

A study on forming process of AA5083 alloy with an infrared local heat treatment

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Abstract. Although the demand of aluminum alloys has been increasing to reduce vehicle's weight in automotive industries, the low formability of aluminum alloys has made a limit on industrial applications. This work presents an infrared ray (IR) local heat treatment in the purpose of improving formability of aluminum alloys. The concept of the IR local heat treatment is focusing IR rays on target areas where the level of plastic deformation reaches the fracture level. The local heat treatment employs the intermediate heat treatment scheme that is conducted between two stages, 1st forming and 2nd forming. In the 1st forming, the blank is deformed until a part of the blank reaches 15% strain. Then, the part is locally heat treated. After the heat treatment, the 2nd forming makes the heat treated blank match the target shape. Authors recently conducted this heat treatment with an IR local heating method to resolve the formability problem of an AA5083 alloy [1]. However, in the paper, the IR heat treatment was applied to only a linear heating shape. Neither the heat treatment for a curved shape nor local heating effect in temperature distribution was discussed in the paper. In this work, the IR heat treatment is studied in three points of view. The first is to shortly introduce the IR heat treatment in the purpose of improving formability with the AA5083 alloy. The second is studying the local heating effects in temperature distribution and application of a curved shape. Finally, an industrial application of tailgate is discussed with reduction of heating energy. The results show that this focused IR heating can improve formability with reducing heating energy for industrial applications.

1. Introduction

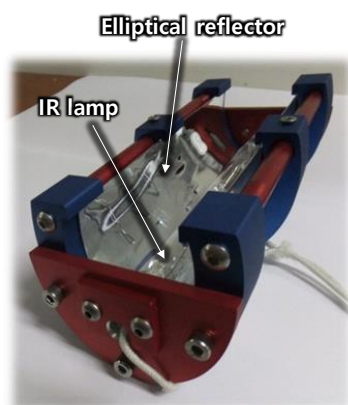
Automotive industries have been trying to reduce vehicle weight in the purpose of improving the fuel efficiency. Because of this trend, the demand of aluminum alloys has increased since aluminum alloys have a relatively high specific stiffness and specific strength. However, the low formability of the alloys has led to a limit on their industrial applications. Academia and industries have made efforts to improve the formability of aluminum alloys [2-8], and authors recently presented an infrared ray (IR) local heat treatment in order to improve the formability with an AA5083 alloy [1]. The principle of the IR local heat treatment is focusing IR rays on target areas where the level of plastic deformation reaches the



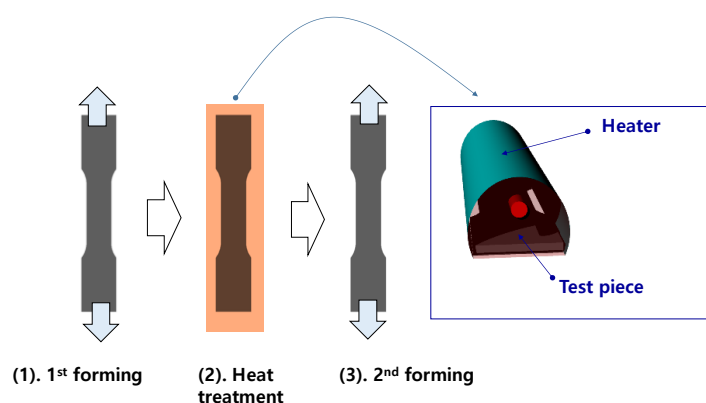
fracture level. The IR heat treatment employed the intermediate heat treatment scheme which is conducted between two stages, 1st forming and 2nd forming. In the 1st forming, the blank was deformed until a part of the blank reached 15% strain. Then the part was locally heat treated. After the heat treatment, the blank was deformed to match the target shape. The study showed that the IR heat treatment was able to improve the formability of the AA5083 alloy. However, the IR heat treatment was applied to only a linear heating shape. Neither an application for a curved shape nor local heating effect in temperature distribution was discussed in the aforementioned study. This paper shortly introduces the IR heat treatment in the purpose of improving the formability with the AA5083 alloy. Then, the local heating effects in temperature distribution and an application for a curved shape is studied. Finally, an industrial application of tailgate is presented in this paper.

