Finite element analysis of pitting pit on residual strength of magnesium alloy welded joint

Xiaoyuan Gong (✉ 515997393@qq.com)
Jinzhong University
Jinming Liu
Taiyuan University of Science and Technology
Junqi Li
Foxconn (China)
Fengqing Xiao
Foxconn (China)

Article

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Abstract

The stress field of pitting corrosion at different depths under tensile load was analyzed by ANSYS finite element method. It was found that the strength of stress field and strain field inside the corrosion pit was much higher than the average level of matrix. Therefore, the corrosion pit will fail first under the action of applied load. Based on the study of pitting corrosion, the mechanism of pitting corrosion crack propagation of magnesium alloy welded joints was described with a model, and the variation of residual strength was revealed.

1 Introduction

The development of magnesium alloy structural is restricted by its poor corrosion resistance. Research on the corrosion resistance of magnesium alloy welded joints is still urgent[1, 2]. Due to poor corrosion resistance, when corrosion occurs, its strength will rapidly decline until complete failure[3]. Therefore, the calculation of residual strength after pitting corrosion is paid more and more attention.

2 Pitting Mechanism And Model Establishment

The magnesium alloy sheet AZ31 used in this test has a size of 200mm × 150mm × 7m, and the filler welding wire is AZ61 magnesium alloy wire. It adopts TIG welding, single-sided welding and double-sided forming. The overall welding condition is relatively ideal, and the welding seam is neat and beautiful, and the surface is smooth without edges, cracks, incomplete welding, porosity, slag inclusion, burn through or other welding defects. X-ray nondestructive testing was conducted on the weld, and the level of flaw detection was grade ▯. No obvious defects were found in the weld.

Pitting corrosion is the corrosion characteristic of magnesium alloy welded joint in Cl- solution medium. Figure 1(a) and (b) show the joint sample corroded in 3.5% NaCl solution, and the microscopic morphology of corrosion pits and the process of crack propagation along the surface. It can be seen from Fig. 1(a) that the pit corrosion is initially formed at the center of the α phase on the surface of the sample. as shown in Fig. 1(b), the pitting pits showed irregular dendrites extending in all directions.

After the corrosion of magnesium alloy welded joints, when there is an external load, the internal stress field and strain field will change greatly compared with those before corrosion. This makes it possible for the welded joint to break under low stress state. With the progress of corrosion, the residual strength of the joint also decreases continuously. The residual strength of corroded welded joint was investigated by analyzing the internal stress and strain field. In this paper, finite element method is used to analyze and calculate the stress and strain field of the joint after corrosion.

ANSYS is a kind of finite element analysis software with powerful free meshing function, which can perform meshing of complex surfaces and even volumes without being restricted by element shapes and modes[4–6]. The analysis and calculation of the stress field and strain field of the corroded welded joint adopts the solid187 space tetrahedron element type, and the element data is 376715. Model size 12*6*2, pressure 0.05MPa. The specific parameter settings are shown in Table 1.

Table 1 Basic parameter setting of stress-strain field simulation of AZ31 magnesium alloy welded joints after corrosion

Element Type	Elastic Modulus E/(GPa)	Poisson's Ratio μ	Applied Surface Load MPa	Element mesh side length	Model size	Pit diameter	Pit depth
solid187	43	0.34	0.05	0.35	12*6*2	1	0/0.1/0.2/ 0.3/0.4/0.5

solid187 is a high-order 3-dimensional 10-node solid structural element, which has a quadratic displacement mode that can better simulate irregular grids. This unit is defined by 10 nodes, each with 3 degrees of freedom, which can be translated in X, Y, and Z directions.

The research object of this paper is a magnesium alloy welded joint, and its shape and load are geometrically symmetrical, because the software itself can only calculate a part of the model, so a part of the middle of the weld is intercepted to establish a symmetrical model. As shown in Fig. 2(a). Figure 2(b) shows the computational model after meshing.

3 Numerical Simulation And Analysis

Figure 3 shows the strain field distribution of the corroded joint under the applied tensile load, and the strain distribution along X and Y directions (Fig. 3(a) and (b)) is roughly the same. It can be seen from the figure that along the Z direction (Fig. 3(c)), the strain at the bottom of the etching pit is the largest. The area of maximum strain is oblate. Due to the poor plasticity of AZ31 magnesium alloy, when the welded joint is subjected to external force, the region with the largest deformation under the action of this strong stress field will become the fracture derived region. According to the simulation of equivalent deformation (Fig. 3(d)), the deformation at the bottom of the pit is the largest when the joint is subjected to external force. When the joint is fractured, the inside of the pit is the origin of the fracture crack, and it is also the largest deformation area when the joint is subjected to tensile stress, which is the driving force for crack nucleation and expansion.

