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Analysis of Laser Heat Distribution in Al-Cu Welding

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알루미늄-구리 용접에서 레이저 열원 분포 분석

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ABSTRACT

A computer simulation was performed to study the effectiveness of temperature on the type of laser heat source in the context of the heterogeneous welding of aluminum and copper materials. Three different types of heat sources were used in the computer simulation: 1) Single Beam Straight Scan, 2) Single Beam Wobble Scan, and 3) Dual Beam Straight Scan. Among these sources, dual beam straight scan was found to be the most effective from the viewpoint of heat source control. Because the difference between the melting temperatures of copper and aluminum is approximately 400°C, a clear separation of heating temperature was required, and the dual beam straight scan provided superior controllability in this regard. When using the dual beam, the temperature of the 90:10 split was considerably easier to control than that of the 50:50 split. The optimal offset was calculated to be 4 mm off to the copper side, where the melting temperature and thermal conductivity were higher. In this manner, computer simulation was effectively used for determining the optimal laser beam hear source control without performing an actual laser welding experiment.

Keywords : Laser Welding(레이저 용접), FEM(유한요소해석), Dissimilar Joining(이종접합)

1. Introduction

As a non-ferrous metal, aluminum and copper, which have excellent electrical conductivity and thermal conductivity, are frequently used as electric vehicles and industrial electrical machinery materials. In the case of aluminum, the specific gravity is only 1/3 of that of iron, so it is often used to lighten vehicles. Copper has a heavy weight, but due to its excellent electrical conductivity, it is frequently used as a vehicle battery and an industrial relay device. If these advantages of aluminum and copper are used, it is expected that their utilization will be very high as electric vehicle batteries or industrial electronic products. However, excellent electrical and thermal properties make the welding process difficult. In particular, it is difficult to control the heat source

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during the welding process due to the large melting point difference between the two materials[1-5]. For this reason, in most cases, the two materials are combined through mechanical joining process.

With the rapid development of laser technology, it provides solutions to various fields that have been considered as challenges. In particular, in the case of welding of dissimilar materials, a relatively high quality welding result can be obtained by using the laser's high peak power, rapid heating time, and precise control characteristics[4-5].

In spite of these technological advances, there are cases of cracks and internal pores in the weld due to the rapid heating and cooling characteristics of the laser beam, and weld brittleness due to deformation and residual stress of the weld occurs. In order to solve this problem, many studies have been conducted to optimize the heat input shape by transforming the laser beam into various shapes[5,9].

In this paper, we will introduce the computer simulation results for the optimal laser heat source design for welding aluminum and copper.

2. Computer Simulation Experiment

Finite Element Method(FEM) was used for this study, and analysis was performed using COMSOL Multiphysics(Ver. 5.2), a commercial finite element analysis software.

As shown in Fig. 1, modeling assumes an aluminum and copper plate with a width of 10mm, a length of 50mm and a thickness of 1mm. The two materials were combined in a butt joint form. The heat source was assumed to be the 3D Gaussian form as Equation (1)[6-8].

$$Q(x,y,z) = \mathrm{Q}_0\left(1-\mathrm{R}_\mathrm{c}\right).\frac{A_c}{\pi\sigma_x\sigma_y} e^{-\left[\frac{(x-x_0)^2}{2\sigma_x^2}+\frac{(y-y_0)^2}{2\sigma_y^2}\right]}.e^{-A_c z} \qquad (1)$$

where, Q_0 is the peak power of the heat source, x, y, z are spatial coordinates, Rc is the surface reflectivity, σ_x, σ_y are the beam radii in the x and y directions, and A_c is the thickness of the surface absorption layer.

The heat source is assumed to be a standard normal distribution (Gaussian) type heat source, the beam shape is a shape factor (Shape Factor) of 2, and the laser power is set to 1 kW. As a boundary condition, the laser is irradiated from the top, and natural convection conditions are set on the entire surface including the top, and the governing equation of heat transfer inside the material is expressed as Equation (2).

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \bullet \nabla T = \nabla \bullet (k \nabla T) + Q \quad (2)$$

where ρ: density, Cp: specific heat, T: temperature, u: velocity vector, and Q: thermal flux.

