Experimental Analysis of the Interference-Fit Joining of Aluminium Tubes by Electromagnetic Forming

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I. INTRODUCTION

Electromagnetic joining of tubular profiles with high electrical conductivity is an effective and affordable alternative to conventional joining processes based on mechanical fixtures, strctural adesives, welding and mechanical crimping in presses with die/punch tools. This technology works at room temperature, allows joining dissimilar materials and offers potential to foster new applications in the assembly of lightweight tubular frame structures and recently in superconductivity applications.This work investigates the main parameters influencing the joint strenght.

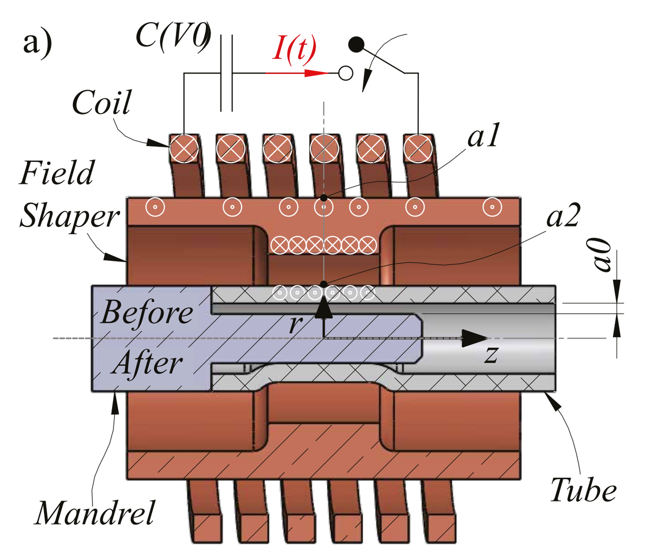
II. OBJECTIVES

Investigate the interference-fit joining of tubes by electromagnetic forming in terms of major process parameters with the aim of identifying their influence on the overall strength of the joints and establish design principles and the useful range of process operating conditions.

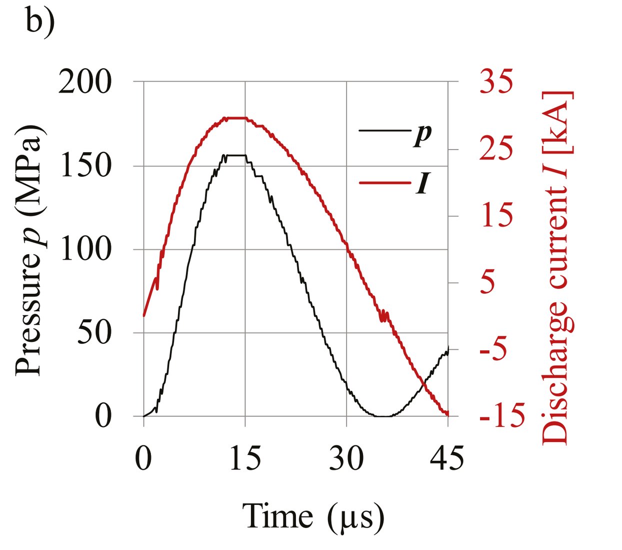
III. JOINING BY ELECTROMAGNETIC FORMING

The joining by electromagnetic forming (EMF) is a high speed manufacturing process which uses the energy density of a transient magnetic field in order to apply a magnetic pressure and radially compress metallic tubes with high electrical conductivity against a mandrel. The EMF system consists of a capacitive pulse power generator, an exchangeable tool coil and the parts to be joined, Fig 1. In general, a tool named field shaper is used to setup in order to shape and concentrate the magnetic field to a specific area of the tube.

a)



b)



$$p(t) = \frac{1}{2}\mu\left[\frac{n}{l_c} I(t)\right]^2 \left[c_H\right]^2$$

$$c_H = B(a_2)/B(a_1)$$

IV. INTERFERENCE-FIT JOINING BY EMF

Interference-fit joints are based on the elasto-plastic interference between joining parts. The mechanical parameters are the remaining residual stress on the mandrel, the joining area and its shape, and the interfacial friction coefficient between tube and mandrel.

