Welding LMECA2860

Heat Flow Project 2024

Homework Report

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November 19, 2024

Question 1

The absorptivity is the ability of a material to capture laser energy during the welding process. It is the opposite of the reflectivity of a material, so the proportion of energy that is reflected rather than absorbed. That's why we will always want to maximize the absorptivity in order to maximize the energy transmitted to the material and so minimize energy losses. The absorptivity depends on the properties of the material such as its composition, color or its roughness. To improve absorptivity there are different processes, for example we can apply a surface treatment to modify the roughness or apply a specific coating. But also a protective gas such as oxygen or argon can be used to concentrate the heat and reduce reflection and therefore improve the efficiency of the welding process. The gas can also play a role in removing oxides or impurities from the surface, and thus increase the absorptivity.

Question 2

Finding the new absorptivity of the plate :

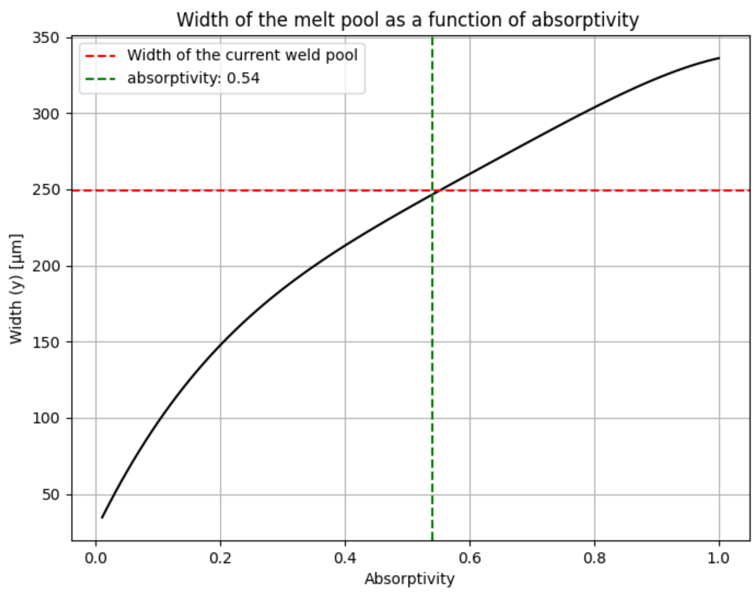

Figure 1: Absorptivity for the modified Stainless Steel

To find the exact absorptivity of the material, we used the 3D Rosenthal equation to obtain a graph of the maximum melting zone size as a function of the absorptivity. As can be seen from the graph, for a melting zone width of 248.9 μm, the absorptivity must be **0.54**.

Plot of the melt-pool in the xy plan and describtion of the melt-pool geometry :

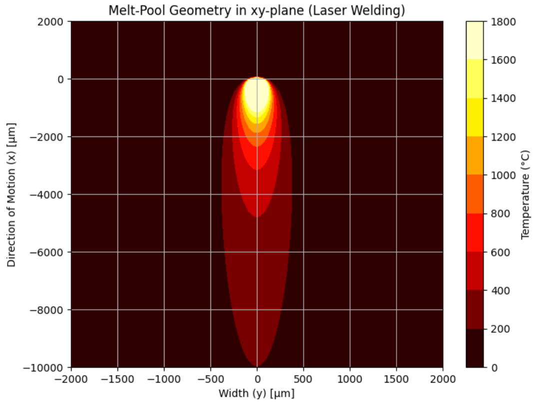

Figure 2: Melt-pool geometry in x-y plane

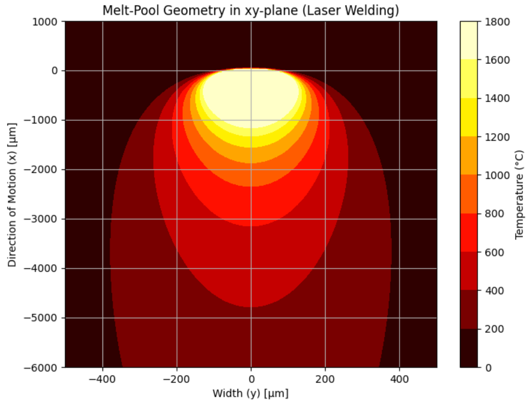

Figure 3: Zoom of the melt-pool geometry in x-y plane

The thermal distribution shows a temperature gradient around the central area of the melt pool, where the temperature reaches 1800 °C. By examining the isotherms, we see there is a gradual temperature transition from the laser impact point, illustrating the heat dissipation in the material.