2. IR heat treatment

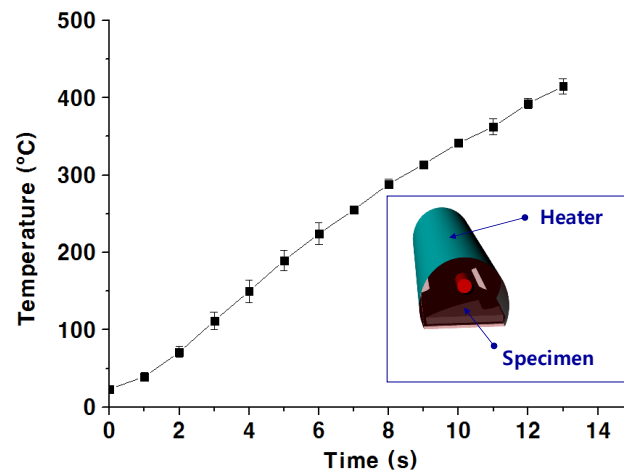
The concept of the IR heat treatment is shown in figure 1. Figure 1(a) shows the employed linear IR heater and figure 1(b) presents the tensile test with the IR heat treatment. The IR heater consists of an IR lamp and a reflector having an elliptical shape. The IR lamp is located at the focus of the elliptical reflector to gather the IR rays on a narrow area. In the experiment, the target material was AA5083 sheet with 1.5mm thickness. The specimens were cut in parallel with the rolling direction and had the gage length 50mm and width 25mm. In the tensile test, a specimen was deformed until 15% of engineering strain, then the deformed specimen was heat treated and cooled. For the heat treatment, the IR heater was placed parallel with the longitudinal direction of the specimen as shown in figure 1(b). The width of gage length was fully covered by the heating width of the IR heater and the length of the IR heater covered the length of the specimen. Details about the IR heater is explained in a previous study [9]. The temperature conditions of the heat treatment were 200°C, 300°C and 400°C. K-type thermal couples were used for temperature measurement. The heating rate of the heat treatment is shown in figure 1(c). It took 12 seconds to heat the specimen to 400°C; the heating rate was about 33°C/s. When temperature of the specimen reached each target temperature, the IR heater was removed to cool the heated specimen. The average of the cooling rate was about 5°C/s with air cooling. After the specimen reached room temperature, it was deformed again until failure. An INSTRON 5583 machine was employed for the test and strain rate was 0.001/s in both 1st and 2nd forming processes.



(a) Linear IR heater



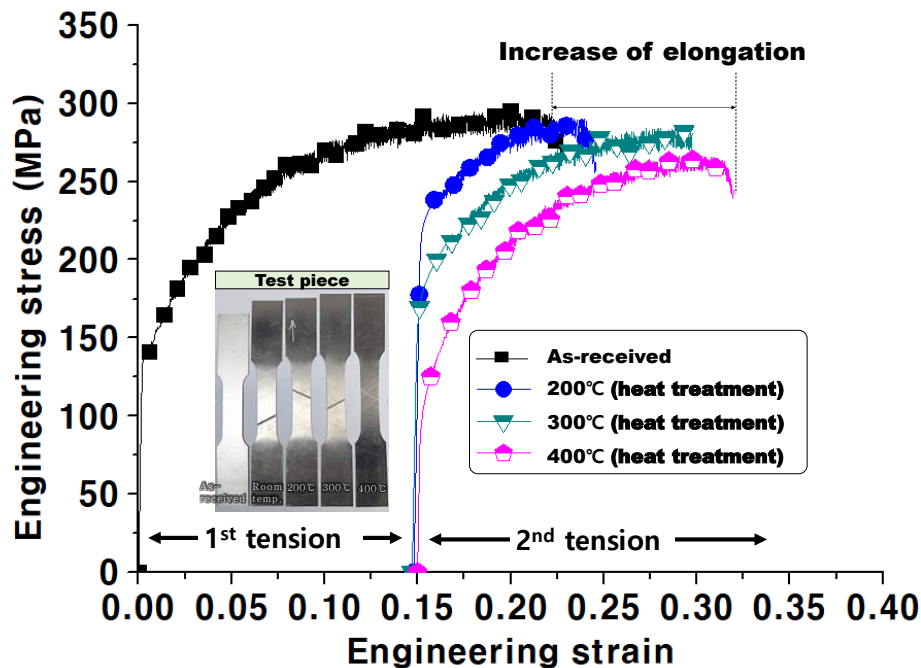
(b) Tensile test with the IR heat treatment



