Numerical simulation and experimental results on the composite process of electromagnetic and electro-hydraulic tube forming

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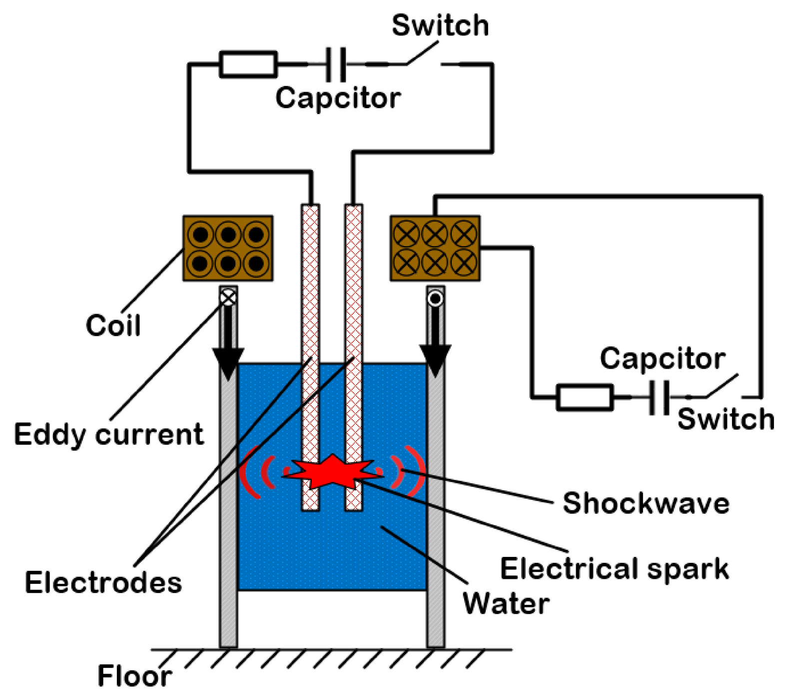
Introduction

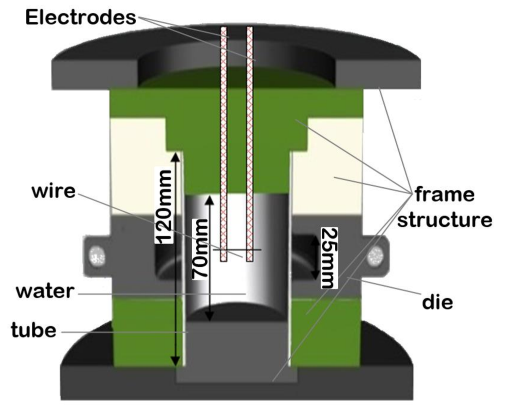
Electro-hydraulic forming (EHF) and electromagnetic forming (EMF) are two common high speed forming processes. However, the EHF is difficult to realize the deep drawing of tube due to the problem of thinning and cracking.
In order to further improve the formability of tube, this paper designs the magnet system and introduces axial Lorentz force to promote material flow in the EHF process. Specifically, this is achieved by placing a electromagnetic coil on the upper end of tube and combining axial and radial bidirectional pulse forces.



Schematic diagram of New proposed process

Experimental Setup and numerical model

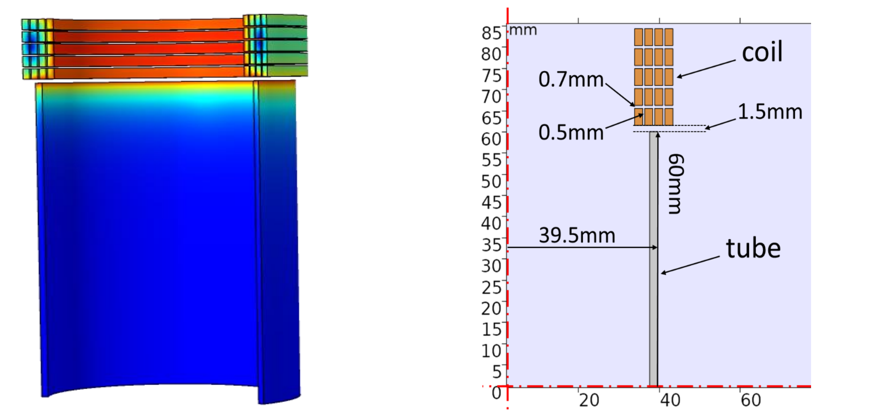
- Adopt 6061 annealed aluminum tube, diameter d=79 mm, height h=120 mm, thickness t=2 mm.
- The coil and electrodes Respectively connect with 3200 μF and 150 μF capacitors. Two switches are connected by the Timing control system.
- The numerical model is established by COMSOL. The 4*5 turns coil is wound by 2 mm*4 mm copper wire.



a) Mechanical structure


b) Experimental setup

Motivation of axial Lorentz force assisted EHF study:
- To design a magnet system to generate axial Lorentz force matching the EHF process.
- To enhance the material flow, suppress the thinning of the tube wall and improve the formability of the tube.
- To control the forming behavior and morphology.



c) COMSOL model for electromagnetic coil system

Results and discussion

1. EHF parameters and Axial electromagnetic force results

(Fig.1) In the experiment(EHF voltage U_1=6.5 kV), The pulse width is 60 μs. There will be a reverse voltage of the explosion voltage, which is about 1.5 kV.

(Fig.2) On the one hand, the peak moment of axial electromagnetic force is about 405 μs, which can meet the needs of EHF process. On the other hand, the maximum electromagnetic force is more than 100 kN and the maximum magnetic pressure is 214 MPa, which far exceeds the yield strength of the tube and meets the axial electromagnetic force required in the new proposed process.

