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Simulation of Explosive Welding with Reasonable Gap Based on ALE Method

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ABSTRACT: *In order to study the range of reasonable gap of explosive welding composite pipe, using Arbitrary Lagrange Euler (ALE) method to carry out Finite Element Analysis of explosive welding composite pipe, and simulating the dynamic process of explosive welding composite pipe in different gaps. The results showed that the influence of the gap to the collision speed, collision pressure, and effective plastic strain were obvious. While the collision speed increases with the increase of the gap, the collision pressure decreases with the gap increases, and the effective plastic strain was increased with the increase of the gap. The lower limit of the gap should meet that the composite tube collision velocity greater than the minimum impact speed. Combined with empirical formulas and experiment, a reasonable gap that was given by the simulation results is 0.5mm-0.8mm for such composite pipe.*

Keywords: *Explosive welding; Al/Ti composite pipe; ALE method; gap*

I. INTRODUCTION

Explosive welding is a welding process that using high temperature, high pressure instantly generate from explosive detonation in a very short period of time to achieve a combination metal. Gap is an important parameter of explosive welding process. Chemical energy of explosives can not be directly supplied to the welding metal; the energy must be passing through the absorption, conversion, and distribution. Therefore, there is no gap, where can not be achieved between the explosive welding metals [1]. Many scholars demonstrated the importance of the gap from the test and theory, and given the empirical formula of gap [2, 3]. Since the explosive welding process with instantaneous and dangerous, there are some technical problems directly to test the process. But using computer simulation, not only can visually reflect the impact circumstances of explosive welding between the base pipe and flyer pipe, but also can reduce the number of tests, and reduce costs. So, it is an effective method to study the explosive welding process.

Currently, numerical simulation study on explosive welding have been reported, such as Akbari et al. simulated the explosion of a composite plate welding process by finite element software AUTODYN, used Willamsburg equation of state simulated different states of explosives in the reference [4,5]. In the reference [6], Grignon et al. simulated the different welding parameters aluminum welding using two-dimensional finite element method, and got the parameters law of the explosive direct combination interface. Ma bei established a three pipe explosive welding model using three-dimensional finite element and study the process of forming and welding quality problems under different gap in the reference [7].Huang Qin et al. described the use of LS-DYNA software to simulate the influence space and charge volume of the pipe explosive welding process in the reference [8]. However, the above references were limited to qualitative analysis, did not give a reasonable method to determine the size of the gap.

In this paper, on the basis of the establishment of the explosive welding composite pipe dimensional finite element model, the relationship between the different size of the gap and the dynamic composite pipe explosion welding process parameters were studied, and a range of composite pipe explosive welding gap was given. This provided an effective method to determine a reasonable composite pipe explosive welding gap.

II. THEORETICAL RANGE OF GAP

The material of base tube is titanium (TA2), and flyer tube is commercial purity aluminum (1060). And the basic performance parameters of Al tube and Ti tube are list in Table 1.

Table 1 Basic performance parameters of Al tube and Ti tube

Material	ρ(g.cm^{-3})	H_V(kg/mm^2)	σ_b(MPa)	melting point(°C)	Thickness (mm)
1060	2.71	72	143	660	1
TA2	4.51	160	560	1668	2

In explosive welding composite pipe, neither the theoretical formula method, nor test calculation method to determined the size of the gap between the base pipe and flyer pipe. Based on this situation, people in determining the size of the gap between the composite pipe, commonly used Ezra empirical formula to determine the gap of the explosive welding composite plate [2]:

$$d<5,\ h/3<S<2h/3 \quad (1)$$

Where: d is the density of flyer material, h is the thickness of the flyer material, S is the gap between the base pipe and flyer pipe.

Table 1 showed gravity and thickness of aluminum flyer tube is 2.71 and 1mm, therefore, the range of gap between the stainless steel base pipe and the aluminum flyer pipe is 0.33mm~0.67mm by the equation (1).