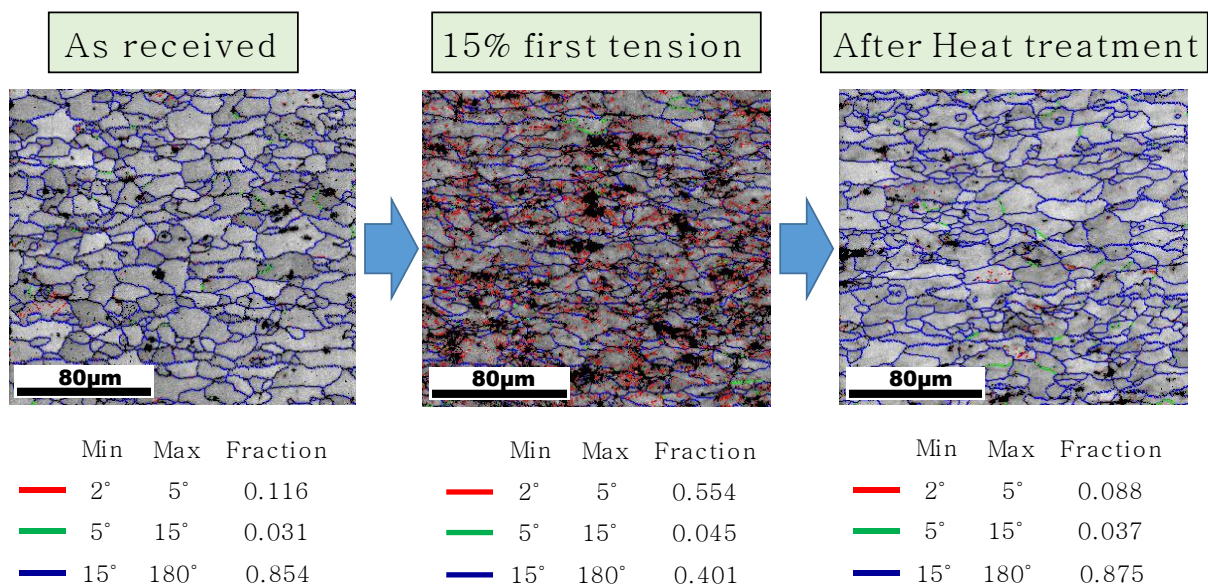
(b) Heating rate

Figure 1. Concept of the IR heat treatment

The tensile test results are shown in figure 2. The black square curve represents the original AA5083 sheet, as-received material, employed for the reference data and the original sheet has about 20% elongation. The total elongation means the summation of the elongation of the 1st and 2nd tensions in this test. With the heat treatment, the total elongation increases as the temperature of the heat treatment increases. The heat treatment condition of 300°C drastically improves the total elongation. Consequently, these results show that the IR heat treatment can significantly improve the formability. The values of the increased elongation with the IR heat treatment are summarized in Table 1. In order to discuss the cause of the formability improvement, microstructure change was observed. An electron back-scatter diffraction (EBSD) system was used in the observation of microstructures for the specimen heat treated at 300°C, as shown in figure 2(b).



