MPA. The hydrogen treatment improves the peak stress of the joint deformation and reduces the superplastic deformation .This is due to the solid solution strengthening of hydrogen. With the increase of hydrogen content, hydrogen-induced solid solution strengthening will become very strong. And after the content of hydrogen exceeding the saturated solid solubility, the formation of the sheet hydride δ will strengthen the alloy and further increase the flow stress of the material. When the deformation temperature and the initial strain rate are constant, the peak flow stress of the welded plate increases with increasing hydrogen content. As shown in Fig.2, the hydrogen content increases from 0.291% to 1.299% and the peak flow stress increases from 35.3MPA to 48.1MPA at the initial strain rate of 10-3S-1, the deformation temperature of 900℃.

It can be seen from Fig.2 that at the same hydrogen content and the same initial strain rate, the peak flow stress of the sample decreases with increasing deformation temperature, because enhanced thermal activation effect can reduce the critical shear stress, improve the free energy of atoms and promote grain boundary slip with increasing deformation temperature. As shown in Fig.2, the peak flow stress decreases from 30.7MPA to 21.3MPA at hydrogen content of 0.291% and strain rate of $10^{-4}S^{-1}$ when the deformation temperature rises from 900℃ to 920℃. At the same hydrogen content and deformation temperature, the peak flow stress increases with the initial strain rate. When the strain rate is high, the dislocation density increases rapidly, which causes dislocation plug. Diffusion creep and dislocation slip cannot effectively coordinate its grain boundary slip. Grain size is not exactly the same. Its shape is not absolutely equated, so the sliding and rotation of the grains must be blocked in some

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places. It results in stress concentration. The internal deformation of the material cannot go on and strain hardening cannot be fully eliminated, which results in increasing flow stress.

3.2 Effect of Hydrogen Content on Superplastic Deformation and Uniformity of Joint

Titanium alloy base metal and welded joints are very different in the phase composition, microstructure and distribution, so there is uneven problem between deformation of the base metal and that of weld deformation. In order to quantitatively measure the unevenness of the deformation of the base material and the welded joint during the superplastic forming of the welded plate, the superplastic deformation unevenness coefficient K of the welded joint is introduced.

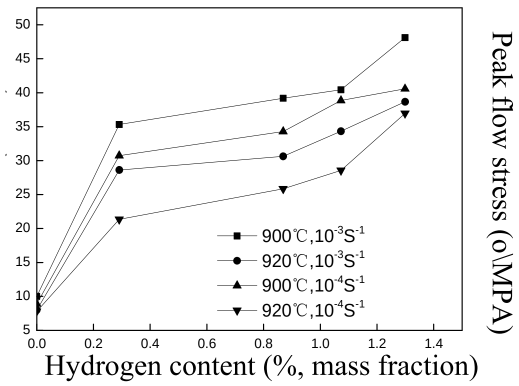

Fig.2 Relationship between peak flow stress and hydrogen content

Define the non-uniformity coefficient K of the superplastic deformation of welded joints as the ratio of the shrinkage of the weld section and the shrinkage of the base metal in the welded joint:

$$K = \Psi h/\Psi m$$

In the formula, Ψh is the cross section shrinkage of weld seam, Ψm is the cross section shrinkage of base material of weld.

it can be seen from the above analysis, the K value is larger, the welded joint make greater contribution to the deformation of the welded plate, the unevenness of the joint deformation is smaller. But because the deformation rate of the welded joint is smaller than that of the base metal, the large K value also reflects the poor ability of superplastic deformation of base material to a certain extent.

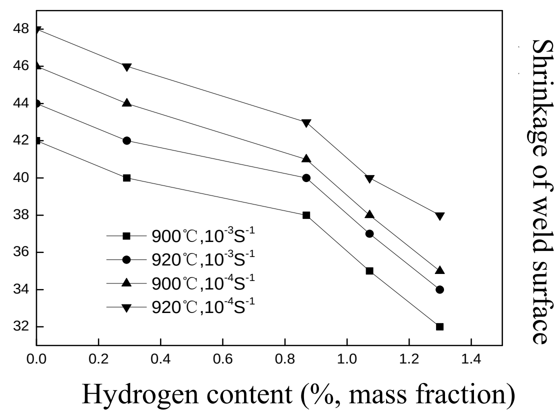

Fig.3 Relationship between sectional shrinkage of weld joint and hydrogen content

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Figure 3 shows the effect of hydrogen on the shrinkage of the weld section. It can be seen from the figure that the hydrogen treatment reduces the cross section shrinkage rate of the whole weld. But, the decrease in the shrinkage of the weld section is relatively large with increasing hydrogen content, because the weld is needle-type marten site. It have small contact surface with hydrogen at high temperature and absorb less hydrogen. On the other hand, hydrogen atoms in the weld is not easy to spread among the atoms because of self-processing hardening and high energy among atoms.