In addition, in order to monitor the welding, the temperature was measured at a point 2mm away from the center in the longitudinal direction. The welding heat source was applied to 1) Single Beam Straight Scan, 2) Single Beam Wobble Scan, and 3) Dual Beam Straight Scan, and computer simulation was performed (Fig. 2). In all three cases, the total power was set to 1 kW, and in the case of Dual Beam, the total power was split into two laser beams.

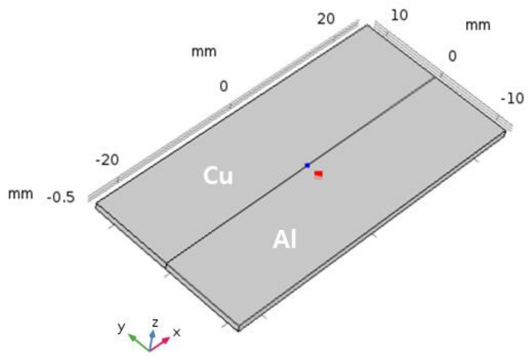


Fig. 1 Model of computer simulation

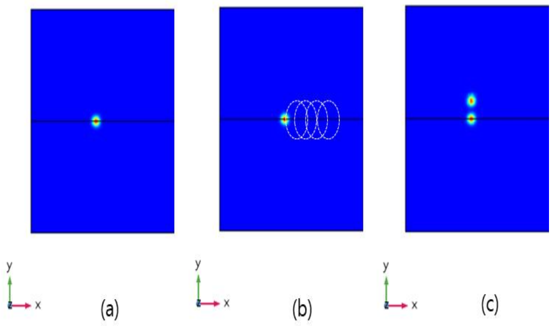
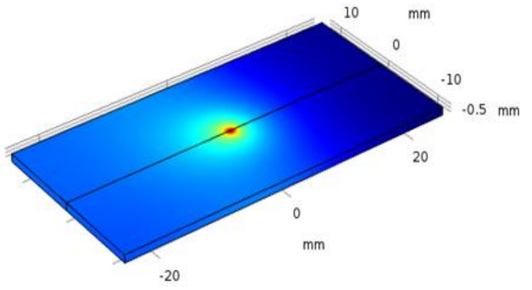


Fig. 2 Heat Source for computer simulation (a) Straight scan (b) Wobble scan (c) Dual beam Scan

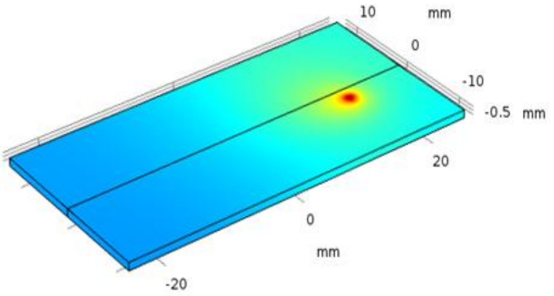
Based on previous studies, in the case of the Sing Beam Straight Scan, the welding speed was set to 10mm/s and the scan position was varied. In the case of Wobble Scan, the Wobble radius was set to 2 mm, and the rotation angular velocity period was set to 10Hz. Finally, in the case of Dual Scan, the distance between the two laser beams was varied from 1.5mm to 2mm, and the beam split ratio was varied from 50:50 to 90:10.

The tendency of thermal diffusion for each of these cases is shown in Fig. 3. As shown in the figure, it can be seen that heat is uniformly propagated to copper and aluminum when welding at a power of 1kw with a straight scan and a scan speed of 10mm/s. However, compared to the thermal conductivity of aluminum (205W/mK), the thermal conductivity of copper (385W/mK) is about 187%, so it can be seen that more thermal diffusion is made toward copper.

