

# Development of electrically assisted rapid heating process for Hot-Stamping

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**Abstract**— Two different concepts of electrically assisted (EA) rapid heating of Al–Si coated hot-stamping steels are compared. In “along the surface” EA heating (or simply EA surface heating), the electric current is simply applied to a specimen by clamping the each end of the specimen length with a set of flat rectangular electrodes. In “through the thickness” EA heating (or simply EA thickness heating), the electric current is applied to a specimen by attaching a set of electrodes with multiple contact points on upper and lower surfaces of the specimen. While the EA surface heating generally requires a shorter heating time due to a higher electrical resistance in the length direction, the EA thickness heating also may provide a technical advantage that the heating area can be more easily configured in a case of partial austenization.

**Index Terms**— electrically assisted, hot-stamping, partial austenization, rapid heating, intermetallic

## 1 INTRODUCTION

Due to the demand for weight reduction of vehicle, improved safety and crashworthiness qualities, increasing hot stamping parts are used for automobile structural components from ultra-high strength steel [1]. As a higher weights leads to increased fuel consumption the body in where must lighter to compensate the weight of additional components. Therefore local heating is applied on those components of automotive body where a high strength or stiffness is necessary. In the conventional hot stamping forming process, the ultra-high strength steel is heated up to the austenization temperature on a heating furnace, then formed and quenched after being transferred into a die during dwell stage [2].

It has been reported that the full martensitic parts are in nature of high strength (1000 – 1500 MPa) and poor ductility generally less than 5% [3]. Therefore, such types of high strength steel but low ductile parts are not suitable especially for energy absorbing parts of automotive vehicles [4]. However, the safety improvement of vehicles and the compatibility of mechanical properties have been reported that various mechanical properties are needed in different regions or joints of the same parts. Such properties are similar as tailored properties [5]. This can be done by applying different temperatures on the blank. The automotive part as A-pillar and B-pillar which can be formed by such tempering and meet the crashworthiness requirement of roof and side.

Many scholars have carried out a series of studies on how to realize the tailored mechanical properties of hot stamping parts. Recently, efforts have been made to implement the partially heating and forming of the blank (referred as tailored tempering). To balance the mechanical properties of metal many scholars have given their own different ways of efforts. Some scholars focused on controlling the cooling rate during

local heating [6]. According to Hein and Wilsius ([7]) have partially prevented quenching by reducing the cooling rate with partially heated tools. On the other hand, Erturk et al. have predicted hardness distribution of tailored tempered blanks by finite element simulation using a thermo-mechanical metallurgical model. However, it is difficult to heat the target area of blank and in this case tailored tempering is really helpful. Mori et al. [8] have developed warm and hot stamping process of ultra-high strength steel using resistance heating. Mori et al. [9] have applied resistance heating to heat the side wall of a cup between two electrodes to decrease flow stress. Mori et al. [10] have improved the quality of sheared edges punching process of ultra-high strength steel sheets by means of electrical resistance heating. The rapid resistance heating is applied to the heating of a local zone by passing current through the local zone.

In this present study, EA partial thickness heating process by using multi contact points of electrodes in hot stamping was developed to produce steel parts having strength distribution and intermetallic behaviour of Al-Si coated steel. In this process blank was partially heated to the austenite and was subsequently hot stamped. Only the heated region of the blank was hardened.

## 2 EXPERIMENTAL PROCESS

### 2.1 Materials

In this paper, the studied high strength steel belongs to specialized for hot stamping process, named BP4120B (HYSCO Steel, Korea). The thickness of the specimen was used in experiment was 1.0 mm. 1 mm thickness hot stamping material which was hot dip coated with a type 1 aluminized coating (87% Al - 15% Si) on both side was used. This type of coating is widely used for hot stamping material in order to prevent oxidation and decarburization during heating process.

### 2.2 Experiment

The experiments of ultra-high strength hot-stamping steel of rectangular blanks were implemented on the local resistance heating system by multiple points of electrode. Specimens

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were prepared as the size of  $65 \times 95 \times 1 \text{ mm}^3$ . Custom made jig used for this experiment. Jig's upper plate was automatically moves by using hydraulic press. Fig. 1 (a) and (b) showed the full system and close view of specimen set up with electrodes respectively. Two bus-bars were used as high electric current needs to flow over the specimen from the transformer to reach the high temperature about  $900 \sim 1000^\circ\text{C}$ . Also two rectangular shapes ( $50 \times 80 \times 10 \text{ mm}^3$ ) custom made electrodes with multi contact points designed/made to heat the blank locally for high temperature (Fig. 2). The distance among the tip points of the electrode was 15 mm each. The tip point was not sharp actually rather it has flat shape at tip of each point to observe the flow of thermal effect over specimen. The schematic of experimental electrical connection is shown in Fig. 3. For the electrically assisted rapid heating experiment under a non-continuous electrical electric current was generated by Vadal SP-1000U welder (Hyosung, South Korea) with a programmable controller.

