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EFFECTS OF ANNEALING ON INTERFACE MICROSTRUCTURE AND TENSILE FRACTURE MORPHOLOGY OF 42CrMo/Q235 CROSS WEDGE ROLLING (CWR) LAMINATED SHAFTS

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The laminated shafts were prepared by CWR process. The heat treatment study was carried out to enhance its properties. The shafts were treated by different annealing processes, the changes of properties before and after annealing were compared. The microstructure and the tensile fracture were analyzed. The results showed that the tensile and shear properties of the laminated shafts were the best when annealing at 700 °C for 60 min, which could reach 576 MPa and 473 MPa, respectively. After annealing, fine interfacial spheroidal structure could be obtained and enhanced the bonding strength; the dimple holes at the tensile fracture became larger and deeper, and the fracture became uniform and stable, clarified the reasons of the change of mechanical properties.

Keywords: laminated shaft; annealing; mechanical properties; microstructure; fracture morphology

INTRODUCTION

A laminated shaft refers to a shaft product made from two different metals, and thus has the advantages of both metals. Under the premise of reducing the use of precious metals, it also ensures the comprehensive properties, so it has been widely used [1]. CWR is superior to traditional forging, casting and other production processes in terms of production efficiency and automation [2]. At the same time, the working environment can be improved. Therefore, the laminated shafts were prepared by CWR process in this paper.

Wang et al. [3] studied the evolution of the bonding interface of Al/ Mg composites during heating. Li et al. [4] studied the tensile properties and microstructure evolution of aluminum-copper composites under dynamic loading. Ren et al. [5] studied the microstructure evolution and the bonding strength of Ti/Al joints. Most of the existing researches focus on improving the performance of laminated shafts by optimizing process parameters and their researches are mainly based on composite panels and composite rods with equal cross-sections. The structures are simple. There are few studies on heat treatment of shafts with variable cross-sections. The deformation zone of the wedge-shaped mold of CWR is complicated, and the influences of the subsequent heat treatment parameters on the interface combination are not clear, and further researches are needed.

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EXPERIMENT

Blanks and rolling

The cladding material is 42CrMo steel and the substrate material is Q235. The samples are as shown in Figure 1.

Figure 1 The laminated sample

Microstructure analysis

The laminated shafts were cut at the position shown in Figure 2. The sample contains both 42CrMo and Q235 parts. Corrosion was carried out with 4% nitric acid alcohol, and the microstructure near the interface was observed with a HiROX KH-8700 digital microscope.

Fracture morphology analysis

The mechanical sample was first broken by the MTS tester to obtain a fresh fracture, and then the stain around

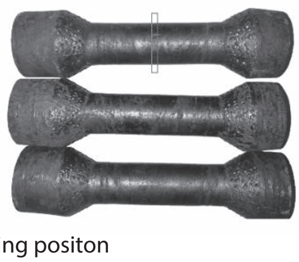

Figure 2 Cutting positon

the fracture sample was rinsed with absolute ethanol. HITACHI SU-70 SEM was used to observe the characteristics of the fracture.

RESULTS AND DISCUSSION

Effect of annealing on interfacial bonding strength

The interfacial tensile strength and shear strength were 530 MPa and 421 MPa respectively after rolling. The specimen was heat treated: annealing temperature was 600 °C, 700 °C and 800 °C, holding time was 1 h. Figure 3 shows that the tensile and shear properties are best at 700 °C.

After annealing for 30, 45, 60 and 75 minutes at 700 °C. The interfacial bonding strength are measured, the results are as shown in Figure 4. The bonding strength of the interface is the highest after holding for 60 minutes.

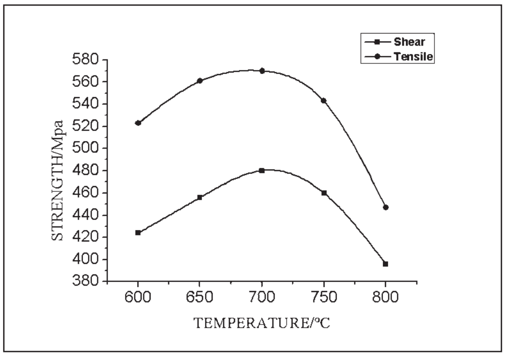

Figure 3 Interface strength varies with annealing temperature

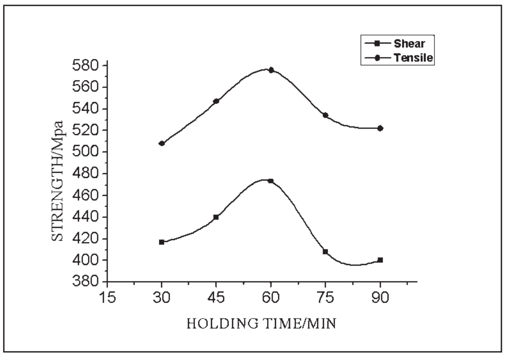

Figure 4 Interface strength varies with holding time

Effect of annealing on interface microstructure

The duplex structure near the interface composed of bainite, ferrite and cementite is as shown in Figure 5 a). Figure 5 b) shows that the grains begin to coarsen at sub-temperature annealing. In Figure 5 c), the pearlite on Q235 side joins into one piece, and a decarburization layer appears. At this time, the pearlite grains on Q235 side near the interface are large and further coarsened. In Figure 5 d), retained austenite on the 42crMo side of the interface transforms to pearlite at 900 °C, and the pearlite grain on the Q235 side is recrystallized and refined compared with 800 °C.