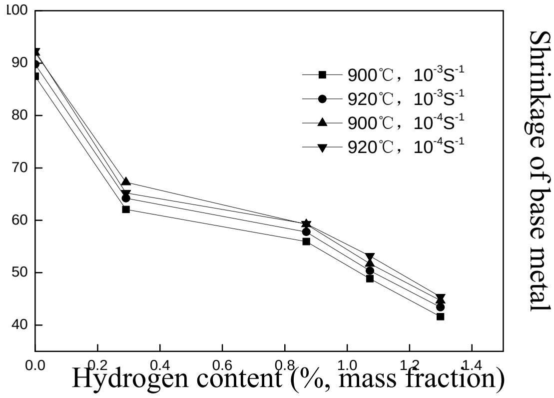

Fig.4 Relationship between elongation of weld plate base metal of weld plate and hydrogen content

Figure 4 shows the effect of hydrogen content on the shrinkage of the base metal. The shrinkage of the base material decreases greatly due to the solid solution strengthening of hydrogen. The solid solution strengthening caused by hydrogen becomes very strong with the increasing hydrogen content. When the hydrogen content increases to a certain extent, the strengthening effect dominates. Hydrogen fixed in the titanium alloy base material produce brittle phase, which leads to the rapid decline of the superplastic deformation of the base metal. When the deformation temperature and the strain rate are constant, the shrinkage rate of the base metal decreases with increasing the hydrogen content.

Comparing with Fig.3 and Fig.4, it can be seen that the hydrogen content is the main factors that affect the deformation ability of the weld and the base metal. It has an effect on the final section shrinkage by influencing the growth of the grain inside the sample and the degree of recrystallization. Section shrinkage of welded plate rate decreases with increasing hydrogen content. Hydrogen dissolves in the titanium alloy laser welding plate to form brittle phase so that the strength and hardness of titanium alloy laser welding plate increase and the cross section shrinkage of the welding plate declines. When the deformation temperature and strain rate are constant, the decrease of shrinkage of the base metal is larger than that of the weld with increasing hydrogen content. There is mainly α+β phase in the base metal. The proper amount of hydrogen can stabilize the β phase and promote the superplastic deformation. But when the excess hydrogen is applied, it can form a gap solid solution in the base metal to hinder the superplastic deformation. On the other hand, the tensile stress is easy to gather at the stress concentration due to the strong diffusion of hydrogen at high temperature. It results in high hydrogen concentration at the defects such as grain boundary, which the pins dislocation.

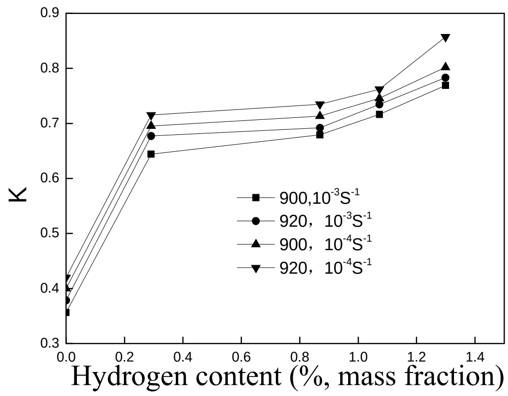

Fig.5 Relationship between K value and hydrogen content

Fig. 5 shows the relationship between the non-uniform deformation coefficient K and the hydrogen content. It can be seen that the K value increases with increasing hydrogen content, increasing deformation temperature and decreasing strain rate. In the case of no hydrogen, the maximal non-uniform deformation coefficient is 0.5 at strain rate of $10^{-4}S^{-1}$, deformation temperature of 920 ℃, which shows the difference between the shrinkage of the weld and the base metal during the superplastic deformation is obvious. The minimal K is 0.62 and the maximal K is 0.84 at hydrogen content of 0.291% -1.299%, deformation temperature of 920℃and 900℃ and strain rate of $10^{-3}S^{-1}$ and $10^{-4}S^{-1}$. The K value is more than 0.5. It suggested that hydrogen can adjust the phase composition of welded joints to improve the superplastic deformation uniformity of the titanium alloy welding joints. Hydrogen treatment decreases the cross section shrinkage of the weld and base metal. When the deformation temperature and strain rate are constant, the shrinkage of the base metal decreases faster with increasing hydrogen content. The higher the K value is, the better the coordination of deformation of the weld and the base metal is. The K value can characterize the deformation heterogeneity during the superplastic deformation of TC4 laser welded joint under certain conditions.

4. Conclusion

1) When the hydrogen content exceeds 0.29%, the super plasticity of the titanium alloy laser welding plate decreases with increasing the hydrogen content. It also shows the peak flow stress increases and the cross section shrinkage decreases.

2) The decrease of the shrinkage of the base metal is larger than that of the weld section with increasing hydrogen content. Hydrogen treatment improves the uniformity of superplastic deformation of titanium alloy laser welding plate.

3) The non-uniform deformation coefficient K can be used to describe the heterogeneity of the weld and the base metal during superplastic deformation. The K value increases with increasing hydrogen content, increasing deformation temperature and decreasing strain rate. The K value reaches the maximum of 0.84 at hydrogen content of 1.299%, deformation temperature of 920 ℃ and strain rate of $10^{-4}S^{-1}$.

Acknowledgments

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