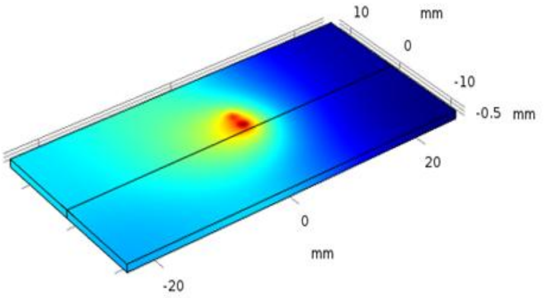
In the case of Wobble Scan, a specific trend of temperature distribution was not observed because the laser beam reciprocates right and left with respect to the junction. In the case of Dual Scan, detailed analysis according to the offset amount is necessary because the tendency of the thermal diffusion distribution varies greatly depending on the offset amount.



(a) Straight scan, P = 1kW, v = 10mm/s



(b) Wobble scan, P = 1kW, ω = 10Hz

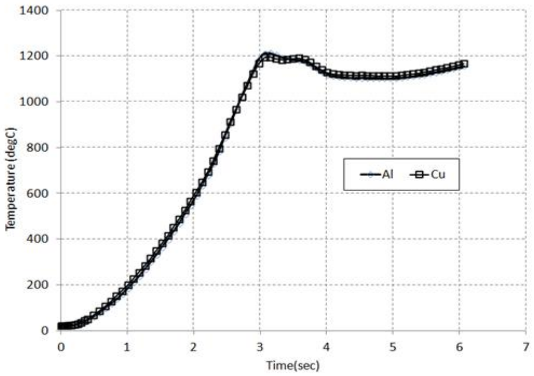


(c) Dual scan, 1.5mm split

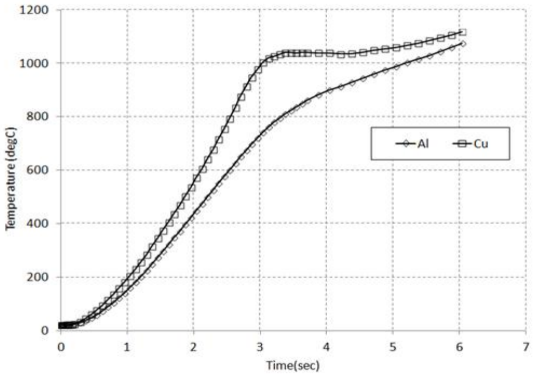
Fig. 3 Heat transfer patterns in welding

3. Results and Discussion

For the purpose of quantitative analysis, the temperature was measured at the locations of the left and right 2mm off from the junction. In Fig. 4, the temperature distribution during linear transfer under the same conditions was compared at the joint position (0mm offset) and the position of 5mm offset toward the copper material.



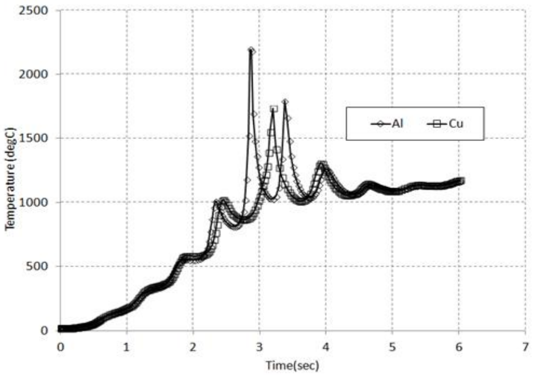
(a) 0mm offset



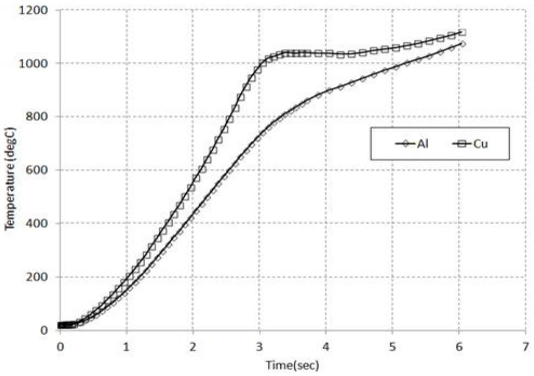
(b) 5mm offset

Fig. 4 Temperature distribution in straight scan

The 1kW laser was moved at a speed of 10mm/s and the results are following. In the case of 0mm offset, the temperature distribution of the two materials was almost similar despite the difference in thermal conductivity. On the other hand, when the laser beam was linearly moved with a 5mm off toward the copper material, a difference of about 260C occurred based on the time point(3 seconds) where the laser beam is passing through the central point. However, this difference does not reach the difference between the melting temperature of copper (1100C) and the melting temperature of aluminum (660C). Various offsets were tried, but the temperature change was around 300C which is not sufficient to differentiate the melting temperature.