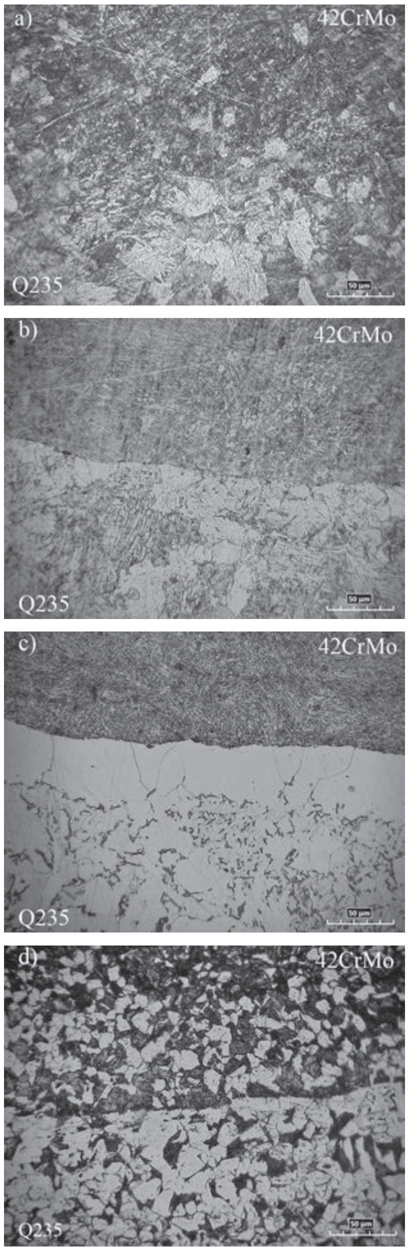

Figure 5 Microstructures at different annealing temperatures, a) 600 °C, b)700 °C, c)800 °C, d)900 °C.

Since 42CrMo interface is dark after being corroded by nitric acid alcohol, its grain structure is not very clear. Therefore, the interface in Figure 6 is observed under the Scanning Electron Microscopy.

In Figure 6 a) the grain spans on both sides of the interface and grows. The reason is that the grain grows with the increase of temperature. A mixture of fine granular cementite and ferrite is distributed near the interface of Figure 6 b). As shown in Figure 6 c), the pearlite reappears on the 42CrMo side, and the mixture composed of pearlite, carbide and ferrite are all around the interface.

Effect of annealing on tensile fracture morphology

Figure 7 a) shows that some of the carbides are flocculent and strip-shaped. Figure 7 b) shows that most of the carbides are spherical, and the sizes of the carbides

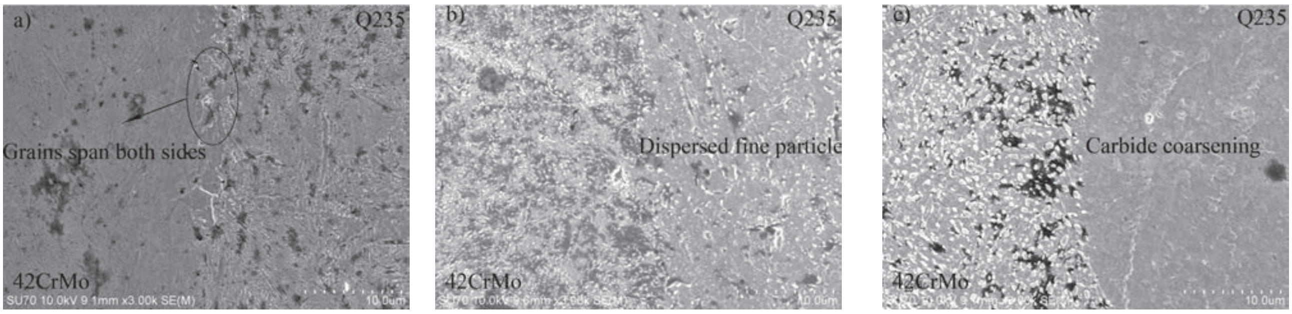

Figure 6 Microstructures at different annealing temperatures, a) 600 °C, b) 700 °C, c) 800 °C.