Figure 4(a), (b) and (c) show the internal stress field of the joint with corrosion pits on the surface under the action of external loads. Stress analysis along X, Y and Z directions shows a high degree of stress concentration in the pits. The calculation and analysis of equivalent stress distribution (Fig. 4(d)) shows that the stress concentration area is perpendicular to the axial direction, which makes the welded joints have a great tendency of fracture failure under the applied load. The results of simulation show that the secondary cracks occur due to the large stress concentration in the pit.

Figure 5 shows the stress field distribution when the pit depths are different (the pit depths in the figure are 0mm, 0.1mm, 0.2mm, 0.4mm and 0.5mm respectively). When the depth of the pit increases, the strength of the stress field in the pit also increases, and the gap with the average stress level of the matrix is also increasing. This also shows that increasing the pit depth makes the stress concentration more obvious.

From the simulation results, it is known that the local corrosion of the joint is the main reason for the instability of mechanical properties. The fracture of the corroded welded joint is because the stress concentration promotes the nucleation and extension of the crack. When there is a large stress concentration, a small load can generate cracks around the corrosion pit. and the crack will rapidly extend and break the joint after continued loading[7–9]. Therefore, often before reaching the maximum stress that the joint can bear, local cracks have begun to appear, resulting in the fracture of the welded joint. As shown in Fig. 6

Combined with Fig. 7(a) and 7(b), the residual strength of the joint decreases with the increase of corrosion time, but the decreasing speed is not uniform, It is first fast and then slow. The residual strength mainly depends on the effective bearing area and stress concentration. The formation and continuous expansion of pitting corrosion is the main reason for the decrease of residual strength of magnesium alloy welded joints. With the progress of corrosion, the cracks around the pit continue to extend, and the residual strength becomes smaller, but the change trend will correspondingly slow down.

Conclusion

(1) The stress concentration caused by local corrosion damage and the decrease of effective bearing area lead to the attenuation of residual strength of magnesium alloy welded joints. Secondly, stress concentration exists in the weld zone itself, coupled with local energy concentration generated in the tensile process, which is the energy factor for the attenuation of residual strength of the welded joint after corrosion.

(2) The ANSYS simulation results show that the internal stress field strength of spherical pits is much higher than that of the matrix, and it is easy to form a large stress concentration. With the progress of corrosion, the strength of the stress concentration increases, and the stress concentration is an important reason for the fracture of the welded joint after corrosion under low stress. The strain field simulation results show that the degree of deformation in the corrosion pit is much higher than the average level of the matrix. Due to the poor deformation ability of magnesium alloy, the large local deformation is the main reason for the initiation of crack nucleation in the corrosion pit.

Declarations

Author Contributions: Xiaoyuan Gong conceived and designed the experiments; Xiaoyuan Gong and Jingming Liu performed the experiments and analyzed the data; Junqi Li and Fengqing Xiao contributed materials and analysis tools; Xiaoyuan Gong wrote the paper.

Conflicts of Interest: All four authors claim that there is no conflict of interest