(a) Wobble Scan- 10Hz



(b) Dual Beam Scan – 2mm offset

Fig. 5 Temperature distribution in wobble and dual beam scan

As another laser beam modulation scheme, Wobble Scan and Dual Beam Scan were simulated (Fig. 5). As shown in Fig. 5(a), in the case of Wobble Scan, the temperature difference between copper and aluminum can be markedly different, but it can be seen that the temperature gradient changes significantly as the heat source moves due to the wobble.

As analyzed in previous studies, it is possible to reduce some of this temperature gradient by changing the cycle of Wobble, but it is unlikely to expect a great advantage in the complexity and economics of actual equipment.

Fig. 5(b) shows the case of dual scan by dividing the laser beam into two. The example in Fig. 5(b) shows an example of dividing the laser beam by 90:10 with offset of laser beam by 2mm. As shown in the result, the temperature on the copper side is 1184C and the temperature on the aluminum side is 805C based on the time point (3 sec) passing through the central point, ausing a difference of 379C.

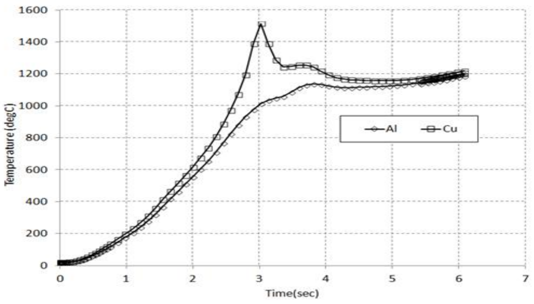
Even though both Straight laser beam scan and Wobble Scan are effective for the dissimilar material joining, the effectiveness of heat distribution is limited due to single laser beam control. Since the difference of melting temperature of both materials is 400C, the heating temperature should be clearly split as much as 400C for the ideal welding condition.

It leads the conclusion that independent heat control is necessary for the dissimilar welding process. Based on the preliminary simulation test, the dual beam scan was found to be the most effective. Therefore, various types of Dual Beam Scan were simulated in this paper.

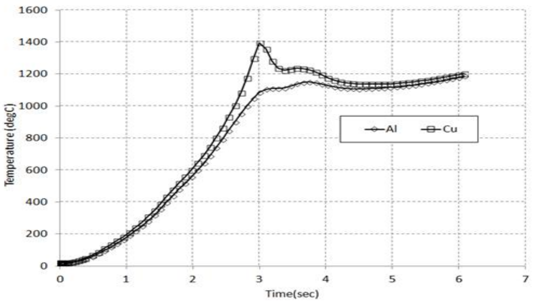
The example in 6(a) shows a case where the laser beam with a total output of 1kW is divided by 50:50 and the position of the beam is set to 0.5mm and 2.0mm with 1.5mm offset, respectively. As shown in the figure, the temperature on the copper side was 1515C and the temperature on the aluminum side was calculated to be 1016C, resulting in a difference of 500C. Although the temperature on the copper side increased, the temperature on the aluminum side far exceeded the melting point temperature (660C).

Fig. 6(b) shows a case where the distance of the beam is offset by 1.5mm by setting the beam position to 2.0mm and 0.5mm, respectively, under the same conditions as in Fig. 6(a). At this time, the temperature of the copper side was 1356C and the temperature of the aluminum side was 1086C, and a difference of 270C occurred. The temperature of copper and aluminum dropped slightly, and the overall temperature difference was observed to decrease.