(a) Stress-strain curve according to temperature condition of the heat treatment



(b) Microstructures

Figure 2. Mechanical property change caused by the IR heat treatment

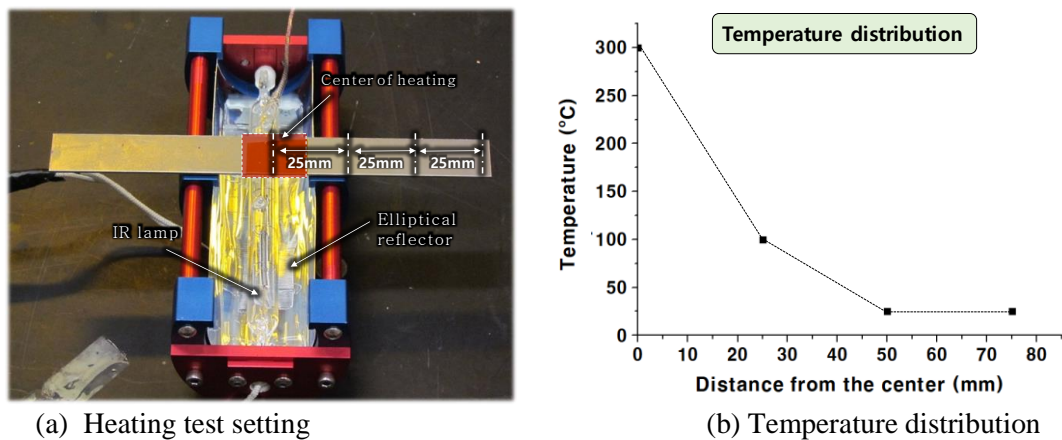
Figure 2(b) shows the boundaries with different misorientation angles of grains in the AA5083 sheet. The red line presents boundaries having misorientation angle from the minimum angle of 2° to the maximum angle of 5°. The green line is the boundary with a range of 5°~15° angle. The blue line shows the boundaries of misorientation angle from 15°~180°. The fraction means the ratio of each boundary to all of the boundaries. This work was focused on the red line in the figure 2(b) because the low angle boundaries (2-5°) have a proportional relation with the composition of dislocation arrays. Figure 2(b) shows that the as-received material had a low fraction (0.116) of the low angle boundaries meaning that the material had a low level of dislocation density. After 15% first tension, the low angle boundaries significantly increased with dislocations. The fraction of the low angle boundaries was 0.554 after the 1st tension. After the heat treatment, the fraction of the low angle boundaries was reduced again (0.088). This principle of annealing is the cause of the increased elongation. This result is also found in other studies to show that an appropriate heat treatment can reduce strain hardening in deformed materials. [10-11].

Table 1. Total elongation results

Temperature (°C)	Room temperature	200	300	400
Total Elongation (%)	20.7 (As-received material)	24.6	30.9	31.9

3. Effect of the local heating and application for a curved shape

One of the important advantages of the IR heat treatment is that it can reduce the heat-affected zone (HAZ). A heating test to analyze temperature distribution was conducted as shown in figure 3(a). The specimen was placed perpendicular to the heater and temperature was measured at 4 points (the center, 25mm, 50mm and 75mm) with K-type thermocouples. Since the specimen was symmetric, only the right side of the specimen was considered in the heating test. Figure 3(b) shows the temperature distribution when the central temperature of the heated area reached 300°C. As shown in figure 3(b), temperature drastically decreases with the distance from the center. This result shows that the IR local heating method can reduce the HAZ when compared to a furnace heating method.

**Figure 3.** Local heating effect

For expansion of application, the IR local heat treatment should be tested with curved shapes. This paper represents a test of a curved shape, as shown in figure 4. In the test of the curved shape, the forming process was the same to the above tensile test. In the 1st forming, the blank was deformed until a limit. In the test, the limit was the punch displacement of 20mm in the 1st forming. After the 1st forming, the curved line was heat treated at 300°C, then 2nd forming was conducted to reach the target shape (the punch displacement was 30mm for the target shape). In order to heat the curved line, a curved heater was made as shown in figure 4(b), and the blank was heat treated with the curved heater, as shown in figure 4(b).