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Figures

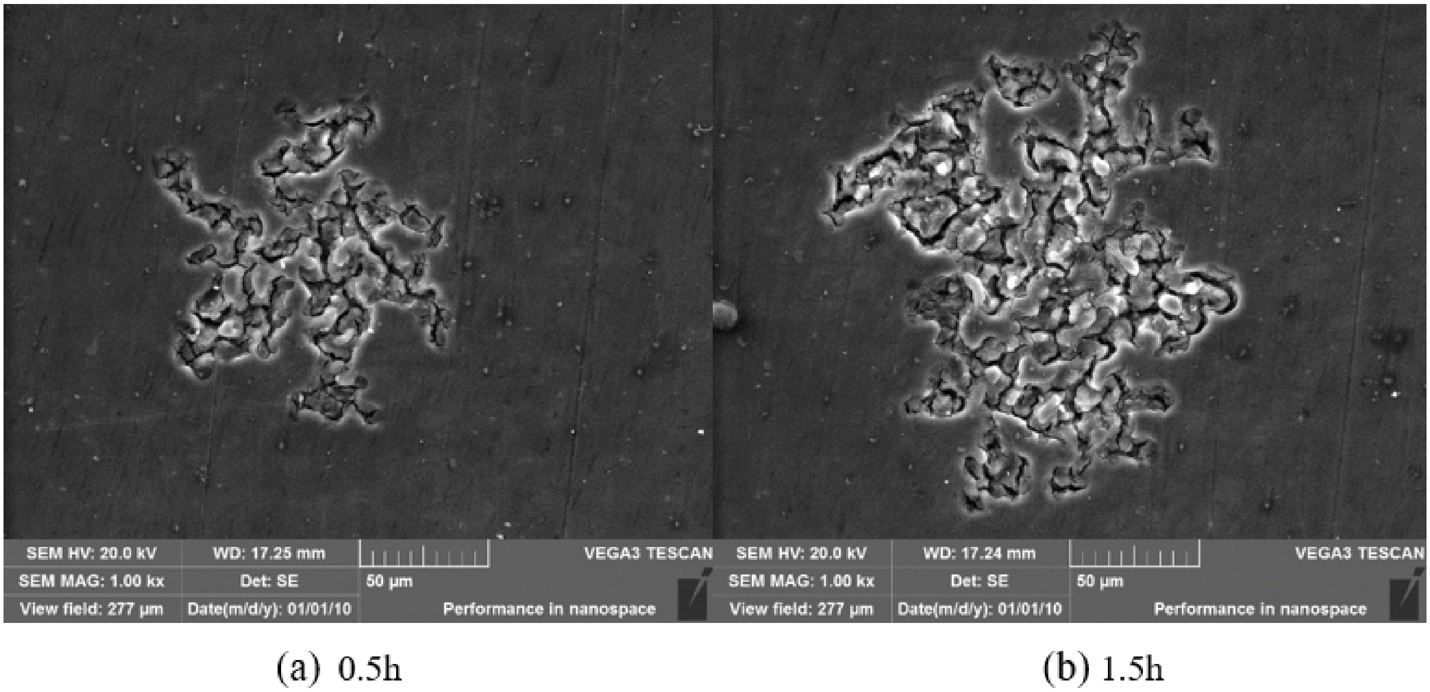


Figure 1

