Influence of Abnormal Ultrasonic signal on the surface of Zr-4 pipe

Hui Lu [1,2,3,*], Hui Dang [1,2,3], Hengyu Li [1,2,3], Jingwei Ma [1,2,3], Xiaoying Li [1,2,3]

[1] State Nuclear BaoTi Zirconium Industry Company, Baoji, China

[2] Shaanxi Key Laboratory of Nuclear Grade Zirconium Materials, Baoji, China

[3.]National R&D Center Zirconium Material Center Baoji, China

* Corresponding Author Email: baotailuhui05@163.com

Abstract. In this paper, the ultrasonic testing, metallographic observation (MO), and electron microscopy observation (ETO) were conducted to investigate characteristics of ultrasonic signal on the surface of Zr-4 pipe, and then the reason of the crack were mdeld by the finite element analysis (FEA). The results showed that the crack on the wall of the inner surface and polishing trace on the outside surface of the Zr-4 finished pipe were leading in the abnormal ultrasonic signal. The crack on the wall of the inner surface were madding up the intermediate pipe of Zr-4 tube. Theoretical analysis is consistent with practice on the crack model for Zr-4 tube by FEA.As seen that the results and FEA model were an efficient quantitative tool to product guidance.

Keywords: Abnormal Ultrasonic signal, Zr-4 pipe, Inner surfaces, Out surface.

1. Introduction

Zr-4 alloys, because of its low thermal neutron capture cross section, desirable corrosion resistance and favorable mechanical properties at high temperature about 300~400℃, are now being increasingly used for nuclear industry and still have the potential materials for the next-generation nuclear reactor[1-3].Zr-4 pipe is an important structure of the nuclear power reactors, which has been mainly cladded the UO_2.Junhui Yu were used to the scanning electron microscope(SEM) and energy spectrum ansys (ESA), researching on Polished Zr-4 alloy. JunHui Yu were built by finite element method (FEM), and show that the model were employed a good perform by tracing the angle, time, displacement and force in different of the step of the fracture [2]. XinXin Tong were modeled the mechanical properties in different Annealing treatments of the Zr-4 pipe by artificial neural network(ANN)-genetic algorithm(GA).The results show that the combined GA–ANN algorithm is efficient and strong method to find the optimum heat treatment technological for Zr-4 alloy[4-7]. However, it is still seldom literatures were published for abnormal ultrasonic signal as far as on the surface of Zr-4 pipe. Therefore, the main objective of the present work is to focus on the influence of roling in the inner and polishing outside of the Zr-4 pipe.

