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Study on Mechanical Properties of 6063 Aluminum Alloy Tube with Defects Under Impact Load

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Abstract. When aluminum alloy tube have defects, they may be damaged by lateral impact in practical applications. Based on the general finite element analysis software, the dynamic analysis and performance research on lateral impact of aluminum alloy tube with and without defects with different diameter to thickness ratios and impact velocities were conducted in this paper. The results show that aluminum alloy tube with defects have weak impact resistance and are prone to local damage. Reducing the diameter to thickness ratio of aluminum alloy tube can improve the impact resistance of the structure; when the impact speed is the same, due to large tensile deformation at the midspan defect, energy is locally absorbed by the defect, and the maximum midspan displacement of the tube with defects is smaller than that of the tube without defects; The larger the impact velocity is, the tube with and without defect reaches the mid-span displacement peak at the same time, but the displacement of the tube with defect enters the stable stage faster.

Keywords. aluminum alloy tube; Lateral impact; numerical simulation

1. Background

Aluminum alloy tube is an important tube widely used in industrial and civil fields, and is widely used for the transportation of gas, liquid, and other media. Defective aluminum alloy tube usually refer to defects that occur during the production, processing, or use of aluminum alloy tube. These defects may include cracks, dents, scratches, and other defects on the inner and outer surfaces. These defects will adversely affect the mechanical properties and service life of aluminum alloy tube. Liu Qiang[1] et al. studied the multiple impact response of aluminum alloy circular tube and the influence of characteristic parameters on the transformation of failure modes through a combination of experimental and simulation methods. Zhao Longlong[2] et al. studied the stress-strain relationship of aluminum alloy under uniaxial tension and used the Ramberg Osgood model to fit its tensile stress-strain relationship, indicating that the Ramberg Osgood model can well describe the constitutive relationship of domestic aluminum alloy.

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At present, there is relatively little research on the lateral impact and mechanical properties of aluminum alloy with defects at home and abroad, especially 6063 aluminum alloy, which is widely used. This article takes 6063 aluminum alloy pipes as the research object, and divides them into two groups: with defects and without defects. The defects are the collapse of the inner side of the pipe wall caused by non-standard production or long-term use. The dynamic response of 6063 aluminum alloy pipes under different impact speeds and different diameter thickness ratios is systematically studied, and the mechanical properties of the alloy under dynamic loads are discussed.

2. Finite Element Model

2.1 Establishment of Finite Element Model

In this paper, a finite element analysis model of 6063 aluminum alloy tube is established using the finite element software ABAQUS, as shown in Figure 1. The reduced integral three-dimensional 8-node solid element (C3D8R) was used in the finite element analysis process[3]. The model was divided into two groups, with and without defects, to study the effects of impact velocity and diameter thickness ratio on tube with defects. The components without defects are represented by 6063, and the components with defects are represented by F6063. The geometric dimensions and load parameters are shown in Table 1. D, d, t, and l represent the outer diameter, inner diameter, wall thickness, and length of the main tube, respectively.

Table 1. Geometric Dimensions and Load Parameters of 6063 Aluminum Alloy tube.

member	D/mm	d/mm	t/mm	l/mm	Hammer /kg	Velocity /(m/s)	D/t
6063-1	100	90	5	800	500	3	20
6063-2	100	80	10	800	500	3	10
6063-3	100	60	20	800	500	3	5
6063-4	100	90	5	800	500	3	20
6063-5	100	90	5	800	500	5	20
6063-6	100	90	5	800	500	7	20
F6063-1	100	90	5	800	500	3	20
F6063-2	100	80	10	800	500	3	10
F6063-3	100	60	20	800	500	3	5
F6063-4	100	90	5	800	500	3	20
F6063-5	100	90	5	800	500	5	20
F6063-6	100	90	5	800	500	7	20

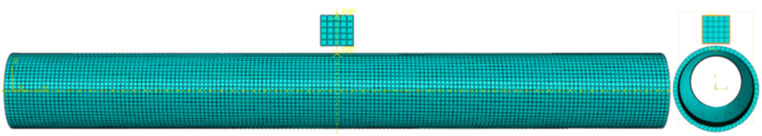

Figure 1. Finite Element Analysis Model of 6063 Aluminum Alloy.

2.2 Defect Modeling

The simulation of aluminum alloy defects in this article is to simulate the inner collapse of aluminum alloy caused by non-standard production processes or long-term use.The method is to use the "offset surface" function to excavate a portion of the inner side to form a collapsed structure, as shown in Figure 2.The collapse is located at the inner center of the lower part of the tube and directly below the impact point of the falling hammer. The collapse depth is 60% of the tube wall thickness t[9], and the pit length is taken as 100 mm along the tube length direction.

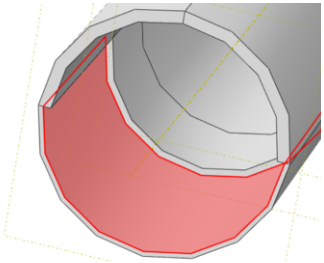

Figure 2. Defect Model.