Changes in etch pits with increasing corrosion time

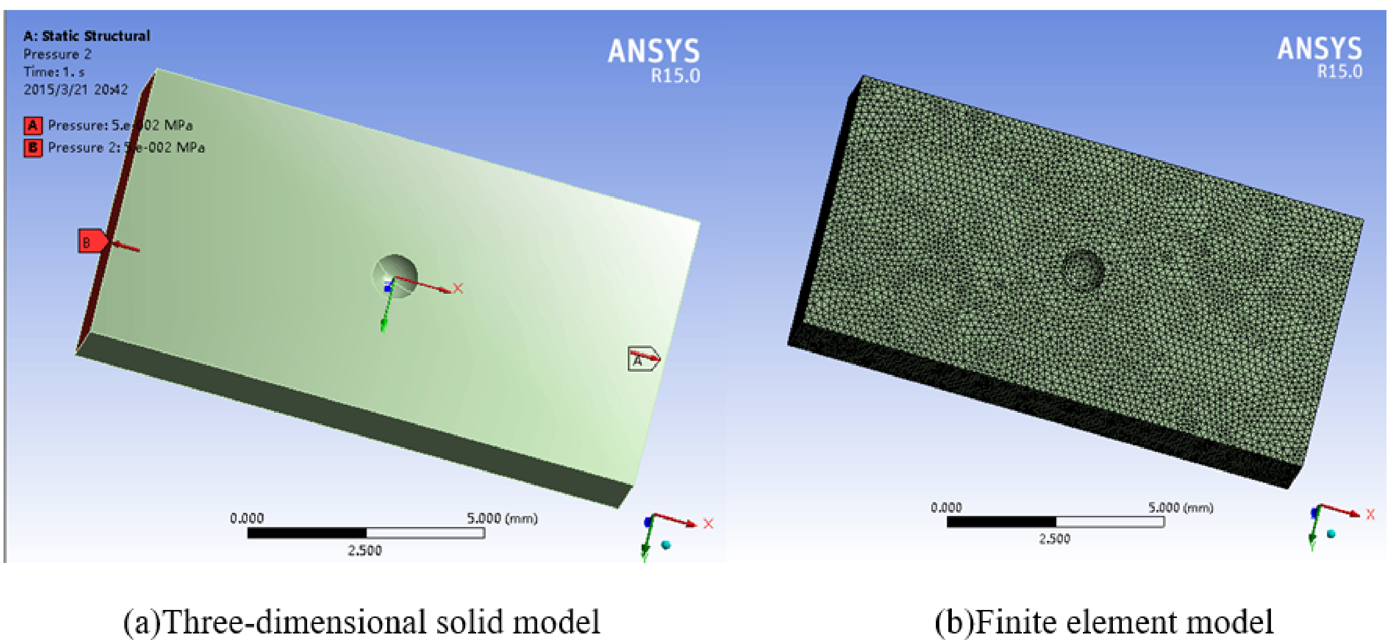
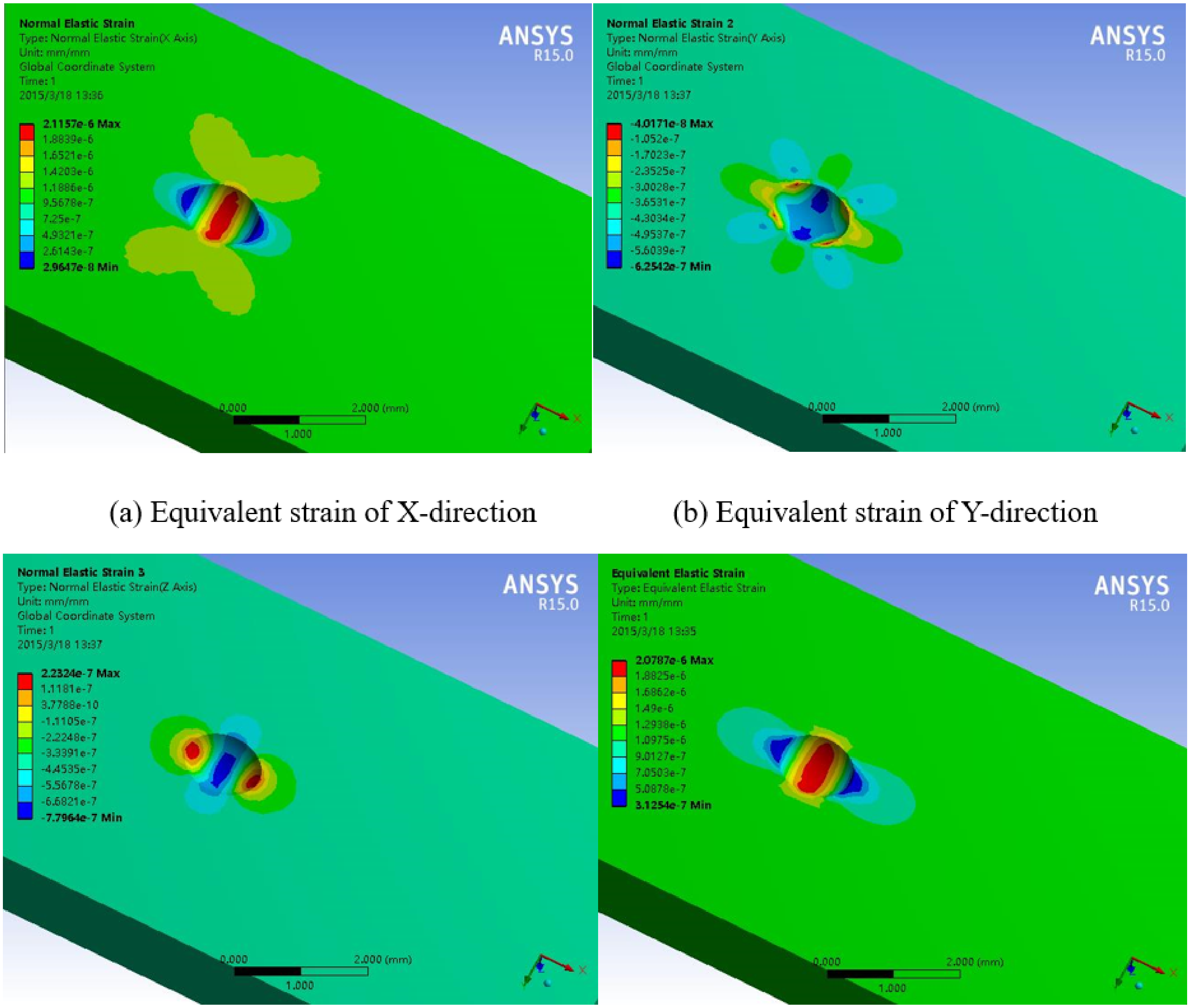