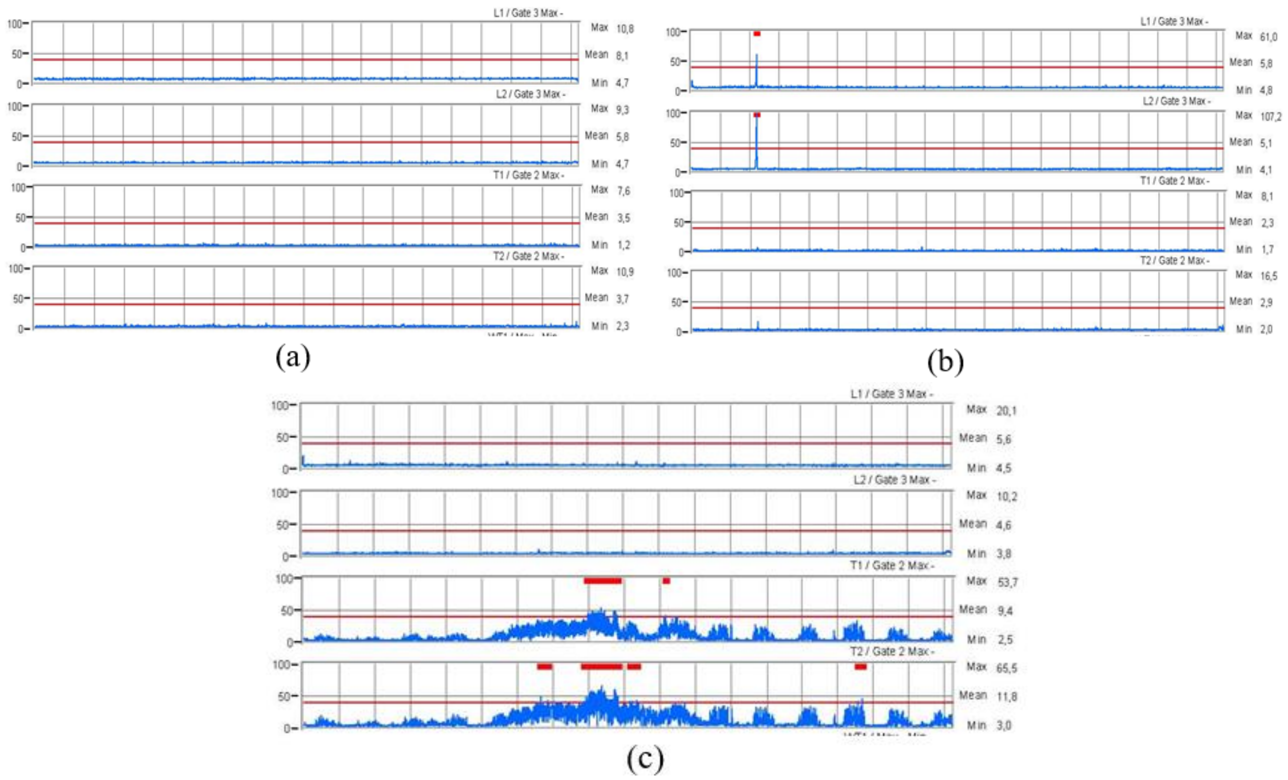

Figure 1. Ultrasonic records (a) normal record (b) Record abnormal signal pipes of longitudinal damage channels (c) Record the continuous abnormal signal pipe of the transverse damage channel

2. Experiment

The composition of Zr-4 pipe material is following (in wt%): 1.2~1.7Sn, 0.18~0.24Fe, 0.07~0.13Cr, ≤0.027 C, ≤0.0026 H, ≤0.16O, Fe balance, used in the present paper. The finished Zr-4 pipe after rongling and poshing treatments are used in NWZ. Firstly, the ROTA25 ultrasonic flaw detection equipment was used to conduct static positioning of Zr-4 alloy tube billet, and then the static calibration of the local area with excessive signal was carried out. And the individual morphology both normal record and un-normal record for Zr-4 pipe were obtained by using the leica DM2500M optical microscope and the s-3400 scanning electron microscope (including energy spectrum analysis function) was used to observe the inner wall of the tube billet in the area of excessive signal. At last and then the reason of the crack were mdeld by the finite element analysis (FEA).

3. Results and discussions

3.1. Internal surface defects

Internal surface defect morphology of Zr-4 alloy pipe on longitudinal damage channels are showed in the figure 2. It is really like a crack as internal surface topography as far as from the figure 2 (a). Meanwh It is really like a oblique crack far more then 45 degree and 11μm long as internal surface profile topography as far as from the figure 2 (b).

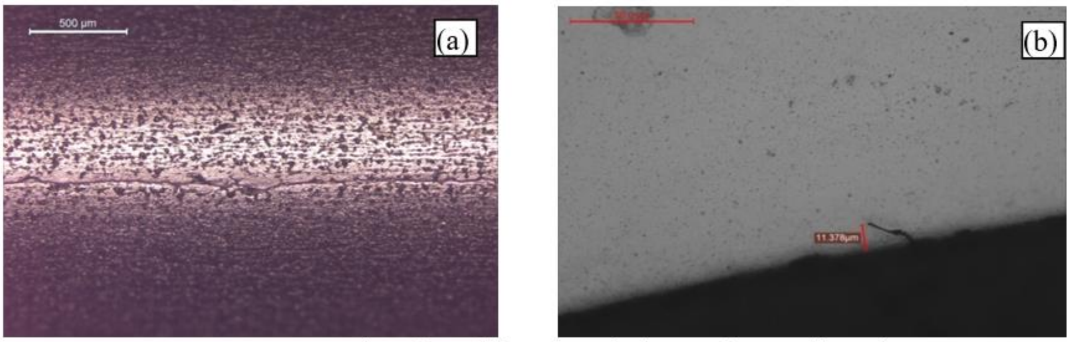

Figure 2. Internal surface defect morphology of Zr-4 alloy pipe (a) Internal surface topography (b) Profile topography