III. ALE SIMULATION IN DIFFERENT GAP AND RESULTS ANALYSIS

3.1 ALE simulation

Arbitrary Lagrange Euler method (ALE) was used to simulate the explosive welding. ALE is neither Euler with a fixed mesh nor Lagrange with the volume mesh, but a suitable mesh that every step of the construction material according to the boundary region and the next step can be calculated facilitate[9]. So this method has a strong advantage calculating the large deformation, while beneficial of observation and analysis the latter results.

A physical model was created using AUTODYN software. In order to save computer resources, to reduce the calculation time, the analysis of the object is 1/4 simplify model when modeling, taking into account the symmetry axis of the tube model. Fig. 1a is a model of the material, the outer layer titanium tube, which has 20mm diameter and 2mm thickness, the middle layer is an aluminum tube, which wall thickness has 1mm. Using the Johnson-Cook equation of state (JC-EOS)described the metal materials instantaneous strain process. Inner layer is emulsion explosive, and using Jones-Wilkins-Lee equation of state (JWL-EOS) described detonation process of explosive [10]. To facilitate the observation of simulation results, the interface combined position of tube were sampling, locations shown in Fig. 1b.

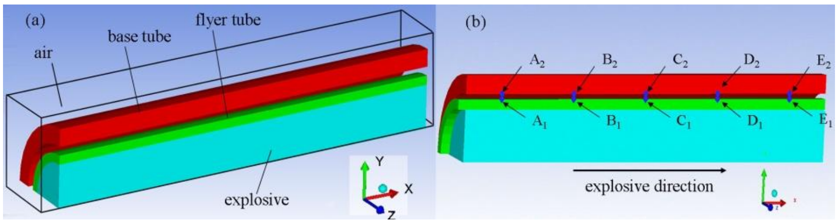

Figure 1 Simulation model (a) and sampling node location (b) combined position of tube

3.2 Numerical simulation

According to the empirical formula obtained from the first section, Gap ranges from 0.33mm~0.67mm. Given the convenience of numerical simulation, the value of gap expanded appropriately when using numerical simulation. And the value of gaps were 0.3mm, 0.4mm, 0.5mm, 0.6mm, 0.7mm, 0.8mm, 0.9mm, 1.0mm.

When the gap was 0.5mm, the traveled distance result of the composite pipe was shown in Fig. 2. It could visually be found the nodes A_1 and A_2, B_1 and B_2, C_1 and C_2, D_1 and D_2, E_1 and E_2, corresponding to the titanium tube and the aluminum tube, were moved by the radial explosive effect in Fig. 2a. And the movement distance difference of titanium tube and the aluminum tube was more than 0.5mm. It is indicates that the aluminum layer and the titanium layer has been welded together, that is the bonding interface of composite pipe welded successful and effective. It was confirmed that this model was reliable model.

It could be found plastic deformation effective occurred in the bonding interface of the aluminum layer with the titanium layer and explosive layer with aluminum layer, compared to the elastic deformation of the rest in Fig. 2b. This was further evidence of successful and effective bonding interface welding.

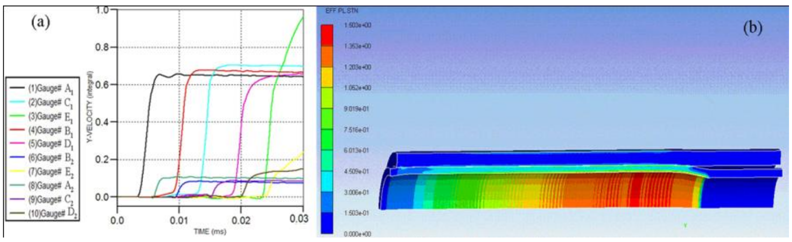

Figure 2 Simulation results of the value gap of 0.5mm (a) Movement distance of interface node (b) effective plastic strain of composite pipe

3.3. Results and Analysis

3.3.1The impact of gap on the collision velocity

It was gotten the collision flight speed of aluminum flyer tube under different gap by numerical simulation, and shown in Fig. 3. It could be found intuitively in graphics that, with the increase of gap distance, meaning that increase of flyer pipe distance to accelerate, collision velocity tube obtained also increase. Gap of 0.3mm, the speed of the aluminum node obtained about 300m/s; gap of 1mm, the speed of the aluminum flyer pipe nodes obtained about 500m/s. Meanwhile it could be found that collision velocity of the flyer pipe in the one same gap also increases along the direction of detonation.