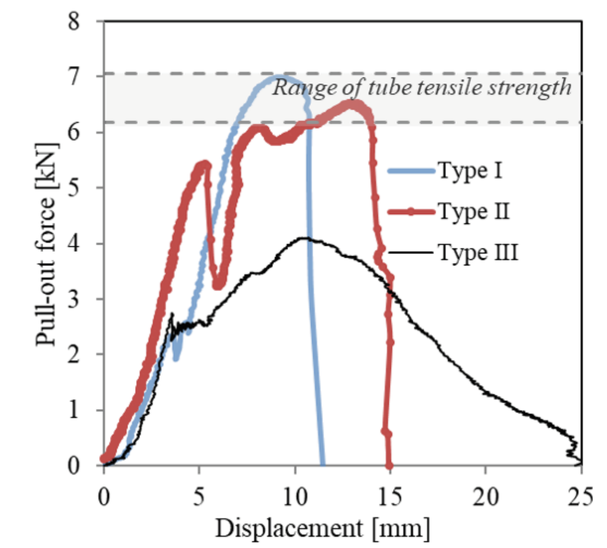
The mechanical parameters are related in a very complex way with electromagnetic compression process parameters, starting with the discharge energy and the magnetic pressure pulse that forming process, the initial gap between the joining parts, the material components and geometry, the shape and surface roughness of the mandrel.

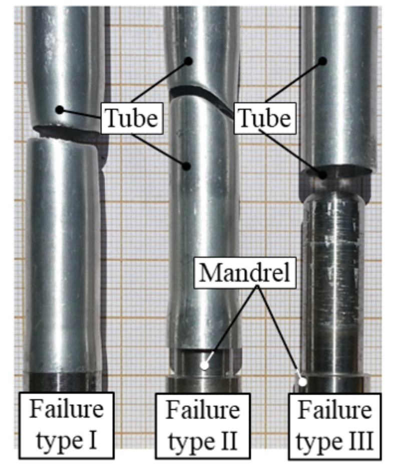
Regarding the EMF parameters:

- the interference stress on the contact interface is also dependent on the impact velocity and mass of the tube being compressed;
- the initial gap represents the available distance for the tube undergoing acceleration and deceleration, exerting a crucial influence on the joint strength;
- increasing the capacitor charging energy increases the magnetic pressure pulse and the constriction speed of the tube wall, so it is important to balance the ratio between the energy pulse and the initial gap in a way that the tube impact velocity reaches the largest value as possible.

The mechanical strength of the interference-fit joints is assessed through pull-out test (a tensile load test) and the maximum load for which the joint fails is called the pull-out force. Literature reports three characteristics types of force vs. displacement in pull-out tests of interference-fit joints between metalic tubes and mandrels:

- type I with maximum rigidity and pull-out force equal to the own tube rupture;
- type II with variable rigidity and pull-out force with tube rupture;
- type III with lowest rigidity and pull-out force with complete separation between tube and mandrel.





IV. MANUFACTURING AND TESTING OF JOINTS

Tube and Mandrel Preparation

AA6082-O tubes were joined on mandrels made of AISI 1045, AA6082-O and AA6082-T6 with different surface roughness.

The outter diameter of the tube was equal to 15 mm with a wall thickness of 1 mm.

The Initial gap between tube and madrel ranged from 0.025 up to 1.5 mm and nominal joint axial lengths varied in 8, 12 and 16 mm.

EMF System

EMF machine: Poyting GmbH SMU1500LC with C=60 µF and max. energy of 1.5 kJ.

Coil: Poynting GmbH SMU-K40-12/30.

Field shapers: in-house manufactured, made from electorlytic copper featuring one axial slot of 0.2 mm width and with effective axial lengths l' of 8, 12 and 16 mm.