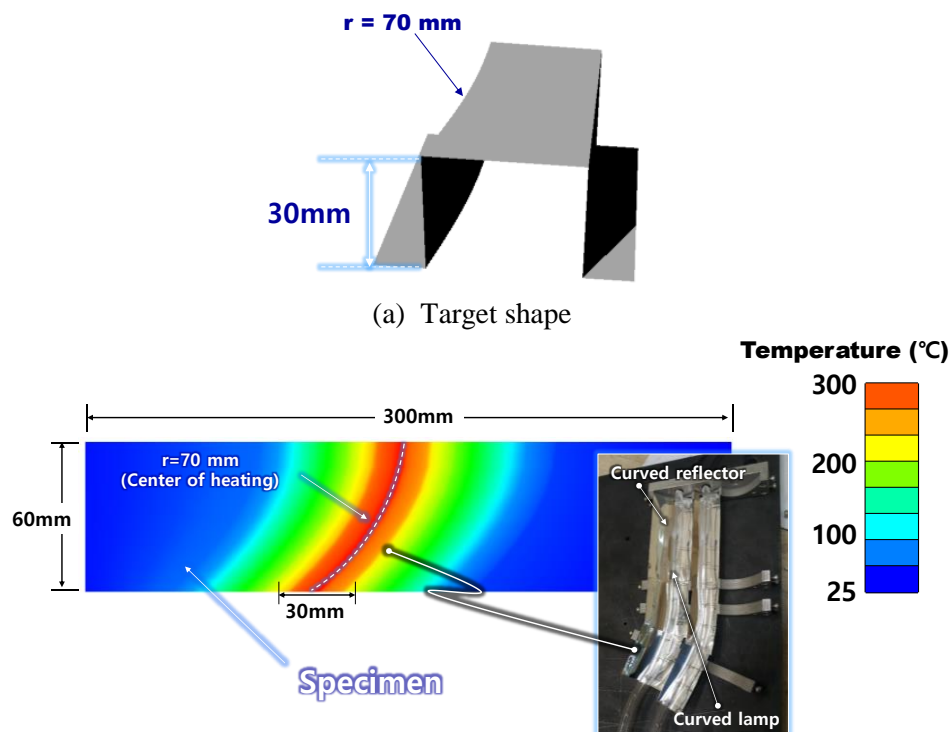
**(b) Local heating for the curved shape****Figure 4.** Application of the curved shape

Figure 5 compares the formed shape of two cases. The first case is the formed blank without the heat treatment shown in the upper side of figure 5 and the second case is the heat treated case. As shown in figure 5, the target shape is not able to be manufactured without the heat treatment because of the fracture. On the other hand, the heat treated blank can be successfully manufactured. This result shows that the IR heat treatment can be applied to the curved shape with the curved IR heater.