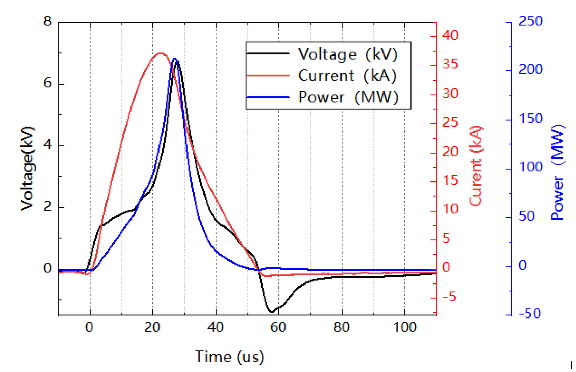


Fig.1 Voltage, current and power curve versus time in EHF process

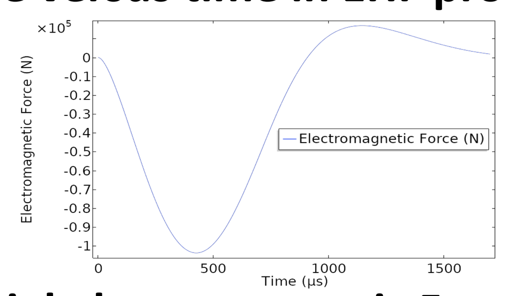
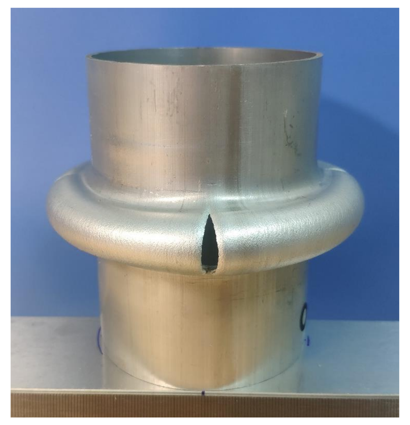


Fig.2 Axial electromagnetic Force curve versus time in New proposed process

2. forming results

1) Conventional EHF process


Case 1: U_1=6 kV
Maximum diameter : 104.7 mm
Axial deformation : 10 mm


Case 2: U_1=7 kV
Maximum diameter : 106 mm
Axial deformation : 13 mm

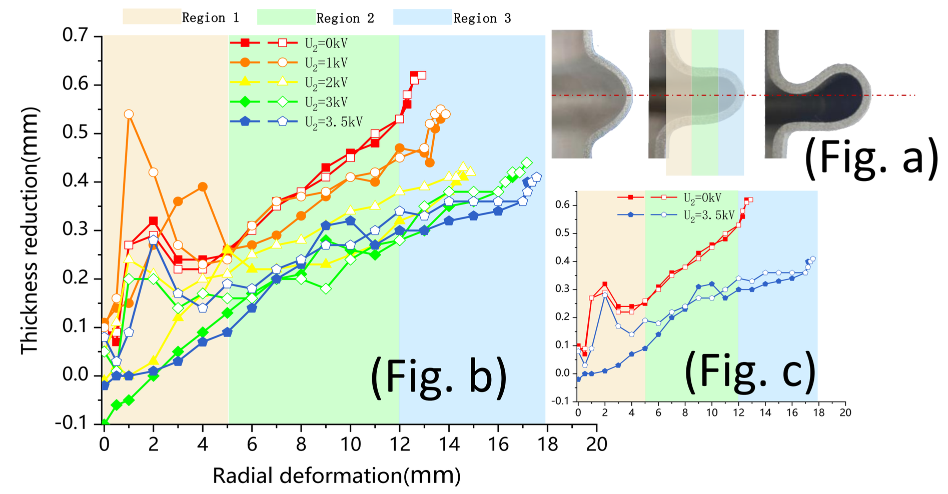
2) Proposed process: EHF voltage U_1: 6 kV


Case 3: U_2=1 kV
Maximum diameter : 106.7 mm
Axial deformation : 13.3 mm


Case 4: U_2=3.5 kV
Maximum diameter : 114 mm
Axial deformation : 31.2 mm

Results:
- Case 2: When EHF voltage U_1=7 kV, the forming limit was exceeded and the tube cracking. It can be predicted that the maximum diameter by Conventional EHF process is about 106mm, and the axial deformation is 13 mm.
- Comparing Case 1 and Case 4: When The EHF voltage U_1 =6 kV, the Maximum diameter increased about 34% , and the Axial deformation improved 21.2 mm by adding the coil with discharge voltage of 3.5 kV.
- Comparing Case 2 and Case 3: The Maximum diameter was the same, 106 mm. The cracking occurred in conventional EHF process, while the axial material deformation in the proposed process increased by 0.3 mm and cracking didn't occur.
- Comparing Case 2 and Case 4: The limit of the forming diameter can be improved at least 25% with the proposed method.

3. Thickness reduction and morphology control



a) Morphology and Region division of forming area
b , c) The distribution of thickness reduction with Radial deformation

- (Fig.a) The EHF voltage U_1 =6 kV and the coil voltage U_2 =1~4 kV. The forming area was divided into three Regions in the radial direction and two parts of upper and lower. The worst thinning is at the position of largest radial deformation.
- (Fig.b,c) The thickness reduction could be effectively restrained in the whole forming area, especially on the upper part. At the thinnest position, Thickness reduction was reduced by 32%.

Conclusion

- 1) We developed a magnet system, which can generate axial Lorentz force with enough strength and proper pulsed width matching the EHF process.
- 2) With the proposed method, the axial deformation can be effectively improved by increasing the axial Lorentz force, thereby increasing the radial bulging limit of the tube and effectively suppressing the thinning of the tube wall.
- 3) The proposed method can control the forming behavior of the tube, and the desired shape of the workpiece can be obtained by adjusting the voltage combination.