

A FEM Study of Explosive Welding of Double Layer Tubes

R. Alipour, F.Najarian

Abstract—Explosive welding is a process which uses explosive detonation to move the flyer plate material into the base material to produce a solid state joint. Experimental tests have been carried out by other researchers; have been considered to explosively welded aluminium 7039 and steel 4340 tubes in one step. The tests have been done using various stand-off distances and explosive ratios. Various interface geometries have been obtained from these experiments. In this paper, all the experiments carried out were simulated using the finite element method. The flyer plate and collision velocities obtained from the analysis were validated by the pin-measurement experiments. The numerical results showed that very high localized plastic deformation produced at the bond interface. The Ls_dyna_971 FEM has been used for all simulation process.

Keywords—Explosive Welding, Johnson-Cook Equation, Finite Element, JWL Equation.

I. INTRODUCTION

EXPLOSIVE welding is an area of study that represents a truly multidisciplinary research as it deals with the dynamics of collision at high velocities and pressures, the transient fluid like behaviour of metals at extremely high strain rates, metallurgical and other physical aspects of colliding metals, modelling of material behaviour, sources of high rate energy and the geometrical parameters of colliding system of metals.

To analyze the process, the hydrodynamic analogy was used by various authors [1, 2, and 3] due to the creation of the high localized pressure and the material fluid like behaviour at the collision zone. The process parameters are the impact velocity, the collision point velocity, the angle, the stand-off distance, the type of the explosive used and the detonation velocity, density and size and distributions of the explosive mix. Welding windows were proposed to show the weld ability ranges of process parameters i.e. impact velocity (or collision point velocity) versus the dynamic angle for various materials [3, 4, 5, and 6]. Nevertheless, the data were obtained by means of large number of experiments performed. However, the process could be simulated using the finite element method and most aspects of the welding process

could be obtained. Few attempts have been reported in the literature to simulate the process. Al-Hassani [7] treated the problem as a normal transient loading of plane stress elements of rectangular shape. In this analysis, cinematically equivalent concentrated loads at the nodes represented the uniformly distributed explosive load. Explosive welding process was simulated by Oberg [8] by means of Lagrangian finite Element computer code, but only produced jetting. The explosive welding process was also modeled by Akihisa [9]. He only produced waves but no jetting. In addition, the author assumed that symmetric or asymmetric shear flow distribution was generated in the flyer and parent plates and the modeling was performed based on this supposition.

II. GENERAL SPECIFICATION

Experimental tests have been performed to explosively welded aluminium 7039 and stainless steel 4340 tubes in one step. The welded tubes had an external diameter of 135mm and internal diameter of 123mm. The outer layer was made of 4340 steel, with the external diameter of 135 and thickness of 4.5mm. The inner tube was made of Al-7039 with 5mm thickness.

The tests have been done using various stand-off distances and explosive ratios. Various interface geometries have been obtained from these experiments. The explosive material was positioned inside the inner tube.

In this investigation, all the experiments were simulated using the finite element method. The JWL equation of state was used to describe the behavior of explosive. The JWL equation of state has been developed for high explosive burn materials. The explosive properties used were tabulated in Table 1. These equations were coded into the FEM software. The JWL equation was described as:

$$P = C_1 \left(1 - \frac{\omega}{r_1}\right) e^{-r_1 v_1} + C_2 \left(1 - \frac{\omega}{r_2}\right) e^{-r_2 v_2} + \frac{\omega \psi}{V} \quad (1)$$

Where C_1 , C_2 , r_1 , r_2 and ω are the constants of JWL equation. V is the ratio of the volume of the product gases to initial volume of undetonated explosive. The constant is given in Table 1 for the PETN used in this investigation [10].

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TABLE I
 THE JWL CONSTANTS EQUATION OF PETAN

Charge Type	C_1 (Gpa)	C_2 (Gpa)	r_1	r_2	ω
PETN	1032.158	90.57014	6	2.6	0.57

The Johnson-Cook constitutive equations were used to model the behaviour of tubes. The Johnson-Cook equations were described as:

$$\sigma = (A + B \varepsilon^n)(1 + C \ln \dot{\varepsilon}_p)(1 - T^{*m}) \quad (2)$$

Where ε is equivalent plastic strain, $\dot{\varepsilon}_p$ is plastic strain rate for $\varepsilon_0 = 1$, that T is absolute temperature for $T^* = \frac{T - T_{room}}{T_{melt} - T_{room}}$ and A, B, C, n, m are constants. Constants in this equations is obtained from simple mechanical tests such as isothermal tension and torsion tests, that is given in Table 2 for the materials used in this study.

TABLE I

THE JOHNSON-COOK EQUATION PARAMETERS FOR A7039 AND 4340 STEEL

Material	A(Mpa)	B(Mpa)	C	n	m	T° (melt)
7039 Al	336.46	342.66	0.01	0.41	1	933
4340 St	792.19	509.51	0.014	0.26	1.03	1793

Quadratic elements were used in the simulations with the adaptive meshing techniques. LAGRANGIAN formulations were used to model the explosive and materials. The proper contact mechanisms were used between the inner and outer tubes.