Materials and Joints Characterization

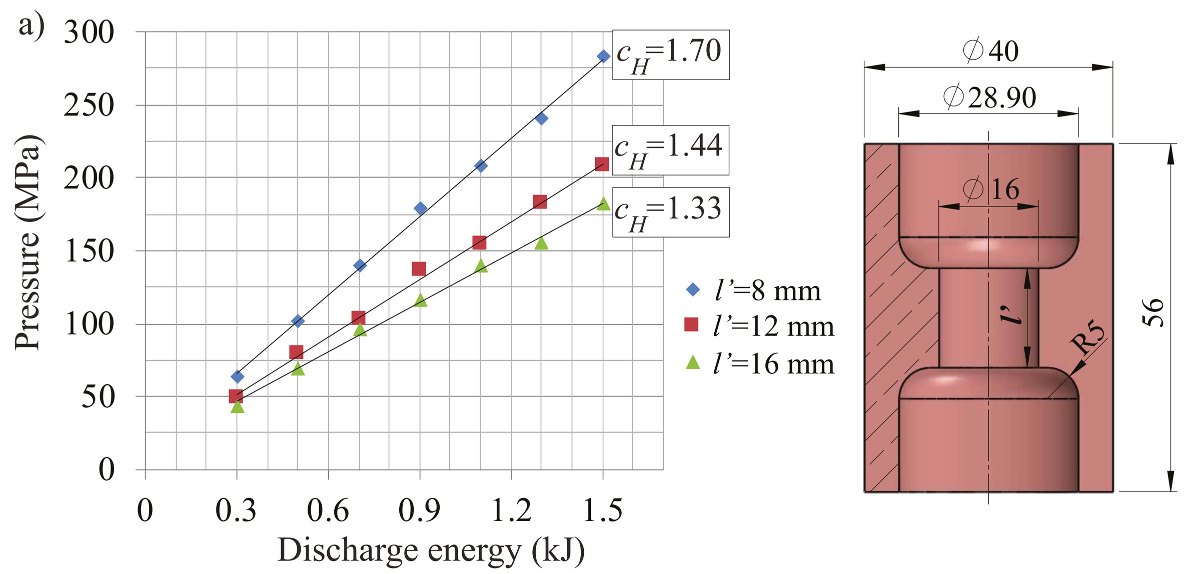
Tensile load tests performed with a Gump WP300 (20 kN) and a LCH-20 United Digital Speedy Tester Machine (89 kN). The pull-out force was measured and compared against the strength of the aluminium AA6082-O tube as reference.

MECHANICAL PROPERTIES OF THE SELECTED MATERIALS

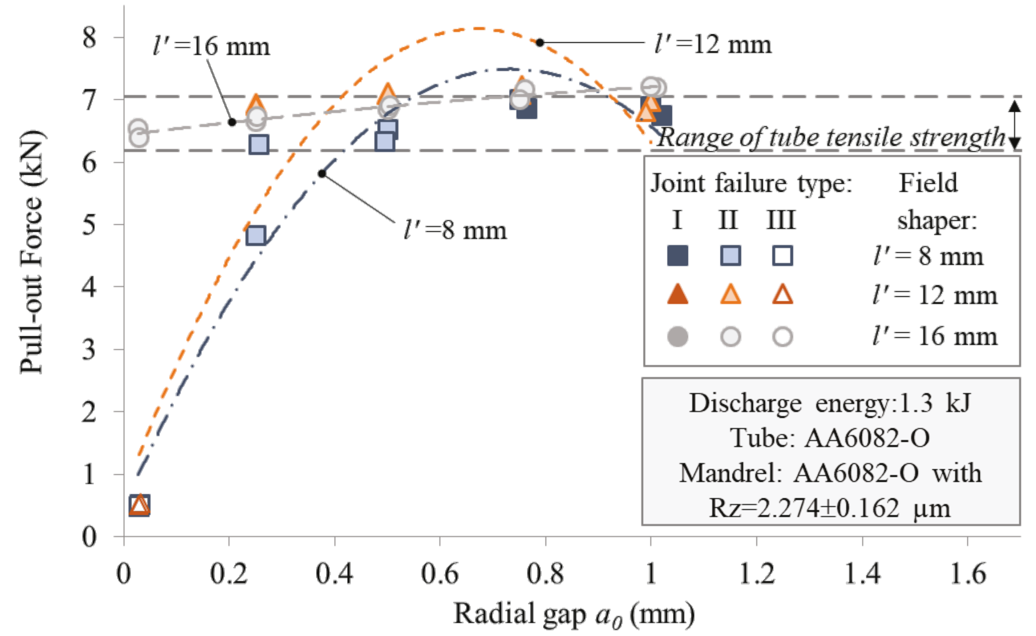
Material	Yield Strength (MPa)	Young Modulus (GPa)
AA6082-O	127	70
AA6082-T6	310	70
AISI 1045	560	205