Figure 2

Modeling



(a) Equivalent strain of X-direction

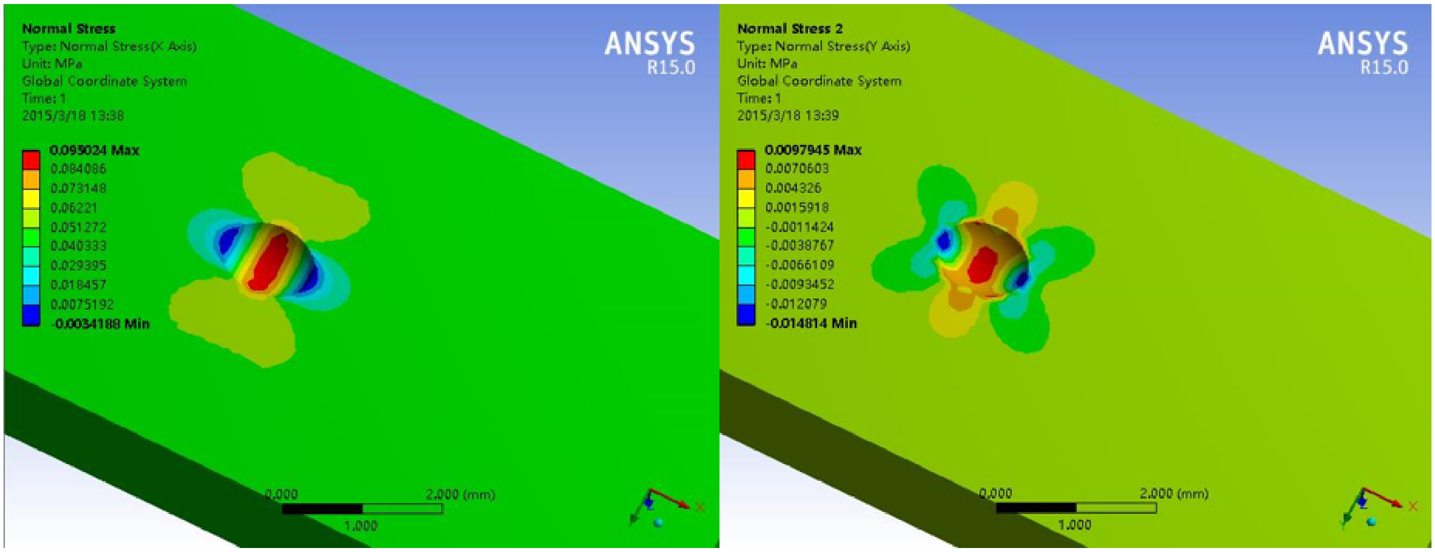
(b) Equivalent strain of Y-direction

(c) Equivalent strain of Z-direction

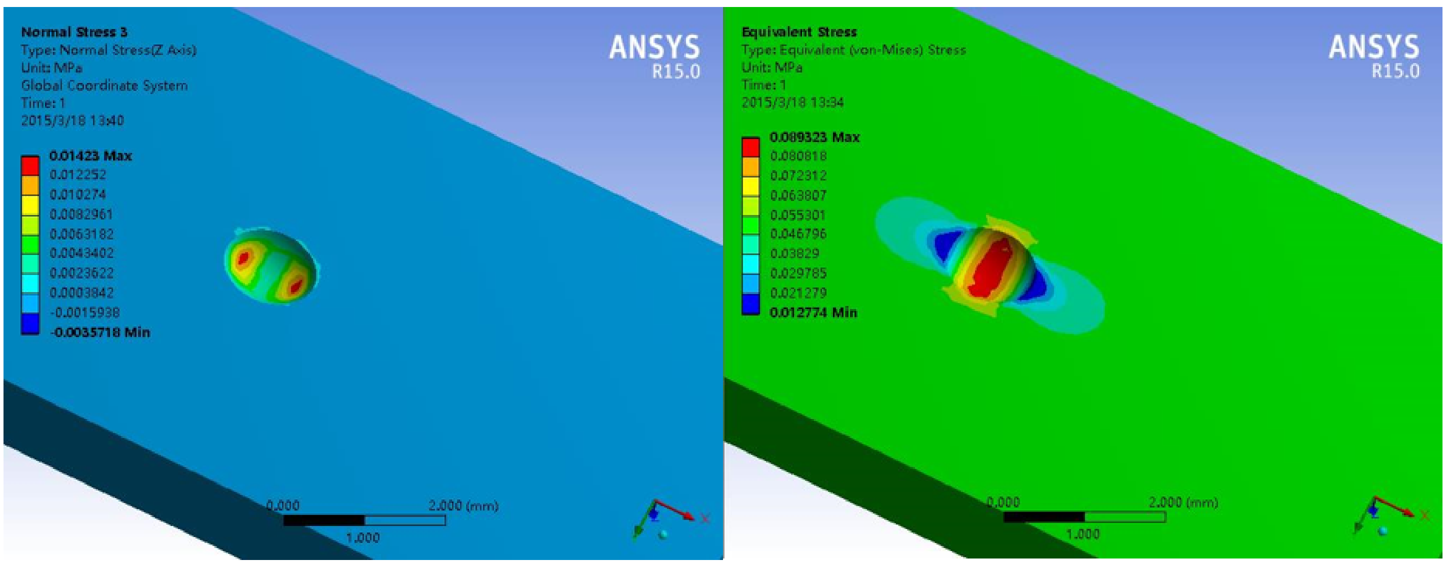
(d) Equivalent strain

Figure 3

Calculation results of strain field (the pit depth is 0.3mm)