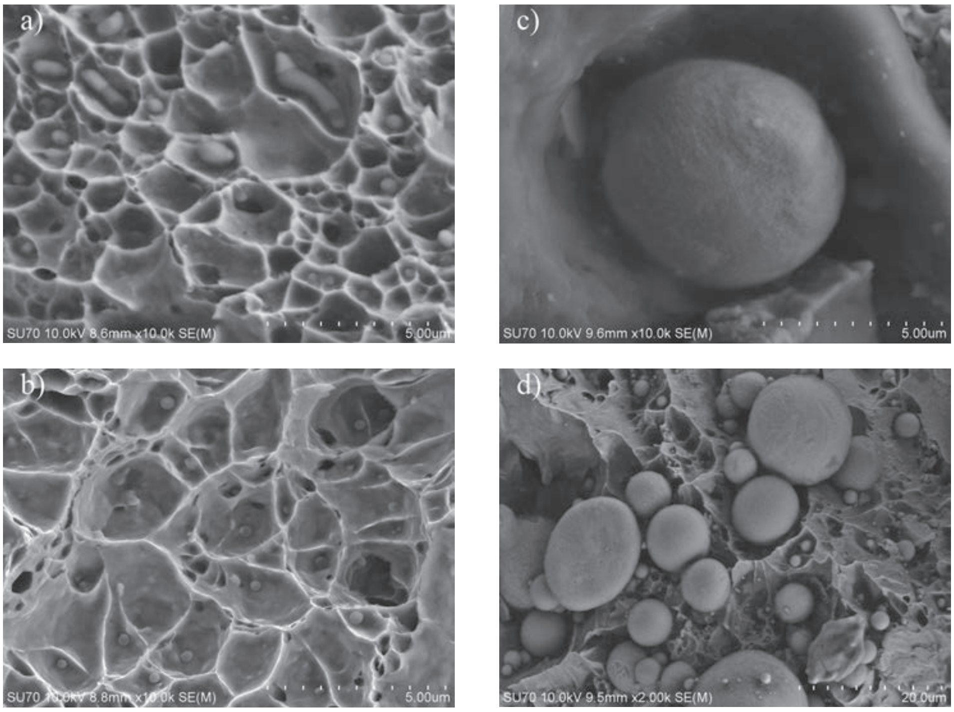

Figure 7 Morphology of tensile fracture, a) 600 °C (5μm), b) 700 °C (5μm), c) 800 °C (5μm), d) 800 °C (20μm).

are almost 2 μm, which are significantly smaller than that in Figure 7 a). Figure 7 c) and d) show that spherical carbides of different sizes appear after annealing at 800 ° C. Spherical carbides are about 160 um, and they are much larger than that in Figure 7 b). Therefore, after heat treatment at 600, 700 and 800 °C, the best structure can be obtained by heat treatment at 700 °C.

After 45 min heat preservation, large carbides begin to decompose, and the shape of carbides changes from initial clusters and flocs to smaller strips. After 60 minutes heat treatment, the size of dimple holes become larger and deeper. At this time, the strips and small blocks of carbides at the bottom of dimples are basically decomposed, and the carbon atoms in saturated solid solution re-precipitated from the bottom of dimples in the form of spherical particles.

Compared with Figure 8 b) and 8 a), after 60 minutes of heat treatment, the structure becomes homogeneous. After 75 minutes heat treatment, there are a little more spheroidized particles. The grain grade of 75 min is smaller than that of 60 min, so the bonding strength of interface is greater after 60 min annealing.

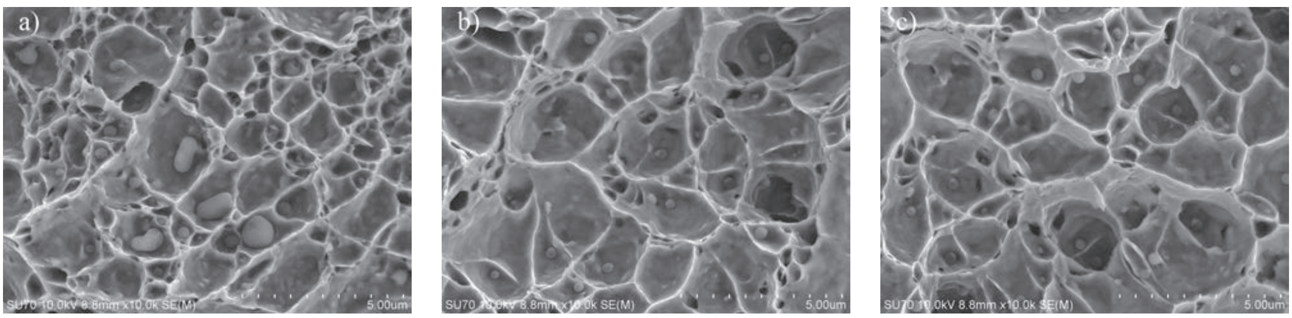

Figure 8 Morphology of tensile fracture at different annealing time (700 °C) a)t = 45 min, b)t = 60 min, c)t = 75 min.

CONCLUSIONS

(1) The interfacial bonding strength is affected by fracture source on the interface, grain size and strong carbon compounds. The results of tensile and shear tests show that the bonding strength obtained by annealing at 700 °C for 60 min is the highest.

(2) After 700 °C annealing for 60 minutes, the dimple holes at the tensile fracture become larger and deeper, and the fracture structure becomes more uniform and stable.

(3) As the temperature and holding time increase, the grains grow up gradually, and the upper bainite on 42CrMo side become a mixture of retained austenite, pearlite and ferrite. At the same time, a decarburization layer is formed on the Q235 side.

Acknowledgements

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Note: The professional translator for the English language is J Jiang, Zhejiang, China.