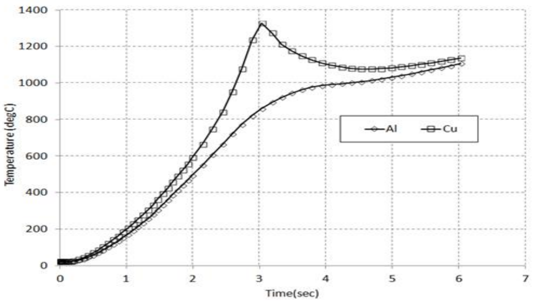
Fig. 6(c) shows an example where the spacing is



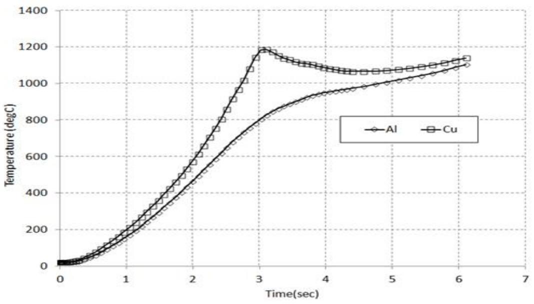
(a) beam location 1.5mm / 0mm



(b) beam location 2.0mm / 0.5mm



(c) beam location 3.0mm / 1.0mm



(d) beam location 4.0mm / 2.0mm

Fig. 6 Temperature distribution in dual beam scan (various offsets)

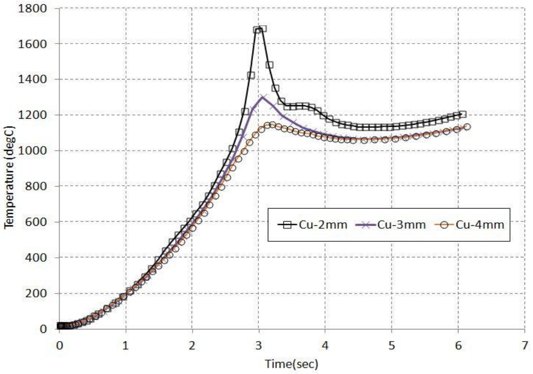


Fig. 7 Analysis of temperature distribution with respect to the offset

2.0mm offset by setting the beam positions to 3.0mm and 1.0mm, respectively. The temperature on the copper side was 1356C, and the temperature on the aluminum side was 948C, resulting in a difference of 408C. In this case, the temperature gap widened as the aluminum temperature decreased.

Finally, Fig. 6(d) shows the simulation result by adjusting not only the offset amount but also the output ratio. As shown in figure, the beam position and offset amount are 4.0mm/2.0mm and 2mm, and the simulation results are obtained by dividing the output into 900Watt and 100Watt. The result showed that the temperature of the copper side was 1184C and the temperature of the aluminum side was 805C, and a difference of 379C occurred. In this case, the temperature gap widened as the aluminum temperature decreased.

In order to evaluate the heat effect with respect to the offset amount, the temperature distribution was measured while varying the offset amount from 2mm to 4mm from the joining boundary. At this time, the laser beam was irradiated with 900Watt on the copper part and 100W on the top of the interface. Fig. 7 shows the temperature distribution calculated at the location of the copper material 2mm from the joining boundary.

When the laser of 100Watt was irradiated on the boundary and the 900Watt laser was irradiated to 2mm offset, the maximum temperature was calculated as 1700C. However, when the heat source was moved to the 4mm offset part, it was confirmed that it was lowered to about 1100C.

4. Conclusion

In this paper, we introduced the results of computer simulations to find out the effect of temperature on the type of laser heat source in heterogeneous welding of aluminum and copper materials. The types of heat sources were computer simulations that were classified into 1) Single Beam Straight Scan, 2) Single Beam Wobble Scan, and 3) Dual Beam Straight Scan.

In conclusion, the dual beam straight scan was found to be the most effective for heat source dispersion than the straight scan beam or single beam wobble scan beam. In the case of copper and aluminum, a melting temperature of about 400C occurs, and dual beam straight scan showed excellent heat source control. When using the dual beam, the temperature of the 90:10 split was much easier to control than the 50:50 split. From the result of the offset test, optimal conditions were found at the 4mm offset.

Although the mechanical or optical device is more complicated than the straight scan beam or the wobble scan type beam and the initial device cost increases, the heat input and offset control can be more flexibly performed. Computer simulation was effectively used for the optimal laser beam hear source control without performing the actual laser welding experiment.

5. Acknowledgement

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