A zoom in on the melt pool clearly shows the layers close to the melting center, where the temperature decreases rapidly due to the strong thermal gradient. This thermal gradient has a significant impact on the residual thermal stresses, which can lead to tensions in the material once solidified.

Comparison with the unmodified SS

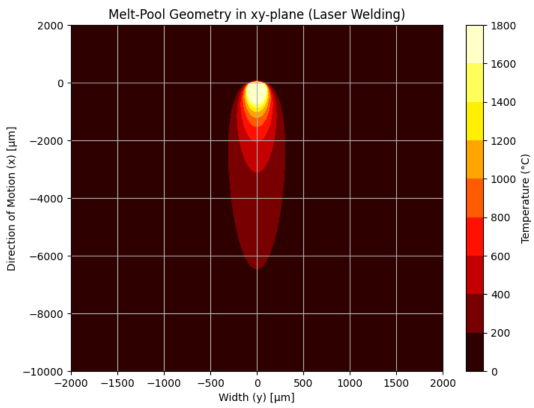

Figure 4: Melt-pool geometry in x-y plane

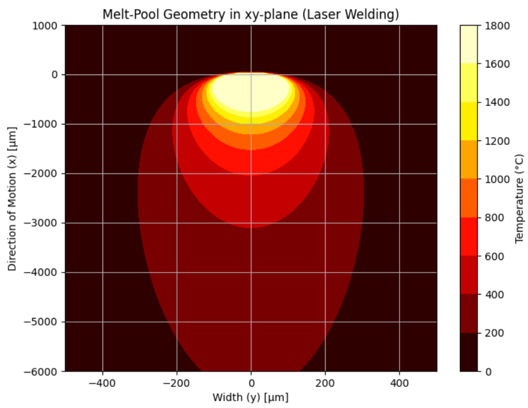

Figure 5: Zoom of the melt-pool geometry in x-y plane

The improvement in the absorptivity of the modified material results in an increase of the width of the melt pool compared to the original material. Specifically, the maximum width of the melt pool for the original material is 198.99 μm, while it reaches 248.9 μm for the modified material, so an increase of approximately 25%.

This difference in width indicates a more efficient energy absorption in the modified material, which generates a larger melting zone. As a result, the isotherms are more spaced, indicating a wider heat dissipation in the modified material. In contrast, the original material, having a lower absorptivity, presents tighter isotherms, characterizing a narrower melt pool and a more restricted thermal diffusion.