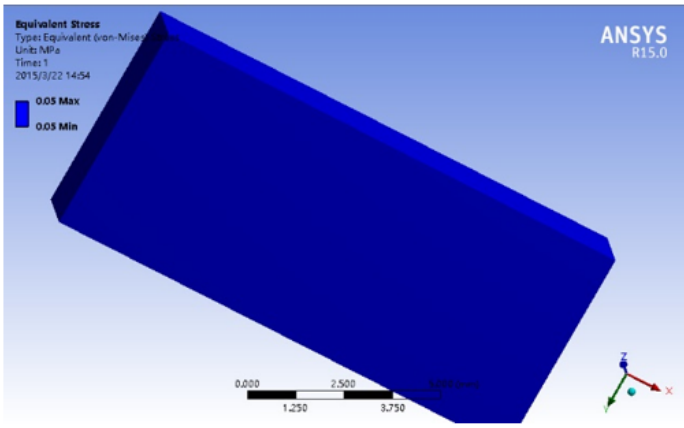
(a) Equivalent stress of X-direction (b) Equivalent stress of Y-direction

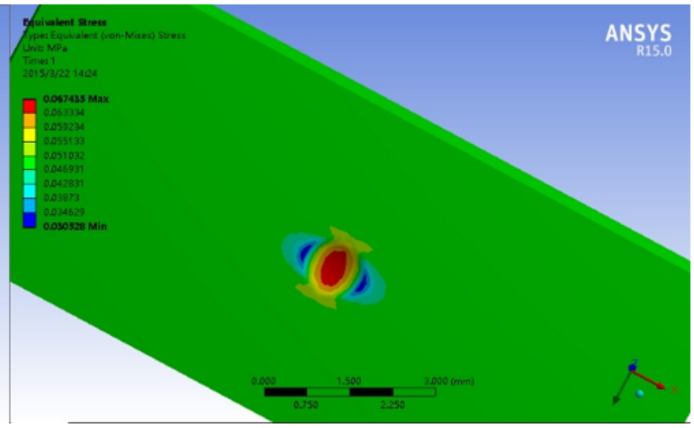


(c) Equivalent stress of Z-direction (d) Equivalent stress

Figure 4

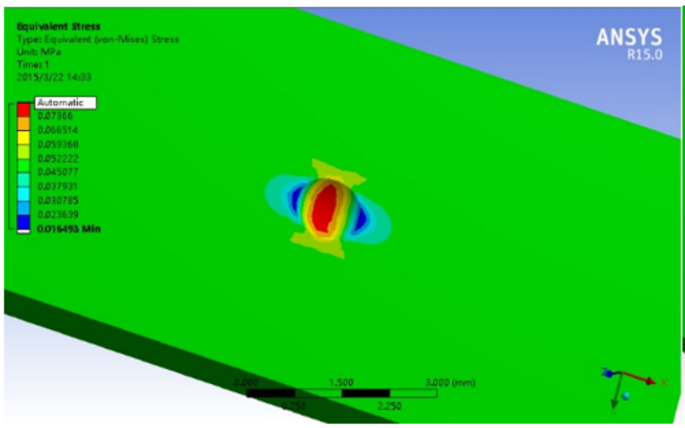
Calculation results of stress field (the pit depth is 0.3mm)