V. RESULTS

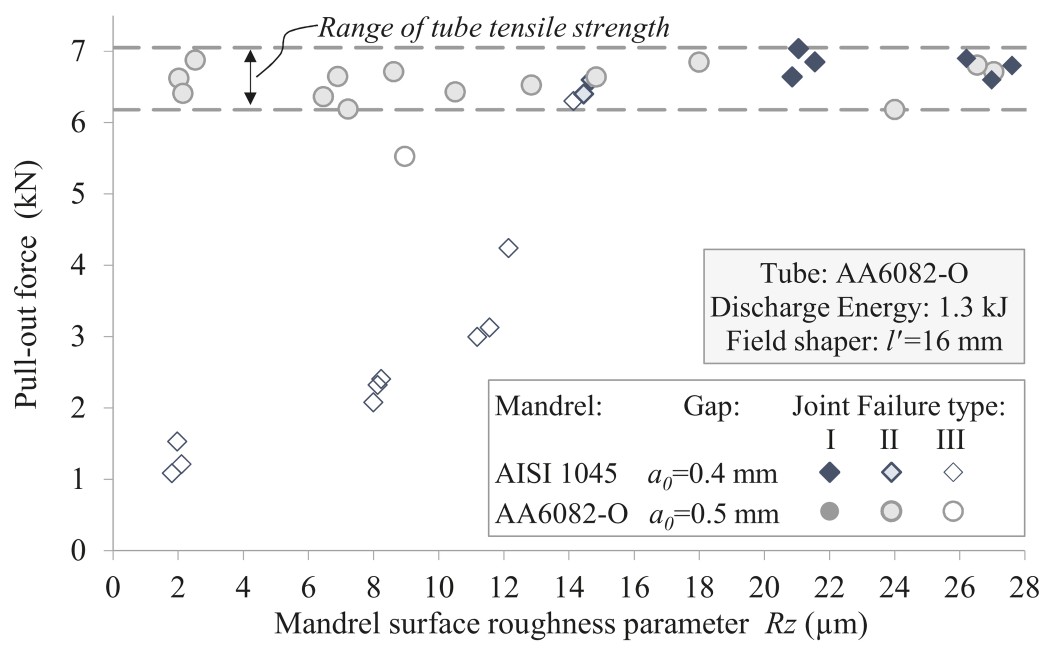
Field Shaper Characterization



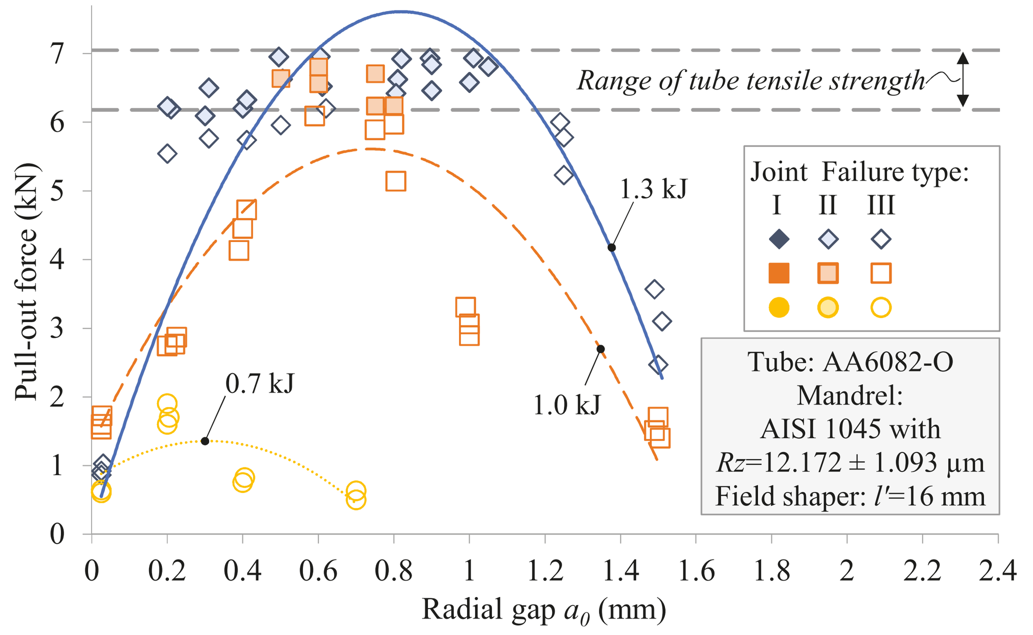
Field Shaper Effective Axial Length l'