According to calculated the material properties of the metal "weld-ability window", minimum collision speed (v_{pmin}) could be represented by the formula in [11]:

$$v_{p\min} = K\sqrt{H_V / \rho_f} \quad (2)$$

Where: K is a constant value between 0.6~1.2; H_V is the material Vickers Hardness of the flyer pipe; ρ_f is material density of the flyer pipe. The H_V andρ_f of aluminum were substituted into the equation (2) and K take 0.7. It could be calculated that the v_{pmin} was 360m/s, which reliably welded required.

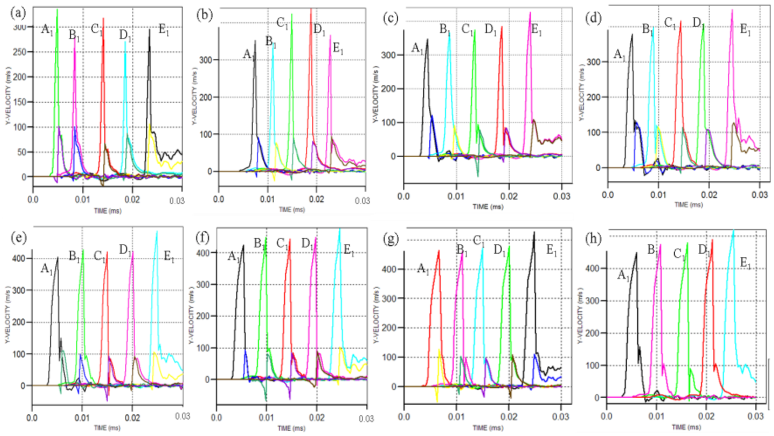

Figure 3 Collision speed of composite pipe under different gap (a)0.3mm gap (b)0.4mm gap (c)0.5mm gap (c)0.6mm gap (e)0.7mm gap (f)0.8mm gap (g)0.9mm gap (h)1mm gap

According to the shown of Fig. 3(a), the flight speed of flyer tube was less than the minimum impact speed 360m/s, when the value gap is the 0.3m, did not meet the speed requirements of explosive welding, and would be lead to weld failure. The speed of the nodes A1 and B1 of flyer tube was less than 360m/s, when the value gap is the 0.4m, was shown in Fig. 3(b), and also would be lead to weld failure. Therefore, the value of gap should be greater than 0.4mm.

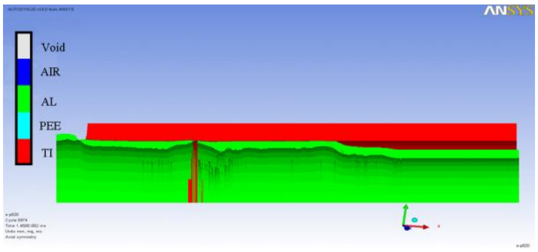

Figure 4 Situation of rupture of flyer tube

According to the shown of Fig. 3(g) and 3(h), the flight speed of flyer tube was greatly exceeded the minimum impact speed 360m/s when the value gap were the 0.9mm and 1mm. Fig. 4 showed that the rupture of flyer tube was occurred in the process of explosive welding when the value gap was the 0.9mm. This is because under the powerful force of explosive detonation, the distance of the outward expansion of aluminum was increased when the gap became large; wall thickness of the tubes was getting thinner, more than its limit; and aluminum pipe would be brook down.

In summary, according to the requirements of critical flight speed of flyer layer and of rupture limit of aluminum material, it could be inferred the range of the gap should be between 0.5~0.8mm.