3.2. Experimental results of Zr-4 alloy tube billet

Fig. 3 shows the observation results of typical defect morphology in the inner wall of zR-4 alloy tube billet in the signal area of excessive standard of longitudinal damage channels. The inner wall of ZR-4 alloy tube billet is mainly composed of bonding defects, and the local area of bonding is large. The specific morphology is shown in FIG. 3 (a) and (b). The folding defects of Zr-4 alloy products are selected and peeled along the defect cracks. The specific morphology is shown in Figure 4. As can be seen from Figure 4, the finished Zr-4 alloy sample can be divided into three morphologies, namely, the inner surface of the finished pipe, the folded surface and the newly peeled surface, after being peeled along the folded surface. The morphology of the new peel surface is obviously different from that of the folded surface. Because the Zr alloy is a ductile material, the new peel surface will have typical dimple morphology along the peel direction, while the morphology of the folded defect is basically consistent with that of the inner wall of the tube billet.

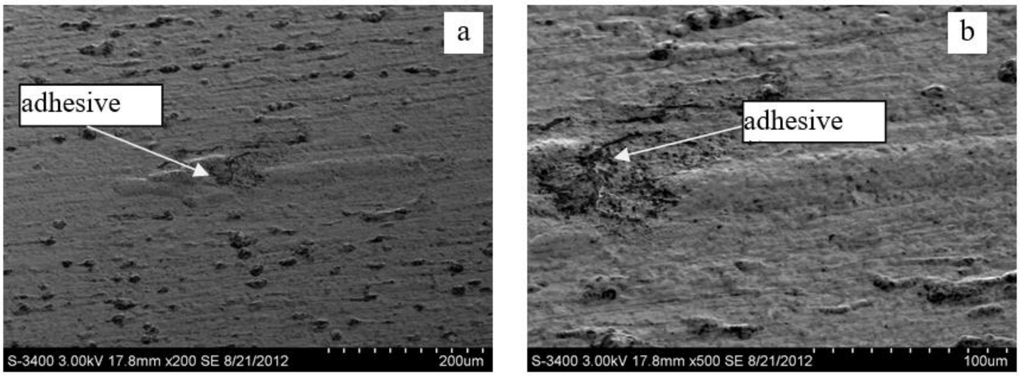

Figure 3. Morphological observation of typical defects in the inner wall of Zr-4 alloy tube billet in the signal area of overbid

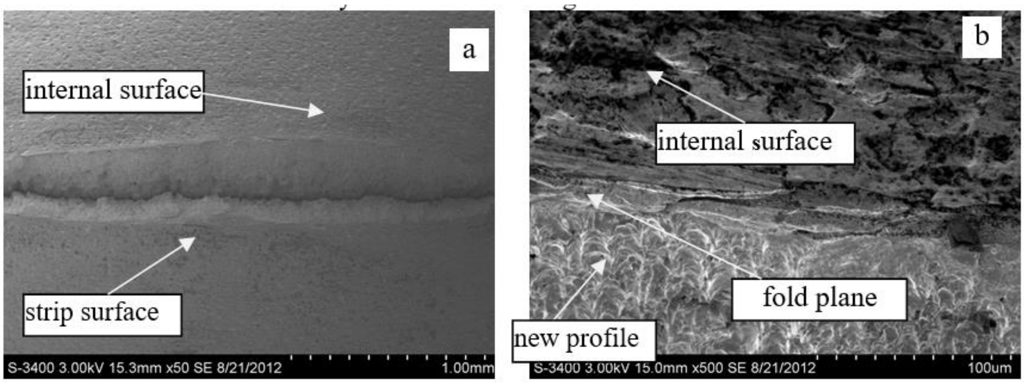

Figure 4. Typical morphology of the inner surface of Zr-4 finished pipe (a) Un-finised pipe (b) finished pipe

3.3. The FEM model is formed by folding

The FEM model formed by the inner wall folding of Zr-4 alloy pipe is established by using the FEM theory, and the specific formation process is shown in Figure 5. In the rolling process of the pipe, due to insufficient lubrication between the inner wall of the tube billet and the core head, the friction force in the rolling process of the pipe is large, so that the local area of the rolled Zr-4 alloy pipe will form bonding defects. The specific morphology is shown in Figure 5 (a). In the next process, the strain distribution of the tube billet containing bonding defects is uneven, which is due to the joint action of the axial tensile stress parallel to the extension direction of the tube and the radial compressive stress perpendicular to the inner wall of the tube. In the subsequent single-channel times when the rolling deformation of the pipe in the rotation of the groove diameter shrinkage under pressure, when the roller rotate to the position of the adhesive, tube wall metal flow under the force of inequality, which formed on the inner wall of the tube, the phenomenon of uneven distribution of strain, and centered on defects formed in the defect area local accumulation phenomenon, fold the early morphology formation, as shown in Figure5 (b) and (c).When the pipe continues to be rolled, the folded edge inside the pipe receives the action of the axial friction force exerted by the core head. Part of the folded edge of the pipe is worn and presents the irregular sawtooth morphology, thus forming the final morphology of the folded line, as shown in Figure 5 (d). The FEM model of Zr-4 alloy pipe folding is established, and the simulation results of the model are consistent with the actual production results, which can provide guidance for the optimization of Zr-4 alloy rolling process. As seen that the results and FEA model were an efficient quantitative tool to product guidance.