Absorptivity needed if we want to weld two 300 μm thick plates together

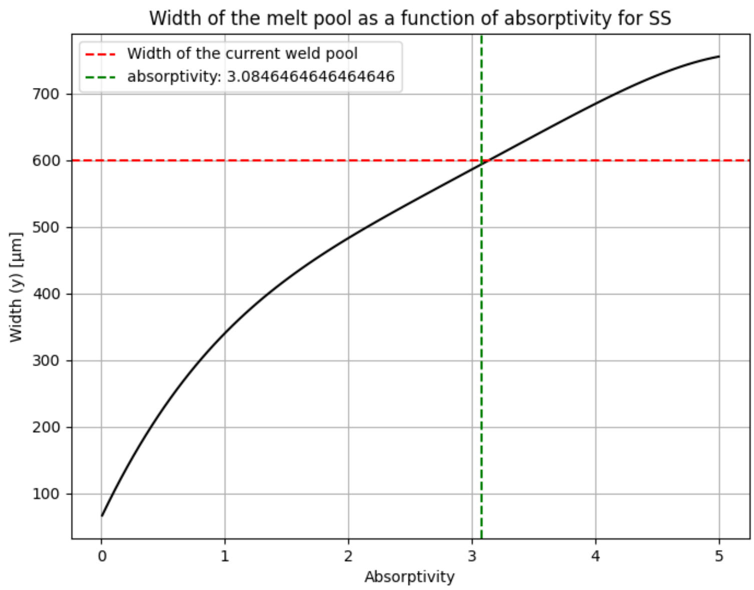

Figure 6: Width of the melt pool as a function of absorptivity

To weld two 300 μm thick plates, the melting temperature would have to be reached at z = -300μm. Since the conduction in the material is isotropic and the convection with the air is negligible we must obtain a melting temperature at z = -300 μm which is equivalent to having it at $y = \pm 300\mu m$. Consequently the width of the bath will be 600 μm. However, to obtain this temperature, an absorptivity of $\approx$ 3.1 is required. Obviously, this value is not realistic and in fact, any value greater than 1.0 is physically unrealistic, since it would imply that the material absorbs more energy than that emitted by the laser beam, which contradicts the fundamental principles of thermodynamics. This absorptivity value is due to the extremely low thermal conductivity of the material which does not allow heat to propagate through it.

Weld-size on an unmodified AlSi10Mg and comparison with Rosenthal 2D

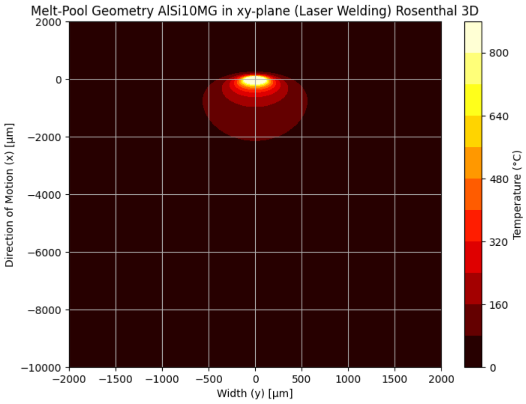

Figure 7: Melt-pool geometry AlSi10MG in x-y plane with Rosenthal 3D

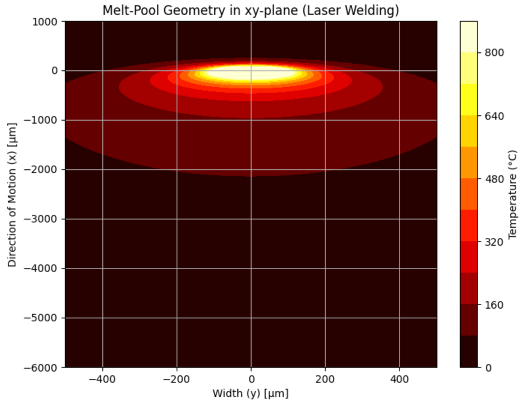

Figure 8: Zoom of the melt-pool AlSi10MG geometry in x-y plane with Rosenthal 3D

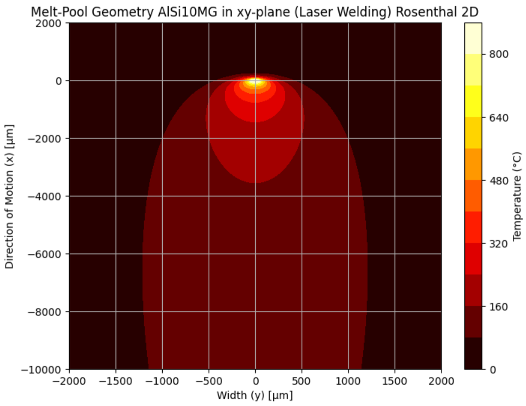

Figure 9: Melt-pool geometry AlSi10MG in x-y plane with Rosenthal 2D

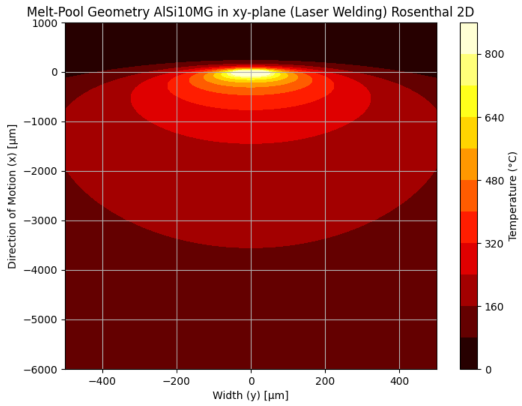

Figure 10: Zoom of the melt-pool AlSi10MG geometry in x-y plane with Rosenthal 2D