3.3.2 The impact of gap on the collision pressure

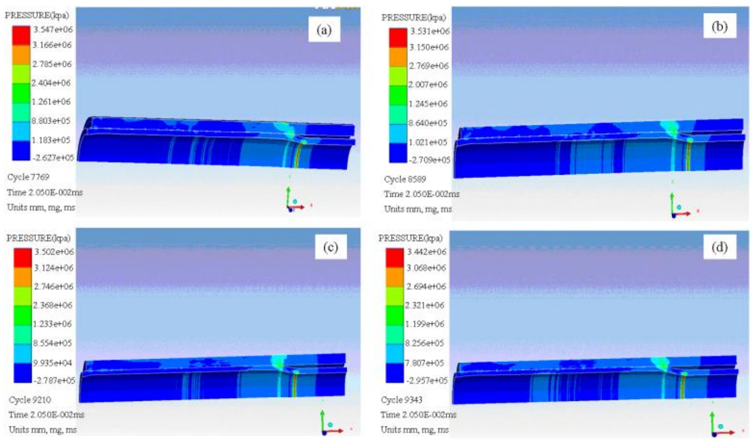

Figure 5 Pressure of composite pipe under different gap (a) 0.5 mm gap (b) 0.6 mm gap (c) 0.7 mm gap (d) 0.8mm gap

It was gotten the collision pressure of pipe under different gap that 0.5mm, 0.6mm, 0.7mm, 0.8mm by numerical simulation in 20.5μs, and shown in Fig. 5.

It could be found that maximum pressure occurred in the position of collision interface of the composite pipe, while the gap increased, the peak pressure was gradually reduced, but the reduction amount was less. It was analyzed that substantially pressure pulse of flyer tube obtained from the explosive detonation was the same instant in the difference distance of gap, and then decreased with increasing time. The time to drive the flyer tube was required accordingly increasing with the increase of gap distance. When the base tube and flyer tube were collided, the pressure was reduced accordingly. Simultaneously, due to the time that accelerated flyer pipe was very short, reduce the amount of collision pressure was little.

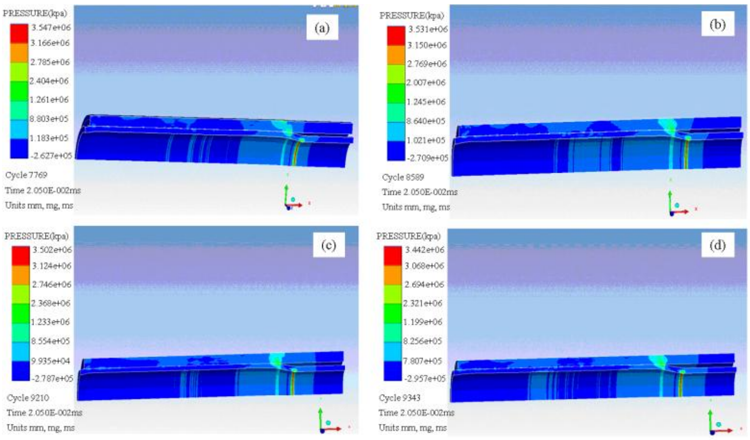

Figure 5 Pressure of composite pipe under different gap (a) 0.5 mm gap (b) 0.6 mm gap (c) 0.7 mm gap (d) 0.8mm gap

3.3.3 The impact of gap on the effective plastic strain

In the explosive welding process, the bonding interface metal plastic strain is the reason and the necessary conditions to achieve succeed welding[1]. It was gotten the effective plastic strain of composite pipe under different gap that 0.5mm, 0.6mm, 0.7mm, 0.8mm by numerical simulation in 20.5μs, and shown in Fig. 6.