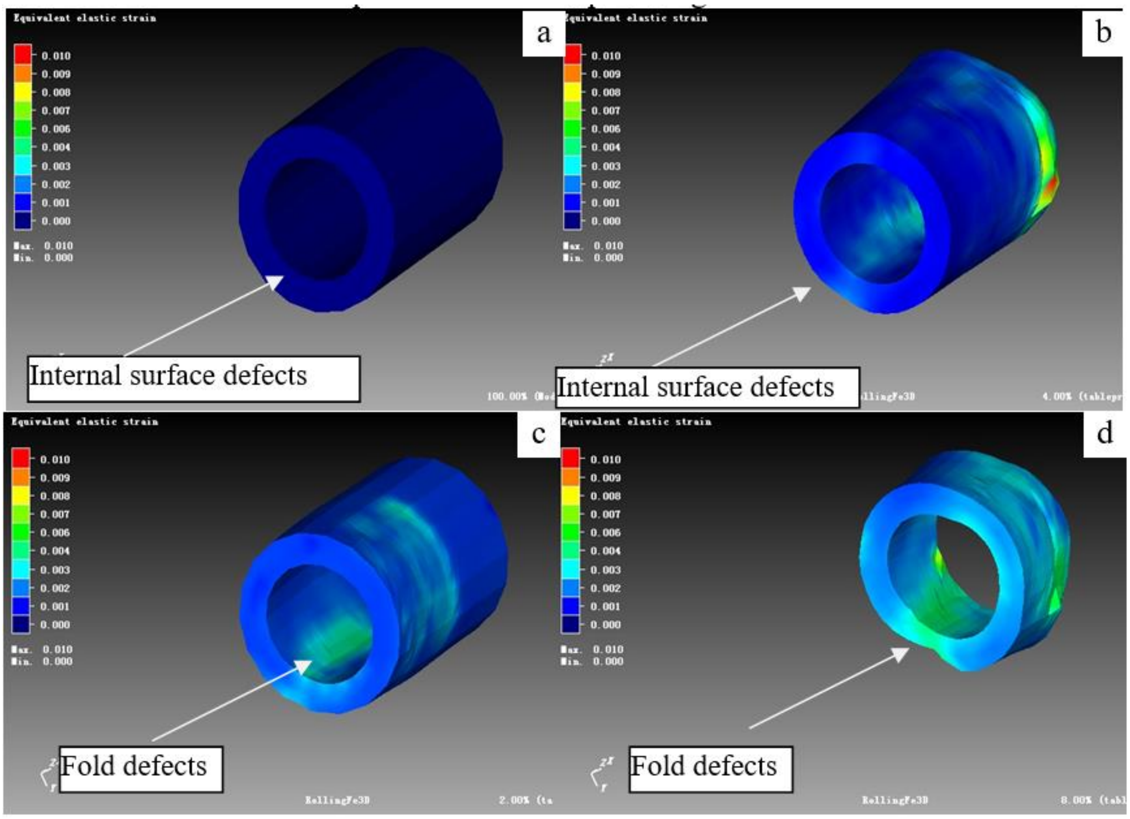

Figure 5. Typical morphology of the inner surface of Zr-4 finished pipe (a) Un-finised pipe (b) finished pipe

3.4. Exterior surface defact

he metallographic images of the defect area transverse damage channel and the normal area are shown in Figure 6. As can be seen from Figure 6, when the magnification is 200X, there are obvious polishing lines in both the defect area and the normal area of the coated pipe. When the magnification is increased to 200X, the scratches caused by polishing on the pipe can be clearly seen. Contrast curve signal area and normal area of metallographic photos as you can see, the defect display area have obvious indentation, and a normal areas with multiple small indentation, preliminary presumably cladding tube outer surface polishing scratches and a large number of polishing abrasive belt small particles into the indentation of the outer surface of the rough, appear in the process of ultrasonic inspection flaw signals.

