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Estimating on the Mechanical Properties of Laser Welded Joint of TC4 Alloy with a Shear Punch Testing

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1. Introduction

The shear punch test (SPT) is a testing technique in which a small amount of material can be used. The sizes of specimen are usually in the range of 0.3 ~ 0.5 mm in thickness. So the SPT can be regarded as an almost non-destructive test that can be used as an engineering Fitness-For-Service technique for in-service pressure equipment. The specimen deformation and rupture occurs in the annular region between the punch and lower die. The data obtained from an SPT can be used to count the tensile yield, ultimate strength, creep rupture life and creep constants of isotropic ductile materials. With the development of research, the SPT has been used for testing biomaterials, welded pipe line, nuclear irradiated materials and composite materials. In ref [1], pre-cracked SPT specimens were tested for estimating fracture properties of the 15.5PH martensitic stainless steel. The shear punch creep test (SPCT) is a highly useful method for creep life assessment of service components.

In this study, a shear punch experiment setup is fit in which displacement is measured at top of the punch directly using a Linear Mechanical Quantity Sensor (LMQS) and a soft ware is installed to the computer has been eliminate the effects of punch and die compliances as much as possible. The intent of current work is to use the shear punch test to investigate the mechanical property of each area in whole welded joint. And then, the relationship of base metal between the tensile stress and shear stress was built and its application to study the heterogeneity mechanical properties of each area in whole welded joint. Finally, influence of different microstructures on mechanical properties of laser welded joint had been investigated.

2. Experiment Procedure

2.1 Welding process

The type of the material used in the experiment was rolled Ti-6Al-4V titanium alloy, the dimensions of the plate were 170×330×2.5 mm^3. The chemical composition of titanium alloy was shown (5.5~6.8 wt% AL, 3.5~4.5 wt% V, ≤0.3 wt% Fe, ≤0.15 wt% Si, ≤0.1 wt% C, ≤0.05 wt% N, ≤0.015 wt% H and ≤0.05 wt% O in titanium alloy). .

The sheets were welded by the CO_2 laser welding, while the beam power was 2500W, the defocusing distance was 0, and the weld speed was 1.5 m/min. Micro-hardness was tested on the whole welded joint, HXD-1000TMC micro-hardness tester was applied during loading at 300 gf with 15 seconds holding time, each point was apart from 0.05 mm. Optical photograph was photographed by C2003B optical microscope. Specimens for optical microscopy were mechanically polished with 6, 3 and 1 um diamond paste, the final polishing was accomplished using colloidal silica of about 40 nm in diameter, followed by etching in Kroll's reagent (3~5vol% HF and 10vol% HNO_3 in water).

2.2 Shear punch test

Under the room temperature, the shear punch sample was stretched by CCS8000 universal tensile test machine, with the specimen thickness was 0.4 mm and tension speed was 0.024 mm·min^{-1}. 3D model was shown in Fig.1.

The load-displacement data was converted to stress-normalized displacement data using the following expressions. The sampling location in whole welded joint was shown in Fig.2a, the load-displacement curves of different micro areas from welded center lines was shown in Fig.2b.

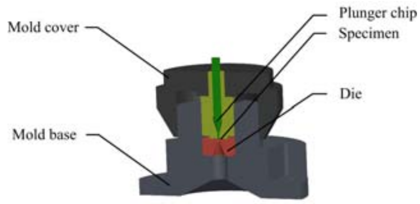


Fig. 1 Schematic representation of shear punch-die assembly

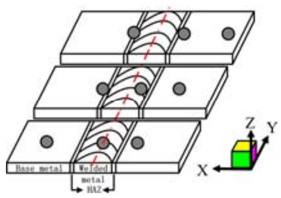
Shear stress can be got from formula (1)

$$\tau = \frac{P}{2\pi r\delta} \tag{1}$$

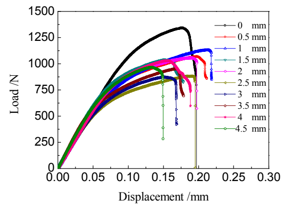
Then, the normalized strain is the following

$$l = \frac{d}{\delta} \tag{2}$$

Where P was the applied load, δ was the specimen thickness, r was the average of punch, d was the displacement.



a sampling location.



