Keyhole Formation During Spot Laser Welding: Heat and Fluid Flow Modeling in a 2D Axisymmetric Configuration

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Abstract

Automotive domain produces a considerable effort to reduce CO2 emissions. This constraint requires designing vehicles always lighter to reduce fuel consumption. Laser welded tailored blanks is a promising technology for limiting the thickness of piece while maintaining security and mechanic structure performances. It is however necessary that the welded zone has no geometrical defects like partial grip or a lack of material (Figure 1). For a better understanding of physical phenomena associated with the appearance of these defects, a heat and fluid flow model is developed using the commercial code COMSOL Multiphysics. This first step of the project is focused on the modeling of a static laser shot on a sample of steel. This 2D axial-symmetric configuration is used to study the main physical phenomena related to the creation of the keyhole. This model takes into account the three phases: metal vapor resulting from a high energy density, the liquid phase and the solid base metal which has not exceeded the melting temperature (Figure 2). To track the evolution of these three phases, coupled equations of energy and momentum are solved. The liquid/vapor interface is tracked using the level-set method. This free boundary undergoes a very strong deformation because of matter vaporization which creates an important vapor mass flow rate. The phase change is treated through a local modification of continuity equation. This departure of vapor will push on the liquid/gas interface because of a "piston effect" resulting from a large difference of velocity and density on both sides of the liquid surface. This pressure will dig the material up to a point of balance sometimes stable, creating a gas cavity fighting against the effects of gravity and surface tension which tends to prevents the formation of the keyhole. In some case, the liquid collapse and traps gas bubble at the origin of residual porosity (Figure 3). The calculated temperature, velocity and free surface deformation fields will be analyzed. The temporal evolution of these variables will be also studied to understand the mechanism of porosities formation. Melt pool shapes will be compared to experimental macrographs and the influence of some parameters like laser power, focal diameter or vapor properties will be discussed.

Figures used in the abstract

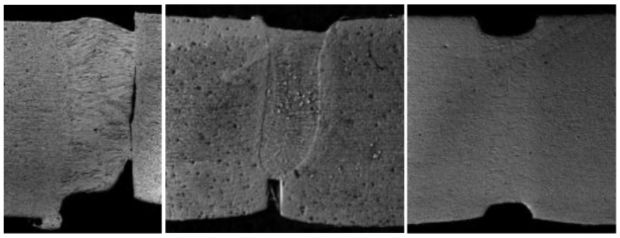

Figure 1: Examples of welded zone defects.

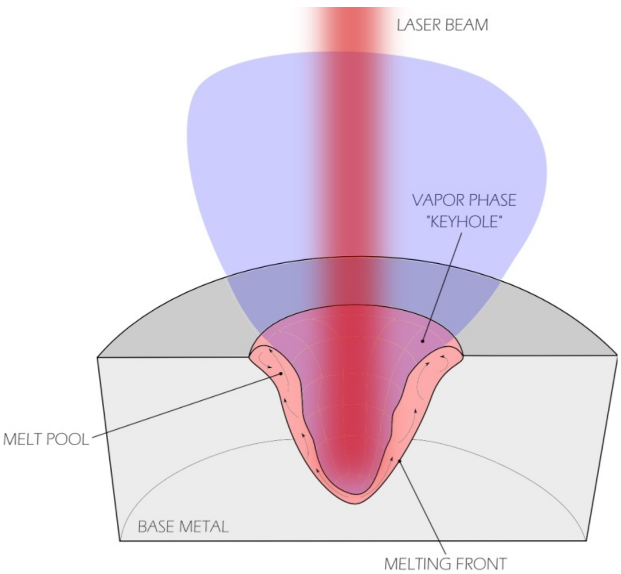

Figure 2: Sketch of the geometry.

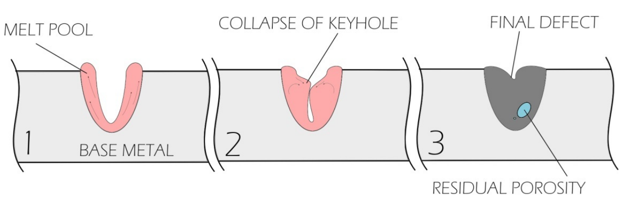

Figure 3: Sketch of the trapping mechanism.