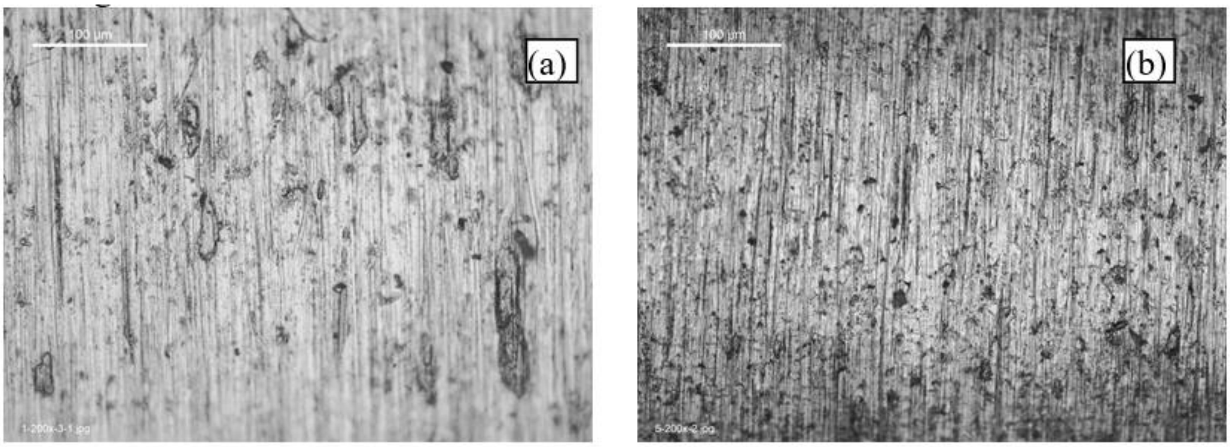

Figure 6. Outer surface of sample 200X (a) on defect area (b) on normal area

By comparing the 10X and 50X metallographic images of the inner surface (pickling state) of the defect signal area and the normal area, no significant difference was found between the two, so the influence of the inner pickling process on the defects of the cladding tube can be preliminarily discharged. Based on the fact that the defect display is mainly reflected in the transverse and longitudinal damage areas of the ultrasonic atlas, in order to more systematically compare the difference between the defect area and the normal area, the coating defect display area and the normal area are divided along the axial direction at the same time. The metallographic photo of the sample is shown in Figure 7. As can be seen from Figure7, there is no significant difference between the axial profile of the defect display area and the normal area. This may be due to the shallow indentation caused by the outer polishing process on the surface of the cladding tube, which is not effectively distinguished in the profile photo in Figure 7.

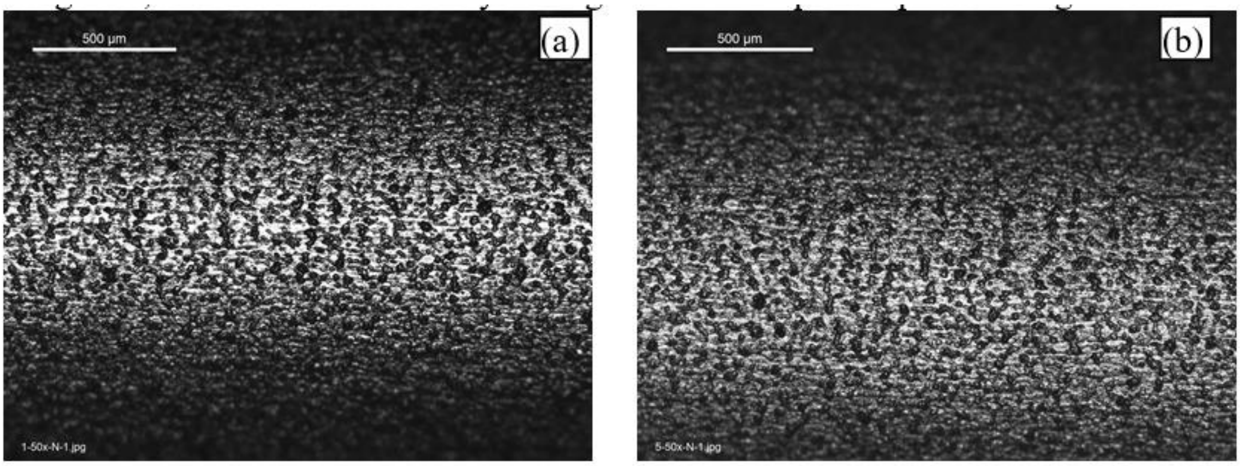

Figure 7. Inter surface of sample 50X (a)Inter surface defect area (b)Inter surface on normal area

In conclusion, by comparing the differences between the metallographic images of the Zr-4 alloy tube defect display area and the normal area, the scratches caused by the polishing of the outer surface of the coated tube and the indentation caused by the small particles of the polishing sand belt produce the rough outer surface, which shows as the defect signal in the ultrasonic inspection process.