III. RESULTS AND DISCUSSION

The effects of process parameters (stand-off distances and explosive ratios) on the physical parameters such as pressure, plastic strain, shear stress and impact velocity at the collision zone were investigated. Typical simulation of the process at an elapsed time of 30 μ s for the stand-off distance of 6mm between Al-7039 and 4340 steel was shown in Figure 1.

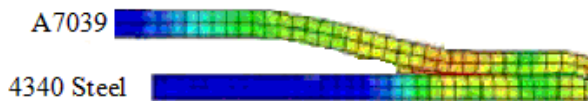


Fig. 1 Typical simulation of explosive welding of double layer tubes during the welding process ($t=30\mu$ s) for the stand-off distance of 6mm between AL-7039 and 4340steel tubes

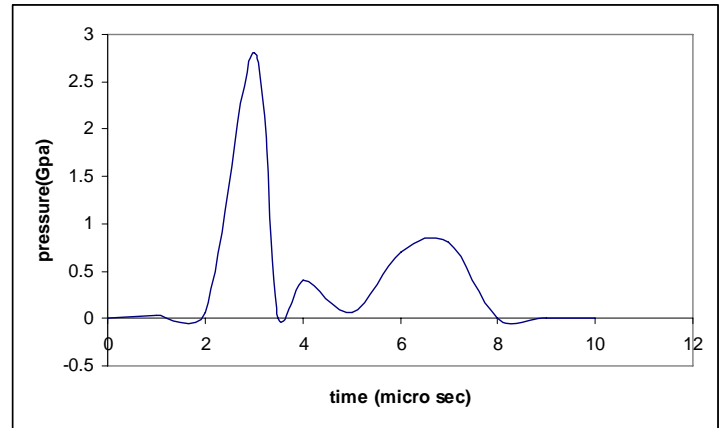


Fig. 2 Typical pressure profiles for the 6mm stand-off between the 4340 steel and A7039 tubes

The highest pressures occur at the collision point. The typical pressure-time variations for the 6mm stand-off distance between the 4340steel and A7039 tubes at an elapsed time of 10 μ s were depicted in Figure 2. Simulation results also showed that the value of the plastic strain was reached to its maximum at the collision point. Comparison of the experiments with the simulations showed that the value of the plastic strain had to be more than a minimum value in order to welding occurs. The typical plastic strain profiles were plotted in Figure 3.

The flyer plate velocity was also monitored and compared with the experimental results. The typical flyer plate velocity profiles for the 7mm stand-off distance between the AL-7039 flyer tube and 4340 steel base tube were shown in Figure 4. (Zero displacement represents the maximum flyer tube velocity obtained at the collision point).

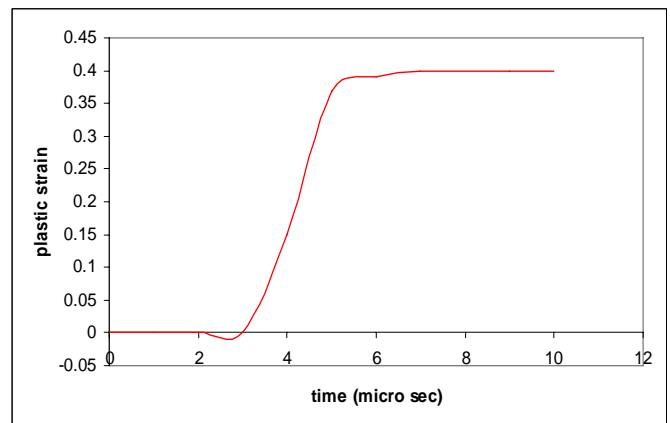


Fig. 3 Typical effective plastic strain profile between the AL-7039 and 4340 steel tubes, stand-off distance=6mm

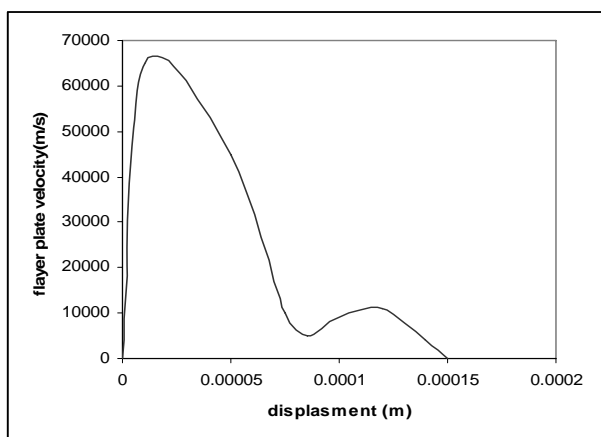


Fig 4 Typical flyer plate velocity profile for the 7mm stand-off distance between the A7039 flyer tube and 4340 steel base

IV. CONCLUSIONS

- The results showed that the value of the plastic strain was reached to its maximum at the collision point.
- This study suggests that the minimum plastic strain may be required to bonding take Place.
- The results showed that zero displacement represents the maximum flyer tube velocity obtained at the collision point.
- According to Fig.1, observation of completed diffusion between flyer and base metals. It can be intimated to explosive welding method, has an applicable method to welding the metals, they have different welding window.
- Numerical results showed that the Langrangian method has good accuracy to modelling same typical problem.

Helpful Hints

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