2.3 Material Properties

The Ramberg Osgood model[2] is consistent with the constitutive relationship of domestic aluminum alloys, and its expression is:

$$\varepsilon = \frac{\sigma}{E} + 0.002\left(\frac{\sigma}{f_{0.2}}\right)^{n} \tag{1}$$

$$n = \frac{\ln 2}{\ln(f_{0.2}/f_{0.1})} \tag{2}$$

E is the elastic modulus; Is the stress corresponding to a non proportional elongation of 0.2%; Is the stress corresponding to a non proportional elongation of 0.1%. According to the calculation of the test results, it is obtained that $f_{0.1}$=174.56MPa,$f_{0.2}$=180.43MP[7], and substitute them into equation (2), n=21.45. Taking this into equation (1), it can be concluded that:

$$\varepsilon = \frac{\sigma}{61240} + 0.002\left(\frac{\sigma}{180.43}\right)^{21.45} \tag{3}$$

Calculate ε according to equation (3). The material density is 2800 kg/m ^ 3, the elastic modulus is 60.1 GPa, and the Poisson's ratio is 0.33. The cube discrete rigid body with a length, width, and height of 40 mm was used as a drop hammer, with a mass of 500 kg and impact velocities of 3 m/s, 5 m/s and 7 m/s[10].

2.4 Boundary Conditions, Interface Treatment, Load Application

The left and right sides of the tube are fully fixed and constrained, The degree of freedom of the drop weight division U2 is constrained, so that the drop hammer can only impact the tube vertically[11], as shown in Figure 3. Use surface to surface contact, and the friction is in the form of a penalty function[4]. Create a predefined speed field. Except for the speed v2 perpendicular to the tube direction, v1 and v3 are set to 0.

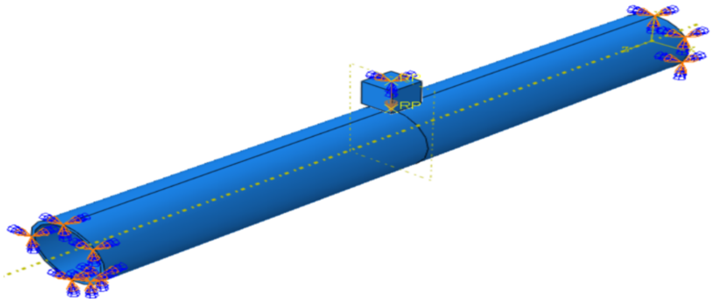

Figure 3. Boundary Condition Settings.

3.Finite Element Calculation Results

3.1 Failure Mode Analysis

Figure 4 and Figure 5 show the deformation diagrams of non defective and defective pipes at the final moment under the same impact load, impact speed, and different diameter to thickness ratios. The deformation of 6063-1 is mainly divided into two parts. One part is the collapse of the pipe at the falling point of the hammer and within a certain range around it, resulting in a reduction in the cross-sectional area of the pipe[12]. The other part is the contraction of the pipe bottom upward under the impact load. The deformation is the coupling of overall deformation and local deformation[5]. F6063-1 as the diameter to thickness ratio decreases, the local deformation around the impact point of the pipe body caused by the impact load increases, and the overall deformation is negligible. Therefore, with other factors unchanged, the larger the diameter to thickness ratio, the more easily the aluminum alloy pipe with defects to undergo local deformation. According to Table 2, the smaller the diameter to thickness ratio, the smaller the midspan displacement, and the smaller the peak stress. The midspan displacement and peak stress of pipes with defects are slightly larger than those of pipes without defects.

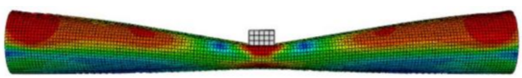

Figure 4. 6063-1

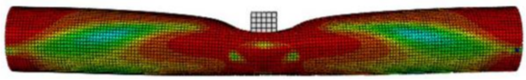

Figure 5. F6063-1

Table 2. Maximum displacement and stress at mid span

number	Maximum displacement	Peak stress
6061-1	61.02mm	196.41Mpa
6061-2	21.41mm	193.31Mpa
6063-3	10.70mm	189.80Mpa
F6063-1	61.73mm	200.00Mpa
F6063-2	22.26mm	195.33Mpa
F6063-3	11.97mm	190.07Mpa

Figure 6 and Figure 7 show the deformation diagrams of tube with and without defects at the final moment under the same impact load, the same diameter to thickness ratio, and different impact speeds. At the upper part of the tube, the stress at the fixed constraints at the left and right ends and at the center impact is the largest and produces significant tensile deformation. As the impact speed increases, the hammer gradually sinks into the tube body, and when the impact speed increases to a certain value, it will penetrate the tube body[6]. Compared to non defective tube, according to Table 3, the maximum displacement in the midspan of tube with defects is smaller than that of non defective tube, which is caused by large tensile deformation at the midspan defects and local absorption of energy by the defects.