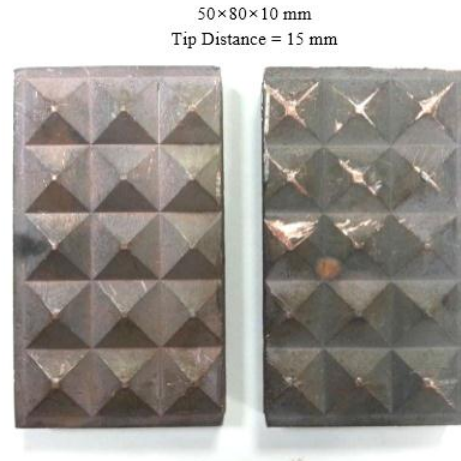
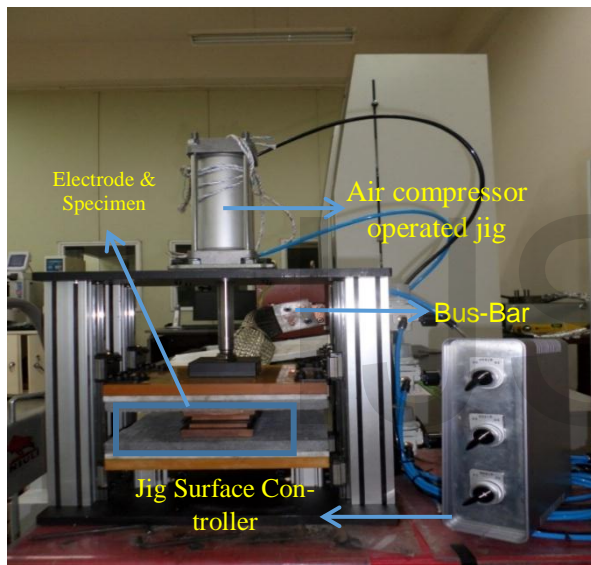


Fig. 2. Multi contact points of electrode



(a)

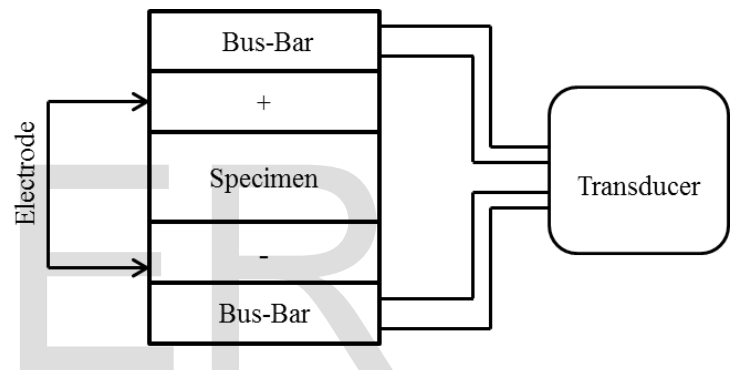
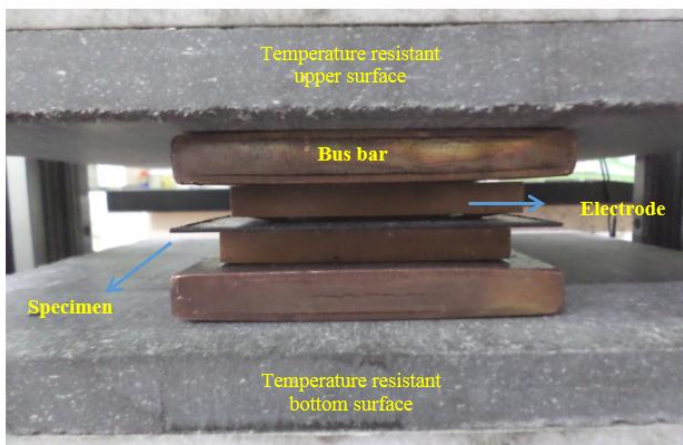
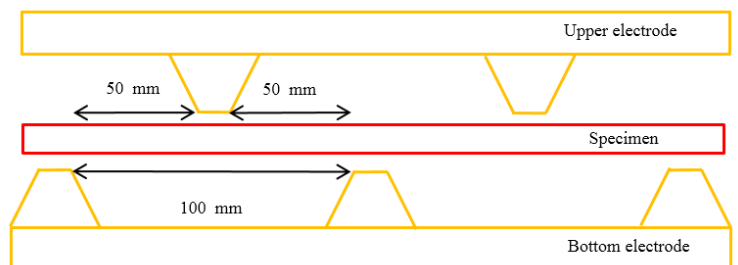