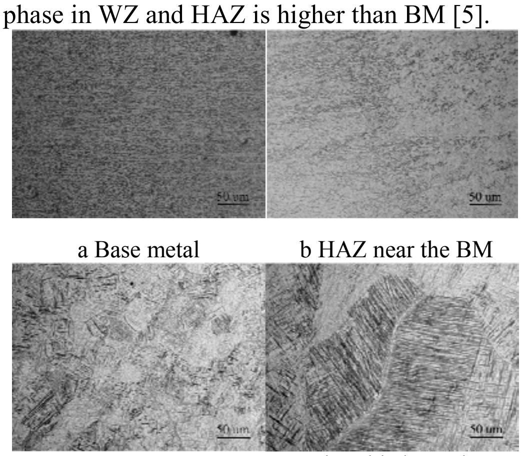
b Load-displacement curves

Fig.2 Sampling location and load-displacement curves of different micro areas from welded center line

2 Result and discussion

2.1 Microstructure

The grain size of Martensite (M) phase and α Phase is above 200~300μm in WM and 5~50μm in HAZ of the whole joint; there are some β phase in HAZ near the BM; The grain size of α Phase and β phase is 1~3μm in BM and the macro morphology of each area in welded joint as shown in Fig.3. Fig.3a shows the microstructure of TC4 titanium alloy. The distribution of M phase becomes more dispersive and glomerate from WM to HAZ due to the cooling rate, as shown in Fig.3b and Fig.3c. Reference [2] considered that M phase from β phase due to the rapid cooling process, so M phase dominated the WM, but also with grain structure of prior columnar β phase In our research, the fast cooling rate had substantially transformed the β phase to M phase with some α Phase left at prior β grain boundaries, as shown in Fig.3d. The β columnar grain structure is dependent on several factors: the weld thermal cycle and the shape of the weld pool [3]. Furthermore, reference [4] on an α Phase and β phase titanium alloy and its welded joint, the fatigue crack propagation rate of the weld having coarse prior β phase grains is slower than that of the base metal. It is also confirmed in the present study that the tensile stress of WM is the highest in whole welded joint due to M phase and coarse prior β phase grains, so tensile stress which impacted by M phase in WZ and HAZ is higher than BM [5].



a Base metal b HAZ near the BM

c HAZ d Welded metal

Fig.3 Microstructure of TC4 laser welded joint

2.2 Microhardness

The microhardness test was performed on whole welded joint and the result is shown in Fig.4 that HV of WM is somewhat higher than that of other areas, which is caused by imparity distribution of M phase content in WM. However, some finer β phase was found in HAZ near BM. For further discussion, the mechanical property of the area would change greatly with a pronounced microstructure gradient. Therefore, it is not difficult to understand the major variation in microhardness between the HAZ and BM as shown in Fig.4. This phenomenon consists with experiment data for shear punch test too. And reference [6] showed the microhardness in WM was higher than that in BM as well, because the WM was full of M phase. So the distribution of microhardness of whole welded joint is consisted well with tensile stress. Furthermore, the distribution of microhardness of whole welded joint is consisted well with tensile stress. It was proved that the excellent tensile property of the laser weld metal was compared to the base metal due to the presence of M phase. All of the experiment results show the microhardness in WM is high than other areas also.

2.3 Shear stress of whole welded joint

Fig.5 shows the maximum shear stress of each point in whole welded joint. The thickness is 0.4 mm. The trends of microhardness are consistent with maximum shear stress. The maximum shear stress in WM is higher than that of HAZ and BM, which is 509MPa. And the HAZ near the base metal is the weakest link in whole welded joint, the maximum shear stress in it is just 369MPa.

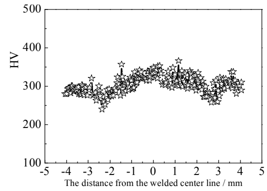


Fig.4 Micro-hardness HV and max shear stress varied with the distance from the weld center line

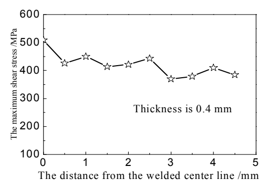


Fig.5 The maximum shear stress in the whole welded joint

From the above all, the SP testing reflects the mechanical heterogeneity of the whole TC4 titanium alloy laser welded joint well, but mostly importantly, it can help me to get the constitutive relationship of each areas in whole welded joint at room temperature. The load displacement curves can be converted to the true stress and true strain curves by inverse finite element analysis. At our present work, the constitutive relationship is inputted into welding residual stress model as a room temperature material parameter.

3 Conclusions

The rationality of SP testing is proved indirectly by fracture surface and load displacement curve. The results show that SP testing as an acceptable method for accurate evaluation of mechanical properties of welded joints from small specimens. And the tendency of maximum shear stress is similar to that of macrohardness. This is a step forward towards the application of small specimen test techniques for heterogeneity of the structure and the mechanical properties of the welded joints.

Acknowledgements

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