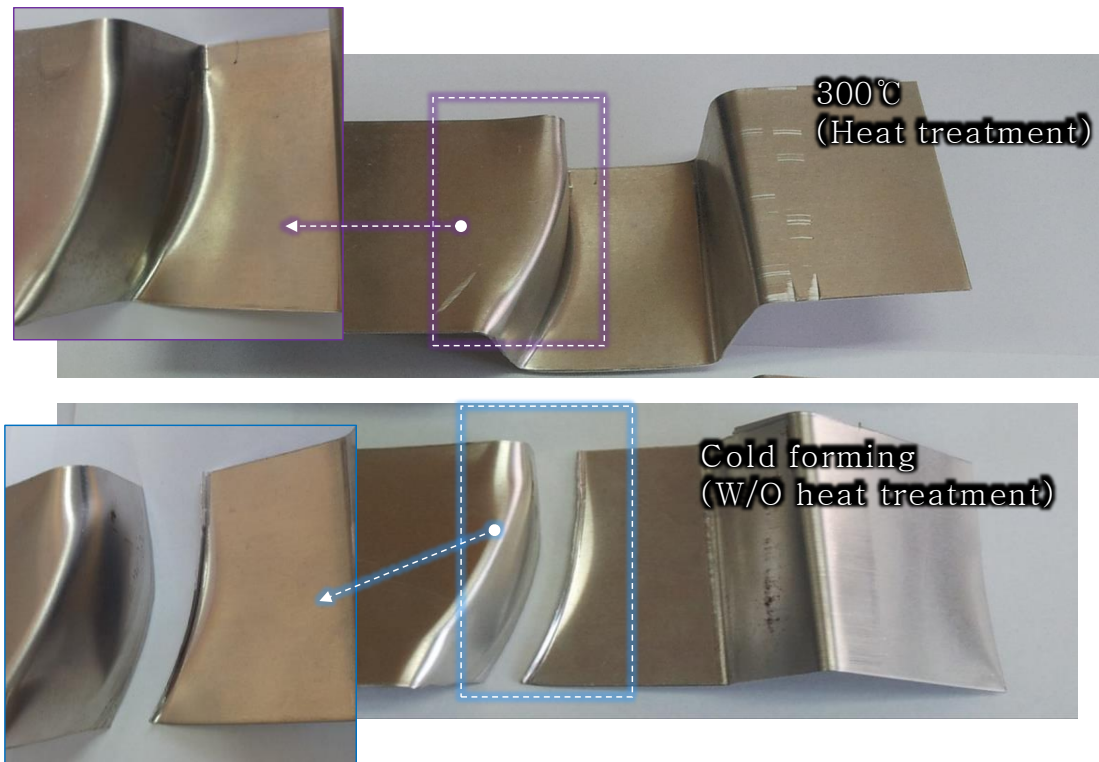
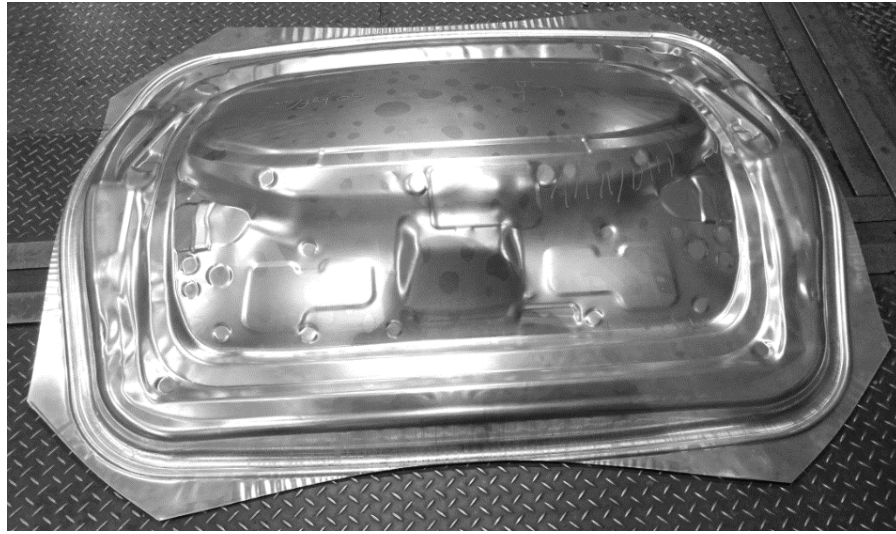
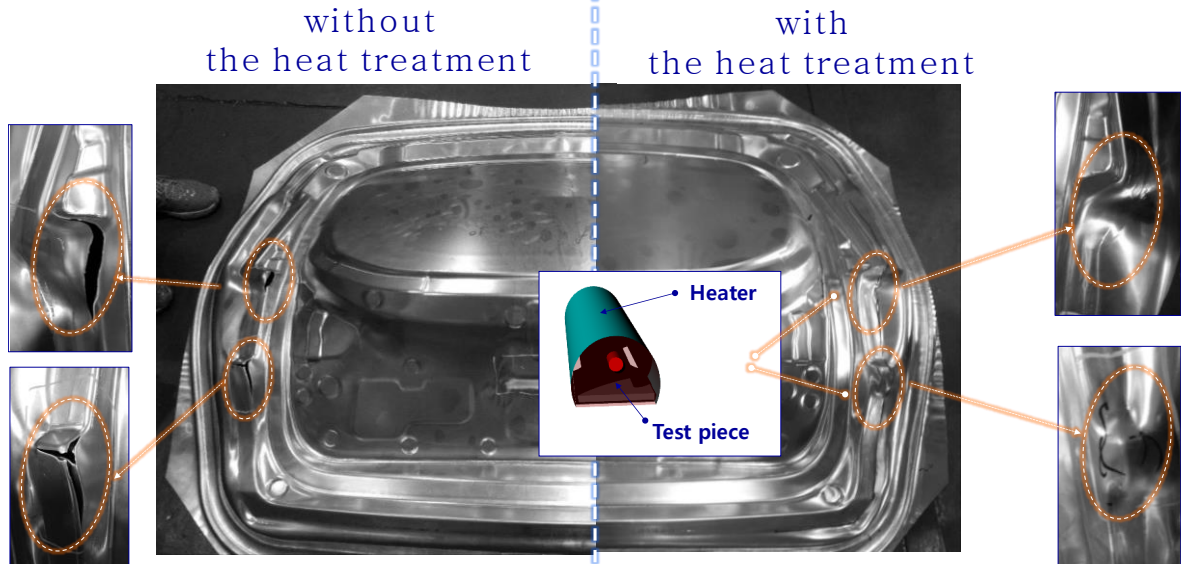


