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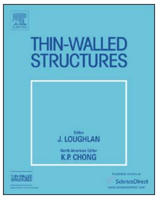

Full length article

Numerical modeling based on coupled Eulerian-Lagrangian approach and experimental investigation of water jet spot welding process

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ABSTRACT

Due to the relatively high degree of complexities involved with water jet spot welding process, the experimental and conventional numerical methods are hardly capable of providing all comprehensive analysis. In present paper, water jet spot welding of copper, brass and aluminum plates has been examined experimentally using a gas-gun. Considering the details of the whole process, numerical modeling of jet formation and interaction between jet and solid surface have been performed, employing the coupled Eulerian-Lagrangian (CEL) approach. In addition, Jonson-Cook damage model has been utilized to predict the damage initiation in solid surfaces. The velocity profiles of jet along axial and radial directions; and also time history of jet are obtained to describe the variation of velocity in different points of jet with time. Results confirm that the presented method has been successful in predicting the behavior of jet during the process, and plate deformation and failure patterns.

1. Introduction

Spot welding is one of the most convenient processes to create a quick and permanent joint between lightweight industrial metallic parts and is an integral part of manufacturing processes especially in automotive industry. Currently, electrical resistance welding is the most applied method in spot welding. However it has some limitations. For instance, welding of metals with far melting points and oxidization of surfaces. Alternative methods such as explosive welding [1], laser spot welding [2], and impact spot welding have been introduced to overcome the limitations of conventional methods of spot welding. The latter proposes high quality, steady and reliable connection between parts by creating solid phase bonding and interlock between surfaces. For this purpose, a high velocity projectile [3–8] or slug of water [9–11] impacts a pre-determined point and a permanent connection would be created at the neighboring zone. The high pressure produced by impact of liquid jet with solid surfaces, lasts for very short intervals of time and is followed by a rapid radial flow of the liquid at speeds which may be several times higher than the impact speed itself [10]. After the maximum peak, the pressure decreases and reaches to a steady state at stagnation point, lasting for a relatively longer time [9]. Areas welded by impact spot welding are generally characterized by wavy and plane texture [8] and the regions with the wavy structure generally being more strongly welded [12]. Observations of Turgutlu et al. [8] showed that the wavy surface increases the area of intimate contact between the two mating surfaces, and enhances interlock and the interaction between the jets from the two surfaces, followed by an almost instantaneous release of load, serves to bond the two metal plates permanently. Salem and Al-Hassani [9,10] found that the amplitudes and lengths of waves increase monotonously with radial distance from the center of impact. They also reported the presence of a central unwelded region. When the speed of a fluid jet is high enough to produce pressures in the vicinity of impact well in excess of the yield shear stress of the target material it can be assumed that the target in this area can flow as an inviscid fluid [9].

High velocity impact of water jet, generates an extremely high pressure on the target surface, and can cause serious damages such as material removal and erosion. Therefore it is important to study the different aspects of this process such as the impact pressure and stresses generated on the solid surface. Several experimental researches have been performed to study the effects of water jet impact on solid surfaces [13–15]. In water jet spot welding, usually a small amount of water is used and the diameter of the jet is too small and the process lasts for only a few microseconds. Therefore high-tech tools are needed to observe and study the process. On the other hand, numerical methods such as FEM are powerful and cost effective tools which can be employed for comprehensive studies of engineering processes including problems related to water jet forming, cutting and welding [16–18].

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Chizari et al. [18] investigated water jet spot welding of metallic parts numerically and experimentally. They used Equivalent plastic strain at high strain rate and shear stress at the collision point as welding criterion and their numerical results confirmed that central contact region remains un-bonded. Recently, CEL method has been implemented in FEM to avoid the undesired mesh distortion through large deformations caused by large strain rates in cutting, forming and welding problems [19–21]. In CEL method both Eulerian and Lagrangian meshes are used in same model. Therefore it's sufficient to model an assembly of fluid and solid structure interacting with each other [22,23]. Hsu et al. [23] studied high-speed water jet impact on solid surfaces numerically, using CEL method. Their CEL simulation predicted peak and stagnation pressure of impact and also geometrical parameters such as deformations of target plate with a good precision.

Though numerous experimental investigations have been performed to study the effects of high velocity water jet, only handful number of researches have been carried out to understand the complex behavior of the mentioned process, numerically.

The present paper describes an experimental investigation of spot welding of Aluminum, Copper and Brass plates with different thicknesses, subjected to impact by water jets with different amounts of water and kinetic energies, using a Gas-Gun apparatus. Also the CEL technique has been employed to simulate the whole process, including the formation of jet, to investigate the associated parameters accurately. In addition, Johnson-Cook damage model has been used to investigate the failure of the specimens under high speed water jet impact.