Figure 6. 6063-6

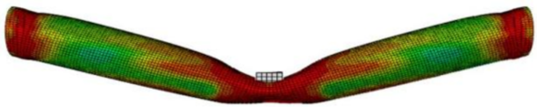

Figure 7. F6063-6

Table 3. Maximum displacement and stress at mid span

number	Maximum displacement	Peak stress
6063-4	61.02mm	196.41Mpa
6063-5	123.50mm	197.11Mpa
6063-6	189.74mm	200.00Mpa
F6063-4	61.73mm	200.00Mpa
F6063-5	108.02mm	200.00Mpa
F6063-6	179.93mm	200.00Mpa

3.2 Midspan Displacement Time History Curve

The midspan displacement variation of defect-free aluminum alloy tube with different diameter to thickness ratios is shown in Figure 8. When the diameter to thickness ratio D/t is 20, the maximum mid-span displacement is 61.02 mm, when the diameter to thickness ratio D/t is 10, it is 21.41 mm, and when the diameter to thickness ratio D/t is 5, it is 10.70 m. The variation of mid span deflection of aluminum alloy tube with defects with different diameter thickness ratios is shown in Figure 9. When the diameter thickness ratio D/t is 20, the maximum mid-span displacement is 61.73mm, when the diameter thickness ratio D/t is 10, it is 22.26mm, and when the diameter thickness ratio D/t is 5, it is 11.97m. When other conditions remain unchanged, the smaller the diameter to thickness ratio, the smaller the midspan displacement. Compared to defective tube, defected tube have greater midspan displacement and peak stress[7].

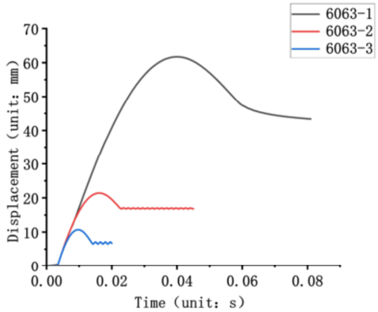

Figure 8. 6063 Impact data diagram.

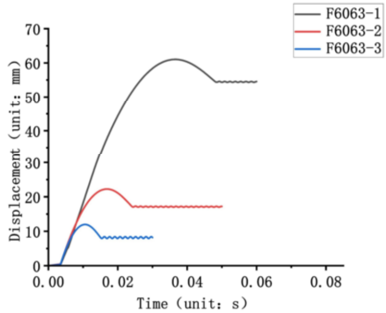

Figure 9. F6063 Impact data diagram.

The midspan displacement variation of defect-free aluminum alloy tube with different impact velocities is shown in Figure 10. When the impact velocity is 3 m/s,the maximum mid-span displacement is 61.02 mm, when the impact velocity is 5 m/s, it is 123.50 mm, and when the impact velocity is 7 m/s, it is 189.74 mm. The midspan deflection variation of aluminum alloy tube with defects at different impact speeds is shown in Figure 11. When the impact speed is 3 m/s, the maximum mid-span displacement is 61.73 mm, when the impact speed is 5 m/s, it is 108.02 mm, and when the impact speed is 7 m/s, it is 179.93 mm. When other conditions remain unchanged, the greater the impact velocity, the greater the midspan displacement[8]. Compared to tube with and without defects, both tube reach the peak midspan displacement at the same time, but the displacement of tube with defects enters the stable stage faster.

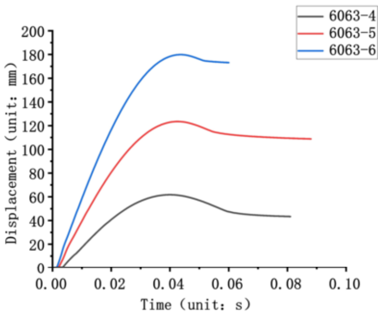

Figure 10. 6063 Impact data diagram.

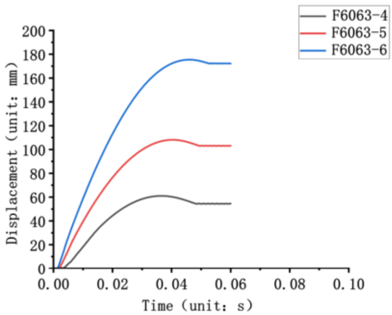

Figure 11. F6063 Impact data diagram.

4. Conclusion

1.When subjected to a lateral impact from the same object, when the diameter to thickness ratio of aluminum alloy tube is the same, the midspan displacement of defective tube is slightly greater than the midspan displacement of non defective tube. The non defective tube mainly undergo overall deformation, while the defective tube mainly undergo local deformation. Reducing the diameter to thickness ratio of aluminum alloy tube can improve the impact resistance of structures.

2.When subjected to a lateral impact from the same object, when the impact speed is the same, the maximum midspan displacement of the tube with defects is smaller than that of the tube without defects, which is caused by large tensile deformation at the midspan defects and the local absorption of energy by the defects.

3.The greater the impact velocity, the greater the midspan displacement. Compared to the defected tube, the defected tube and the defected tube reach the peak midspan displacement at the same time, but the defected tube displacement enters the stable stage faster.

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