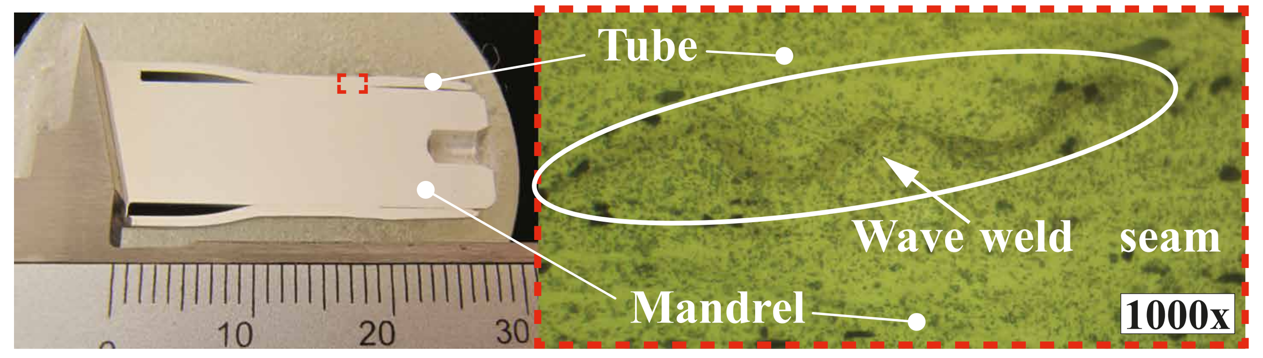
Mandrel Surface Roughness



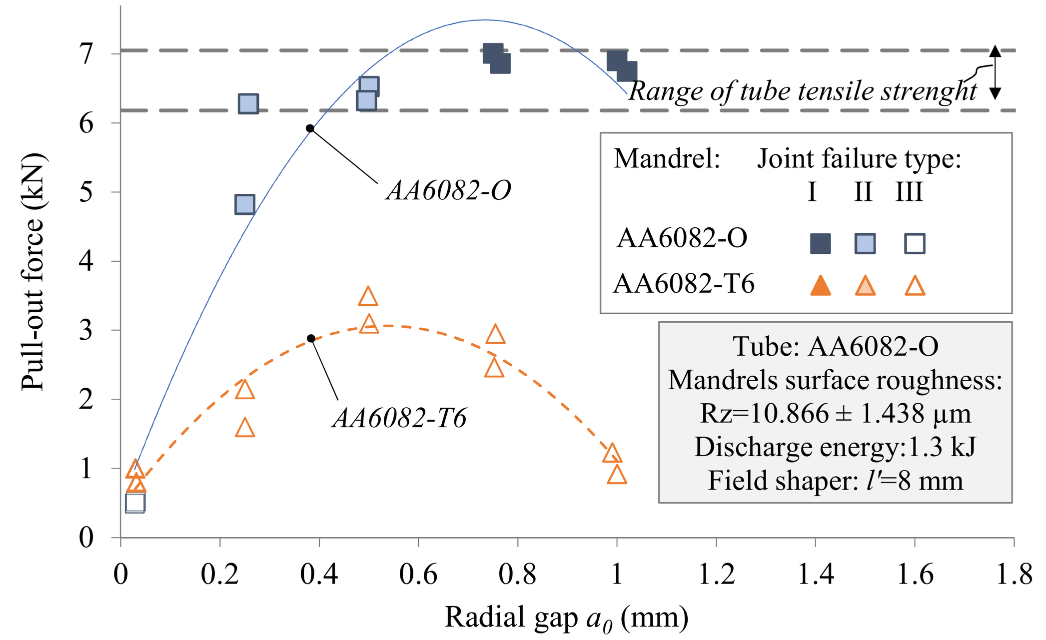
Discharge Energy and Initial Gap Between Joining Partners



Occurrence of impact welded joint with field shaper of l'= 8mm, a discharge energy equal to 1.3 kJ and an initial gap $a0$= 0.75mm.



Mandrel Material Condition



VI. CONCLUSIONS

The strength of interference-fit joining AA6082-O tubes produced by EMF was studied considering the influence of process parameters. The process main parameters were analyzed in a gradual manner, regarding the initial gap between joining tube and mandrel, the discharge energy, the field shaper effective axial length and mandrel material and surface conditions.

Results demonstrate that the joint strength and failure characteristics are strongly influenced by the aforementioned parameters. As new contribution, it was presented that the joint strength can be improved by altering other process parameters like the mandrel surface roughness and the field shaper effective axial length (concentration factor) while keeping constant a specific initial gap value and the discharge energy level constant, as demonstrated for the case of AA6082-O tubes joints with mandrels made of AISI 1045. For the case of joints with AA6082-T6 mandrels the highest joint strength was achieved by using the field shaper of an effective axial length equal to 8 mm, which was able to produce an impact welded joint.

For future works it is suggested to extend the parameter analysis considering other materials and measurement of the tube constriction velocity, its correlation with the pressure pulse and how it influences on the overall joint quality and strength.

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