If we look at the weld pool geometry for unmodified AlSi10Mg we can clearly see the difference between Rosenthal 3D and 2D. With the Rosenthal 3D model, the weld pool is smaller and more localized, because the heat dissipates in all three spatial directions (x, y and z) which is more realistic. In contrast, the Rosenthal 2D model limits the heat dissipation to the x and y directions only. We therefore have an artificially large weld pool. This simplification ignores the effect of thermal conduction in depth (z), which amplifies the pool size in an idealized way. Therefore and as expected, the 3D model gives a better idea of the weld based on the thermal properties of the material, in particular the high conductivity of AlSi10Mg, which promotes rapid heat diffusion and limits the fusion zone.

Question 3

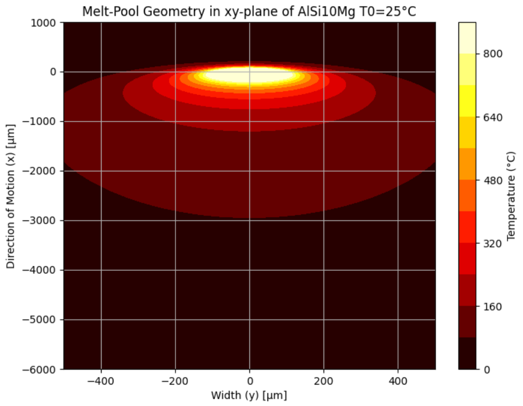

Figure 11: Melt-Pool Geometry in xy-plane of AlSi10Mg T0=25°C

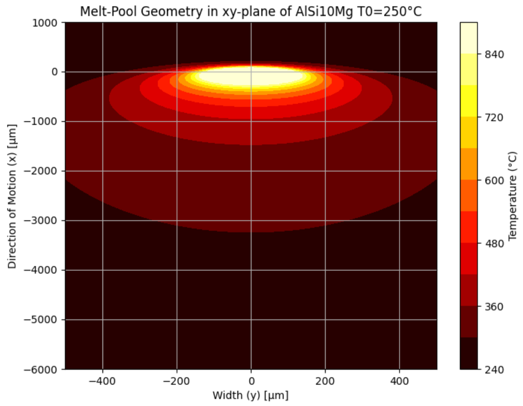

Figure 12: Melt-Pool Geometry in xy-plane of AlSi10Mg T0=250°C

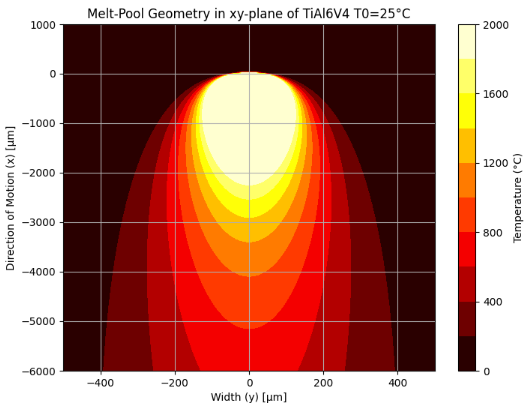

Figure 13: Melt-Pool Geometry in xy-plane of TiAl6V4 T0=25°C

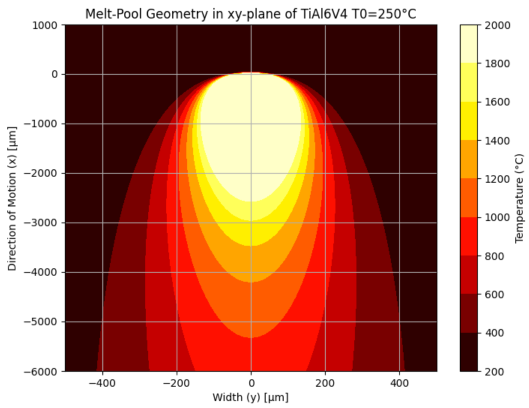

Figure 14: Melt-Pool Geometry in xy-plane of TiAl6V4 T0=250°C

The melt-pool geometries of AlSi10Mg and TiAl6V4 differ significantly due to their distinct thermal properties. AlSi10Mg has a wider melt pools, due to its high thermal conductivity, which leads to a rapid lateral heat dissipation and limits penetration depth. on the contrary, TiAl6V4 forms deeper and more elongated melt pools due to its lower thermal conductivity and higher thermal diffusivity, that's why the heat will remain localized.

