Numerical investigation of asymmetric weld fusion geometry in laser welding of aluminium alloy with beam oscillation

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Supplementary information includes:

1. Fresnel absorption model
2. Multi-reflection model

1. Fresnel absorption model

The laser energy is absorbed by the keyhole wall through Fresnel absorption, and the rest is reflected. The absorption rate α can be described as:

$$\alpha = 1 - \frac{1}{2}\left(\frac{1 + (1 - \varepsilon\,cos\,\varphi)^2}{1 + (1 + \varepsilon\,cos\,\varphi)^2} + \frac{\varepsilon^2 - 2\varepsilon\,cos\,\varphi + 2\,cos^2\,\varphi}{\varepsilon^2 + 2\varepsilon\,cos\,\varphi + 2\,cos^2\,\varphi}\right) \qquad (S1)$$

where, φ is the angle between the incident ray x_i and the surface normal n, ε is an electrical conductance coefficient dependent on the laser type and material properties, which can be expressed as:

$$\varepsilon^2 = \frac{2\varepsilon_2}{\varepsilon_1 + \left[\varepsilon_1^2 + \left(\frac{\sigma}{\omega\varepsilon_0}\right)^2\right]^{\frac{1}{2}}} \qquad (S2)$$

where ε_0 , ε_1 , ε_2 is the relative permittivity of vacuum, plasma, and base material, respectively. ω is the laser angular frequency, and σ is the electrical conductance per unit depth of metal.

2. Multi-reflection model

To accurately describe the laser-materials interaction during laser welding, the laser beam is divided into many beam bundles. In the model, a ray-tracing algorithm is adopted to consider multi-reflection inside the keyhole. When the beam impinges on the keyhole wall, some of laser energy is absorbed by Fresnel mechanism, and the other is reflected on the keyhole wall. x_i, n , x_r are incident ray, the surface normal, and reflected ray, respectively. The x_r is expressed using the following equation:

$$x_r = x_i - 2(x_i \cdot n) \qquad (S3)$$

In the laser heat source model, the ray tracing will be terminated when the energy of reflected ray is lower than 1% of the energy of original ray or it escapes out of the keyhole.