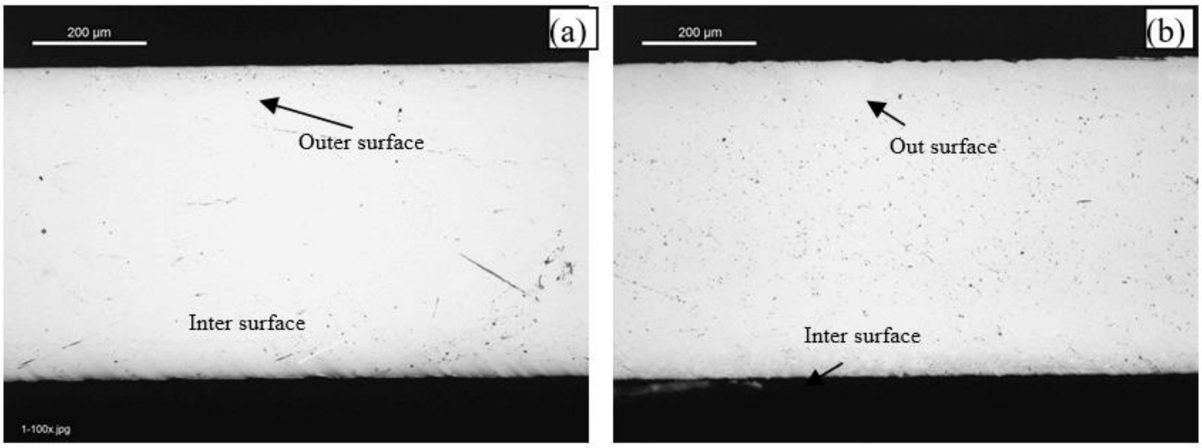

Figure 8. Profile sample 100X (a)defect area (b) normal area

4. Conclusions

1) The crack on the wall of the inner surface and polishing trace on the outside surface of the Zr-4 finished pipe were leading in the abnormal ultrasonic signal.

2) The crack on the wall of the inner surface were madding up the intermediate pipe of Zr-4 tube.

3) The reason of the crack of Zr-4 pipe were mdeld by the finite element analysis. As seen that the results and FEA model were an efficient quantitative tool to product guidance.

References

[1] Junhui Yu, Xiaoning Lu, Yan Zhai, et, al. BP ANN Model for Annealing Parameter and Hardness of Zirconium Base Alloy. Rare Metal Materials and Engineering, 2012, 41(8): 1346-1350.

[2] Junhui Yu. Study on the crack propagation of Zr alloy by FEM.2012th Association of zirconium and hafnium. 2012: 113-115.

[3] Junhui Yu, Lan Ding, Zhouqiang et.allGuo Analysis on the Low of the Ultrasonic Qualified rate for the Nuclear Grade Zirconium ube. Metal World 2018(3): 9-12,21.

[4] Xingxing Tong. Usin, g ANN-GA to Optimize Annealing Treatment technolo-gical Parameters on Mechanical Properties in Zr-4 alloy pipe. (GEMFE 2019) Chengdu, China, 2019: 63-65.

[5] HaiHui Yu, JunHui Yu, Xiaoning Li. Modeling of the fold on Zr-4 alloy tube in the rolling by FEM, Hot Working Technology. 2015, 44(19): 169-171.

[6] Hui Dang, Junhui Yu. Analysis on grass shape shows of nuclear grade zirconium pipe after annealing based on fault tree. Metal World, 2018(3): 9-12,21.

[7] Junhui Yu, Gaihuang Yuan, Zengming Wang,et, all. The Study on Fluorine Residue of Zr-4 Alloy Pipe after Pickling Based on Finite Element Method (FEM). Rare Metals and Cemented Carbides, 2015, 43(2): 64-68.