At $T_0 = 250°\text{C}$, the melt-pool size increases for both materials, because the thermal gradients is smaller, that's lead to a larger melt pool. However, the effect is more pronounced for TiAl6V4, which demonstrates deeper penetration compared to AlSi10Mg. Thermal management in L-PBF is critical to control melt-pool size and shape, as it directly impacts solidification rates, microstructure, residual stresses, and dimensional accuracy. Preheating will reduces thermal gradients and residual stresses but must be optimized to prevent overheating and maintain dimensional stability.

Question 4

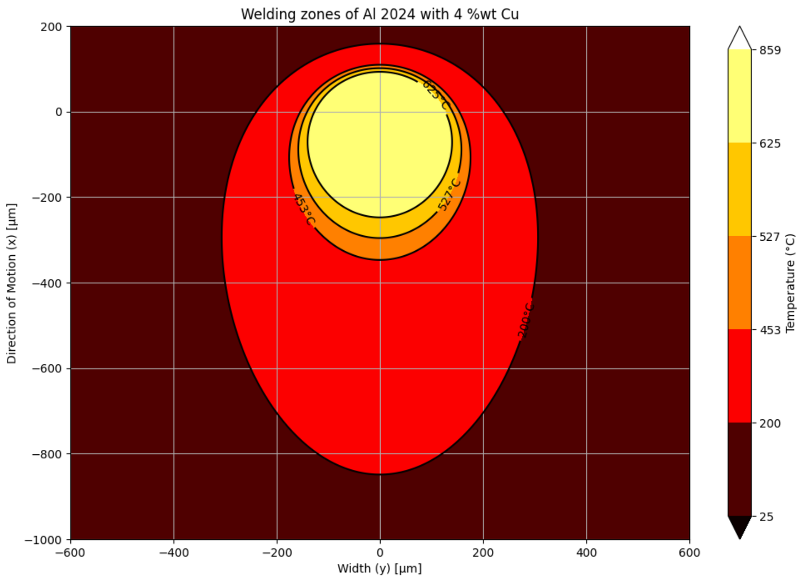

Figure 15: Welding zones of Al 2024 with 4 %wt Cu

The graph above shows the different areas of the Al 2024 with 4 %wt Cu weld. The Aging area measures 358691.57 μm^2, the Solvus area 27342.54 μm^2, the Solidus area 23687.62 μm^2 and finally the Liquidus area 30153.13 μm^2.

The location where the melt pool is widest is at y corresponds to the extreme values on the x axis for a temperature $T \geq T_{melt}$ at $x \approx -60.3\mu m$. We can also see on the graph below the different widths of each zone. We note that we find the 5 theoretical zones expected as in the statement.

We can then find the length of each zone along one side of the meltpool :