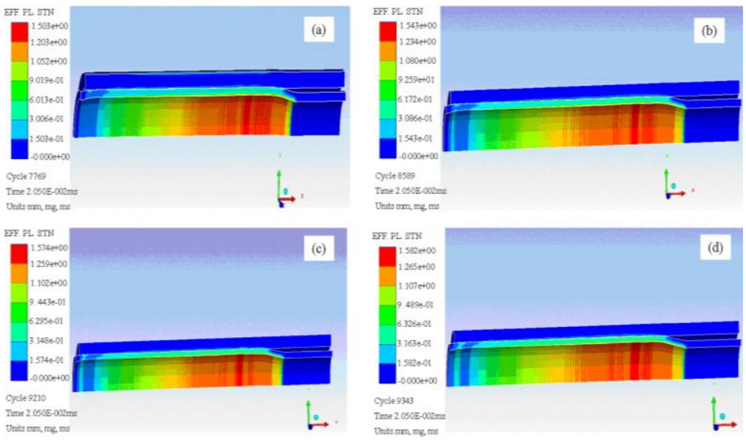

Figure 6 Effective plastic strain of composite pipe under different gap(a) 0.5 mm gap (b) 0.6 mm gap (c) 0.7 mm gap (d)0.8mm gap

It could be found that the areas of large plastic deformation were mainly concentrated in the interface of flyer tube in contact with the base tube and interface with explosives in contact with flyer tube. As the detonation process, the plastic strain at the interface had an increasing trend along the detonation direction. The gap larger, the effective plastic strain at the interface was greater. It was analyzed that the gap larger, the distance that accelerated the flyer tube by the explosive detonation would be greater. The speed and the collision energy of the flyer pipe would be greater. That would be lead to an increased effective plastic strain inevitably.

IV. EXPERIMENT

According to simulation results of a gap in the range 0.5~0.8mm, it was carried out 5 group experiments for each gap using the experiment method was used in [12], as shown in Fig. 7.

Figure 7 Composite tube of Al/Ti

Any composite tube sample was taken from each group carried out analysis. After intercepting the middle of the sample, the scanning electron microscope (SEM) was conducted. According to the SEM image of the sample was found as Fig. 8, combined bonding interface was wavy, and there were no gaps and voids of the bonding interface microscopic defects. It was suggested that those were good composite pipe welding following those gaps.

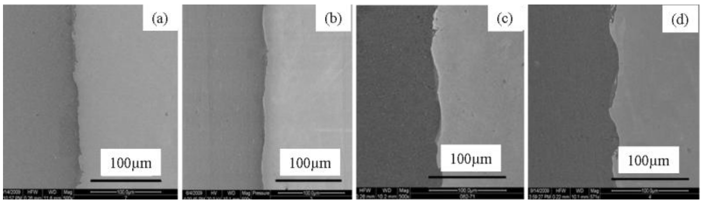

Figure 8 SEM Morphology of Al/Ti composite pipe under different gap (a) 0.5 mm gap (b) 0.6 mm gap (c) 0.7 mm gap (d) 0.8mm gap

To demonstrate the rationality of 0.5~0.8mm gap more, from the view of the mechanical properties of the composite pipe, the quality of the combines of the extracted samples was studied. Fig. 9 was the picture of the mechanical properties test of the sample. It was carried out compression test, flattening test and bending test. Any division phenomenon of composite pipe joint surface did not occur. From the above tests shown that composite pipe in range gap of 0.5~0.8mm can achieve good quality welding.

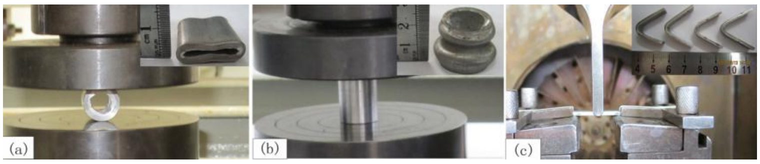

Figure 9 Mechanical properties test and result of the sample (a) flattening test and result (b) compression test and result(c) bending test and result

V. CONCLUSION

Numerical simulation can accurately simulate the whole dynamics process of composite pipe explosive welding. The value of the gap has an important influence on collision speed, collision pressure and effective plastic deformation of composite pipe. The reasonable range of the gap should be between 0.5~0.8mm when the density of flyer material was less than 5g/cm3.

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