Fig. 3. Schematic of electrical current connection

During experiment electrode's set up of both side of specimen was not parallel. The setup is schematically shown in Fig. 4. By setting up electrodes of both side of specimen according to the Fig.3 we observed thermal flow through the point contacts. Temperature profile provides uniform temperature over specimen. A Multi pulse of electric current was used to heat the specimen locally. For electrically assisted rapid heating the temperature of the specimen through thickness was measured by a FLIR-T621 infrared thermal imaging camera (FLIR, Sweden). Special insulation was used in jig so that there was no heat energy loss during experiment. At the starting of the experiment the room temperature was  $12^\circ\text{C}$ .



(b)

Fig. 1. (a) Experimental setup (b) close view of experimental setup (electrode and specimen)

Fig. 4. Schematic of electrode set up

### 2.3 Temperature Calculation

Due to passage of electric current through a specimen, the temperature is generated. The amount of heat released is proportional to the square of the current such that:

$$Q = I^2Rt$$

The temperature increment ( $\Delta T$ ) is calculated from the adiabatic approximation:

$$Q = I^2Rt = mc\Delta T$$

$$\Delta T = \frac{I^2Rt}{mc}$$

where,  $\Delta T$  (0C) is the temperature increment of specimen, I (A) is the current traveling through the specimen, R is resistance of specimen, t (sec) is the duration of applying current into specimen, m (kg) is the quality of specimen, c (J/Kg.K) is the specific heat of specimen. The concept of electrically assisted local rapid heating was examined by employing different electrical pulse with a fixed amount of current and duration, as listed in Table 1.

Size of electrode (Tip distance)	Current (A)	Number of Pulses
15 mm	3000	17

## 3 RESULT

### 3.1 Temperature

The temperature rising rate of the blank by electrically assisted local heating is shown in Fig.5. Heating the blank to austenite temperature about 900°C required very short period by using multiple contact points of electrode heating. During heating multi pulsed electric current was applied. At certain temperature around 620°C holding time was used for cooling. Holding time was around 10 seconds. By using the holding time temperature was spread over the specimen evenly as well as Al-Si intermetallic was increased. Intermetallic is useful to protect from the oxidation and decarburization of Al-Si coated steel.

### 3.2 Intermetallic Development

By using holding time during rapid heating of Al-Si coated steel at room temperature, the Al matrix and the Si distribution cannot be distinguished because of their equivalent atomic

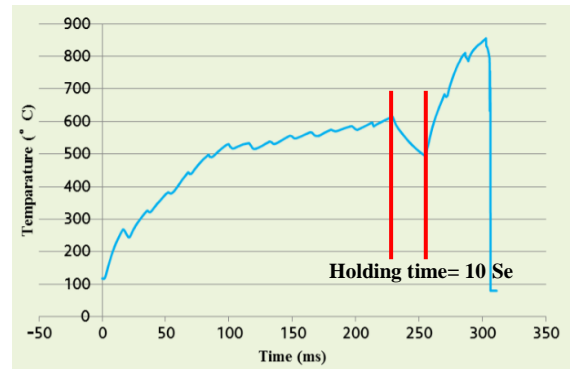


Fig. 5. Temperature profile by pulsed current of heating

weights. Comparing with base materials, the intermetallic layers of heated specimens are thicker due to the reaction of the coating with the substrate steel. As can be summarized in figure 6 that EA heating specimen achieved the highest result of  $5.04 \pm 0.66 \mu\text{m}$  of intermetallic layer while it was  $3.75 \pm 0.13 \mu\text{m}$  in case CH and  $3.24 \pm 0.58$  in case IH. Fig. 6 shows the OM view of development of intermetallic after heating the blank with respect to no heat treatment.