Zone	Width [μm]
Liquidus	136.4
Solidus	17.8
Solvus	15.2
Aging	91.1

Table 1: Width of each zone for an Al 2024 with 4 %wt Cu along the meltpool

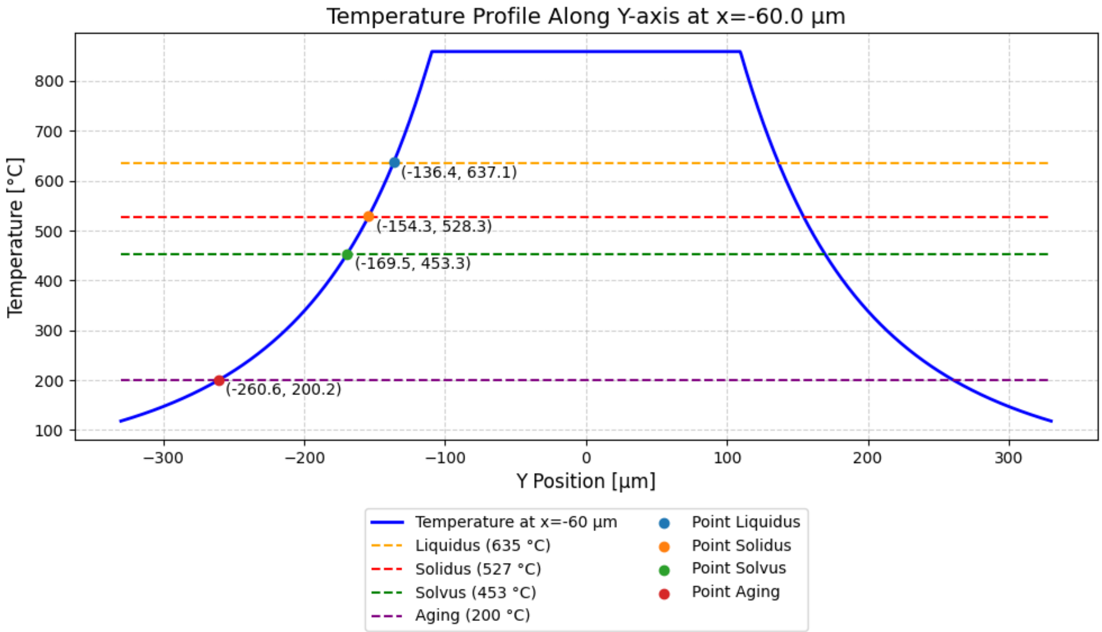

Figure 16: Temperature Profile Along Y-axis at x=60 μm

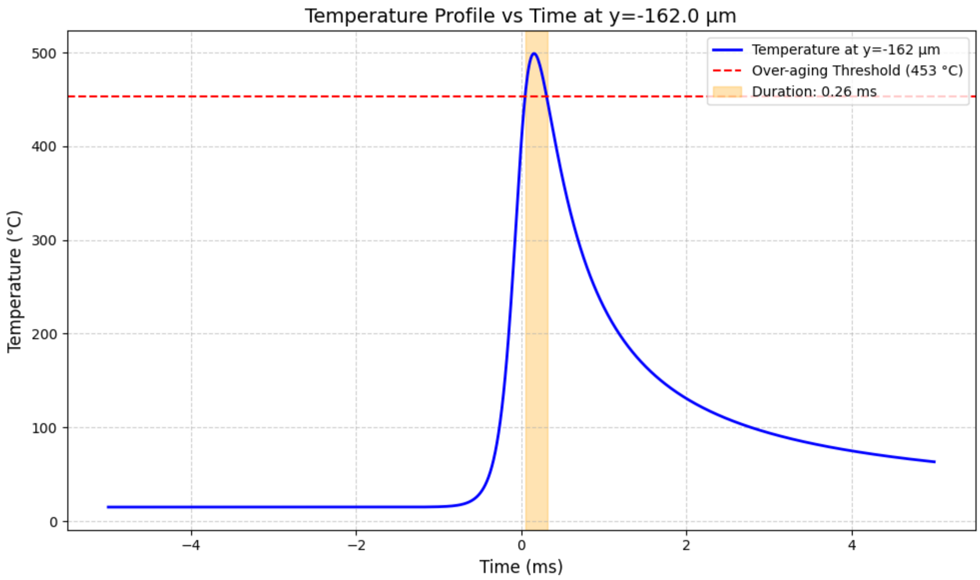

Figure 17: Temperature Profile vs Time at y= -162 μm

If we take a point in the middle of the solution zone, that is about y = + 162 μm or y = - 162 μm. We can see that over time this point remains only 0.26 ms above the solvus temperature.

Question 5

The two images correspond to the welding of the same material but in two different welding mode.

On the left, we see a huge and a much deeper weld pool , which means that we have a great penetration and that we work at high powers or at too low scan speed. This mode occurs when the power density exceeds a critical threshold, which causes the vaporization of the material and the formation of a keyhole. As explained in the course slides, "the keyhole mode significantly decreases the reflectivity (i.e. better absorption) because the beam is trapped in the keyhole and makes multiple reflections". This phenomenon will therefore improve the energy absorption and allow a deeper fusion but we will see porosities and voids appear.

In the right image, we see that the weld pool is smaller that's mean we have a stable or "non-keyhole" fusion mode. Unlike the keyhole mode, here we have a lower power density and the energy is mainly transferred by conduction, thus limiting vaporization. This mode favors a controlled fusion, which has the effect of minimizing defects such as porosities.