Figure 5. Results of the curved shape

4. Industrial application

With the IR heat treatment, a commercial auto part, tailgate, was manufactured. The stamping process of the tailgate consists of two stages, 1st forming and 2nd forming. In the 1st forming, a blank was pre-formed to make an outline of the tailgate, as shown in Fig 6(a). In the 2nd forming, the blank was deformed to reach the target shape. However, in the 2nd forming, some sharp edges led to fractures as shown in the left side of figure 6(b). In order to avoid these fractures, the sharp edges of the blank were heat treated at 300°C with the IR local heating between the 1st and 2nd forming stages. In the experiment, a 1000 ton hydraulic press was used and the press speed was 5mm/s. With the IR heat treatment, the tailgate could be successfully manufactured without the fractures, as shown in the right side of figure 6(b). The result shows that the IR local heat treatment can be applied to the aluminum alloy for improving the formability in the industrial application.

(a) 1st forming(b) 2nd forming (left : without the heat treatment, right : with the IR heat treatment)**Figure 6.** Tailgate application

This section additionally discusses the heating energy. This work compares the difference of heating energy between the IR local heat treatment and a furnace heating. In the case of furnace heating, consumed energy of a furnace changes with respect to the size and power of furnace even though the same object is heated. For this reason, this work analyzes the required energy to heat a specified area of blank to a target temperature in order to make an objective comparison. In this case, the following relation can be employed to compare the heating energy of the IR local heating with that of a furnace heating,

$$\frac{\Delta E_{\text{local}}}{\Delta E_{\text{whole}}} = \frac{C_p(\rho A_{\text{local}} t) \Delta T}{C_p(\rho A_{\text{whole}} t) \Delta T} = \frac{A_{\text{local}}}{A_{\text{whole}}}, \quad (1)$$

where ΔE_{local} is the required heating energy to heat the local areas and ΔE_{whole} means the required energy to heat the whole blank. t denotes the thickness of the blank, A is heated area, C_p is specific heat capacity, ΔT is elevated temperature, and ρ is density. Under the assumption that the same material is heated to the same temperature in both the whole and local heating methods, the comparison of energy is

approximately simplified to the comparison of areas, as shown in equation (1). The dimensions of the tailgate blank (refer to section 2) were 500mm x 500mm, and the local heating covers four areas of 100mm x 40mm in the experiments. The ratio between two heating methods is 0.064. This means that the IR local heating method reduces the heating energy by about 93.6% in the tailgate application when compared to a furnace heating method.

5. Conclusion

This paper studies forming process with an IR local heat treatment in order to improve formability of aluminum alloy. Details are summarized as below:

- (1) The IR local heat treatment which is conducted between two forming stages can increase the elongation of AA5083 alloy.
- (2) Since the IR heat treatment employs focused IR energy, it can reduce heating energy and heat-affected zone.
- (3) The IR heat treatment was successfully applied to a tailgate manufacturing process and curved shape. These results show that the IR heat treatment can be applied to industrial applications.

Acknowledgments

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