2. Numerical simulation

2.1. Coupled Eulerian-Lagrangian in FEM

Eulerian analysis is a suitable technique for problems in which the material undergoes extreme deformations, especially in modeling of fluid flow. Through an eulerian analysis in FEM, the nodes are completely fixed in space and the material flows through elements which will remain undeformed during the analysis. This advantage would let the material to experience extreme deformations and strain rates, with elimination of the possibility of element distortion. On the other hand, in Lagrangian analysis nods are fixed within the material and the material boundary coincides with elements boundaries. Therefore the elements would deform, as the material deforms. The Lagrangian technique is well suited for the problems in which the material is in solid state. Nevertheless, in case of problems in which the strain rate in solid medium is too high and the material acts like a fluid medium, e.g. in granular materials [20], the eulerian analysis would be more effective.

Many practical issues in engineering analysis are neither pure Lagrangian nor pure Eulerian problems [25], therefore it's needed to model an assembly consist of Eulerian and Lagrangian domains together to achieve realistic simulations. In ABAQUS [26], CEL technique has been implemented to solve the problems in which, Eulerian and Lagrangian domains interact with each other, i.e. fluid-structure problems.

The Eulerian analysis in Abaqus explicit is based on Eulerian volume fraction (EVF) technique. In this technique, in each time increment as the material flows through elements, the percentage of the material filled in an each element is calculated. If the whole element is filled with material, its EVF is one and if no material present in the element, its EVF would be zero. If material volume fraction in an element is less than one, the remainder of the element is automatically filled with void material. Void material has neither mass nor strength. Fig. 1 illustrates a schematic of deformation in Eulerian and Lagrangian mesh with representation of the concept of EVF in Eulerian analysis.

To perform an eulerian analysis in Abaqus, an eulerian domain must be defined for the material to flow in and also a Lagrangian part should be defined inside the Eulerian domain only to determine the initial EVF and position of material. Fig. 2 shows the initial position of water inside the Eulerian domain and nozzle in the present study.

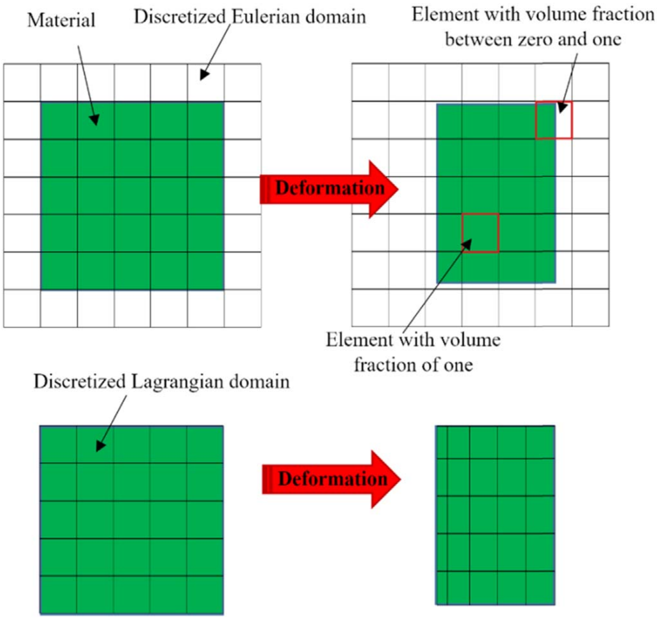

Fig. 1. Illustration of deformation in Eulerian and Lagrangian mesh; and concept of Eulerian volume fraction.

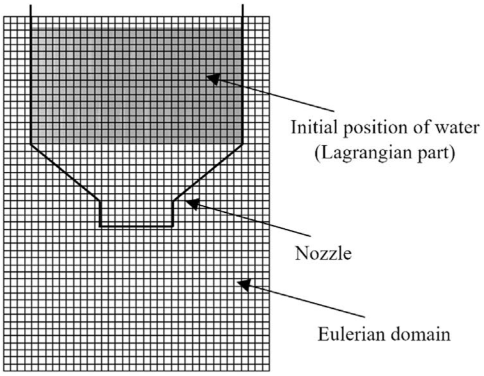

Fig. 2. Initial EVF of water.

2.2. Material models

2.2.1. Mie-Grüneisen equations of state

To provide a hydrodynamic material model to define the behavior of fluids, an equation of state (EOS) should be determined. Modeling of incompressible viscous and inviscid laminar flow can be achieved by using the linear $U_s - U_p$ form of the Mie-Grüneisen equation of state. According to Mie-Grüneisen equations of state, the pressure can be expressed as a linear function of internal energy [26]. The most common form of Mie-Grüneisen equations of state is:

$$p - p_H = \Gamma\rho(E_m - E_H) \tag{1}$$

where p and E_m are pressure and internal energy per unit mass respectively. p_H and E_H are the Hugoniot pressure and specific energy per unit mass which are functions of density ρ, only. Also Γ is the Grüneisen ratio and is defined as

$$\Gamma = \Gamma_0\frac{\rho_0}{\rho} \tag{2}$$

related to the Hugoniot pressure by