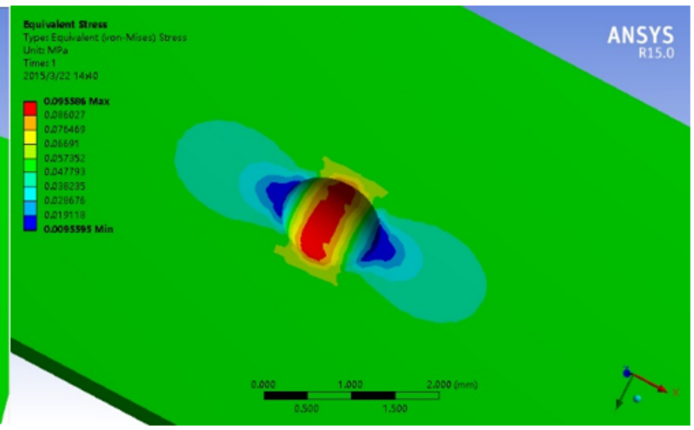




(a) Depth of the corrosion pit is 0mm

(b) Depth of the corrosion pit is 0.1mm





(c) Depth of the corrosion pit is 0.2mm

(d) Depth of the corrosion pit is 0.4mm

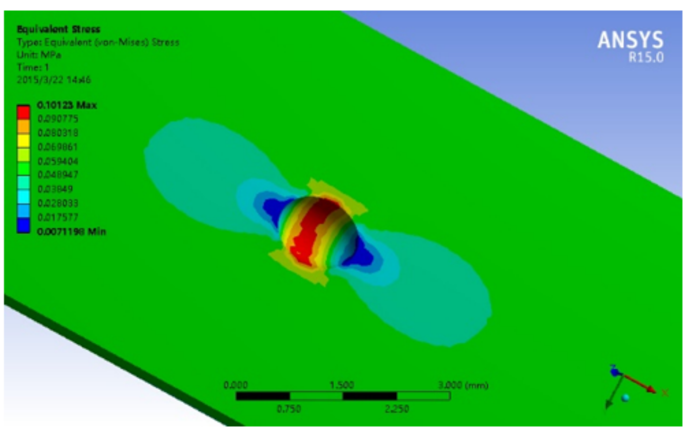


Figure 5

Calculation results of stress field with different pit depths

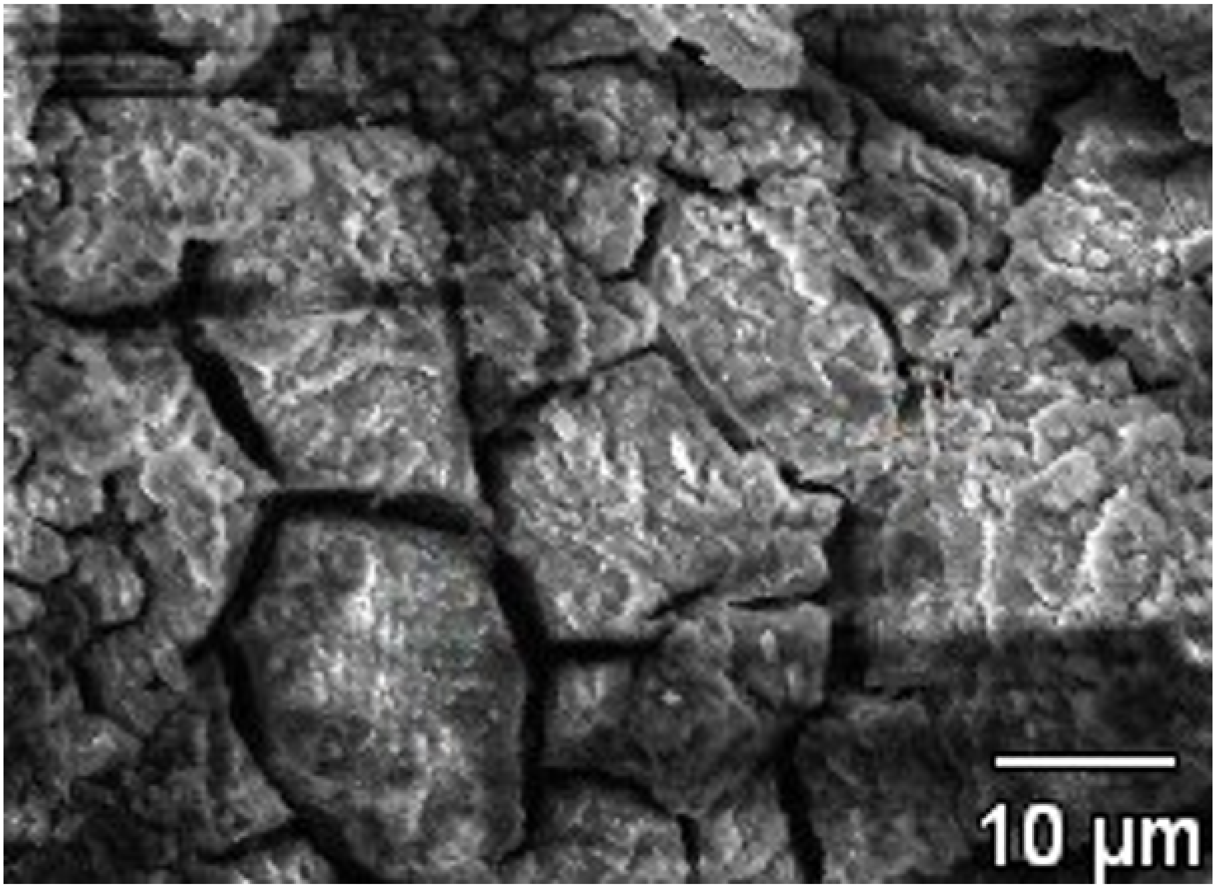
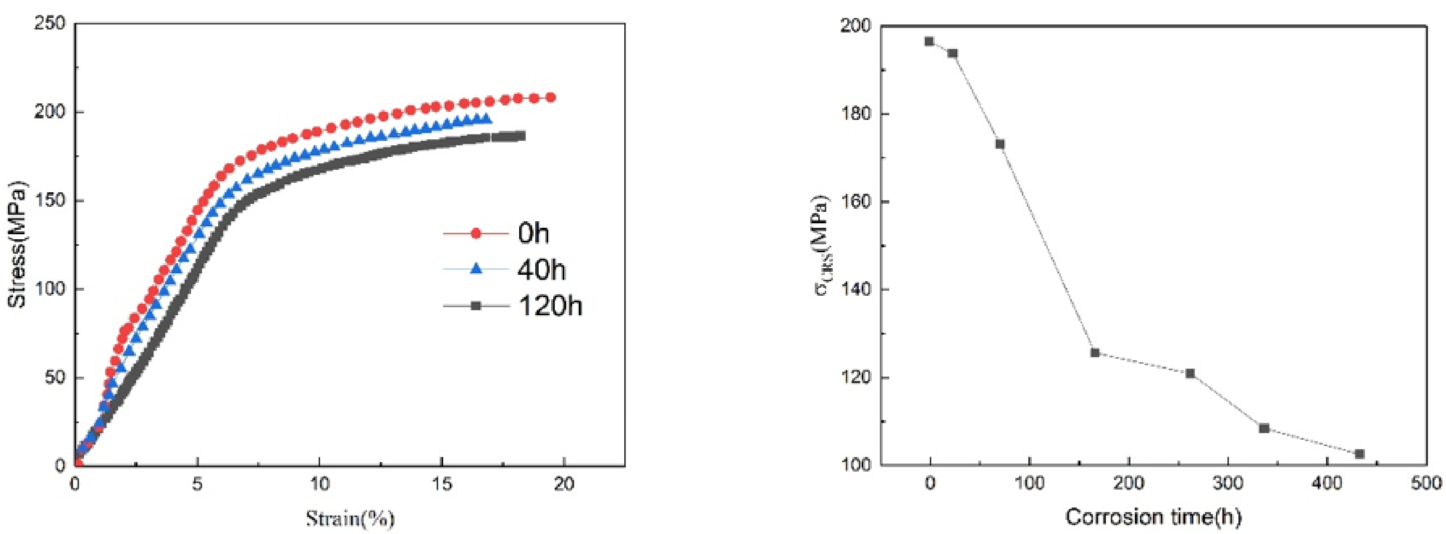


Figure 6

The crack extends into the matrix



(a) (b)

Figure 7

(a) stress-strain curve and (b) residual strength-corrosion time curve of magnesium alloy welded joints corroded in 3.5%NaCl solution for different times