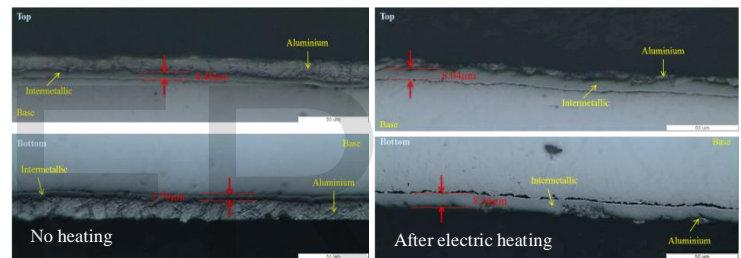


Fig. 6. Intermetallic development by pulsed electric current

### 3.3 Temperature Distribution

The steady temperature variation in the blank is shown in Fig.7. The temperature of the blank fluctuated due to heat generation in contact points of electrodes by multiple pulses of electric current. As we see in Fig.7, temperature generated at the initial stage of heating was not uniform over the blank. We marked two points (A, B) on thermal image of different stages of heating and analyzed the heat distribution. At initial stage Fig.7 (a) (300°C) between two points we can see unsteady temperature distribution of heating that is marked with red box. Furthermore, in Fig. 7 (b) higher temperature (470°C) the unsteady temperature region was reduced due to heat generation and spreading over the blank. Finally, at 900°C in Fig. 7(c) we see the uniform temperature distribution of blank.

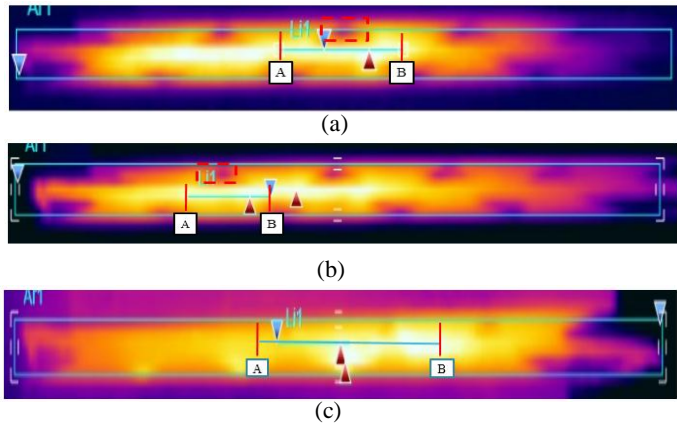


Fig. 7. (a) Temperature distribution at 300°C over specimen; (b) Temperature distribution at 450°C over specimen; (c) Temperature distribution at 850°C over specimen

### 3.4 Tensile Test

After rapid heating, specimen was observed carefully. Centre part of the blank was locally heated shown in Fig. 8 (a). Discolored parts inside the heated area is being considered as result of cooling the specimen consisting of spraying through the copper electrodes. Tensile test was carried out by tensile specimen which produced in a heated area, as shown in Fig.8 (a). Tensile speed was 2mm/min. The average value of tensile strength from locally heated blanks is about more than 1 GPa. Tensile test result is shown in Fig 8 (b).

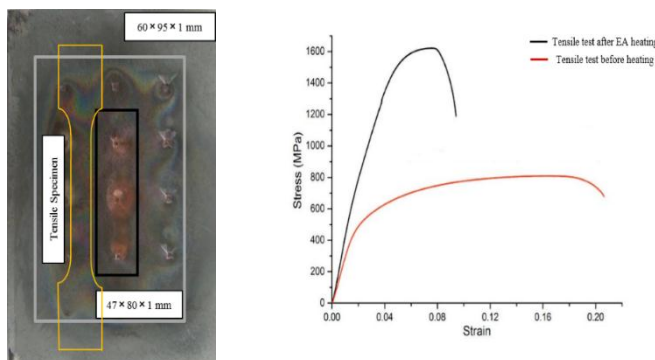


Fig. 8. (a) Heated specimen and schematic of tensile specimen for the heated zone; (b) Tensile test after rapid heating

### 3.5 Hardness Distribution

The hardness was tested under 430 SVD Vickers Instrument. The hardness data of the blanks represented an average measurement of five different points considering heated zone, transition zone and unheated zone. The heated area's hardness varies from 620 HV to 680 HV, which indicated full martensite

obtained in this area. While the hardness of transition area varies from 453 HV20 to 643 HV20. Finally the unheated area hardness was measured and the value is 149.5 HV. Every hardness value was measured by double checking with its repeatability value. These results demonstrated the hot stamping blank with

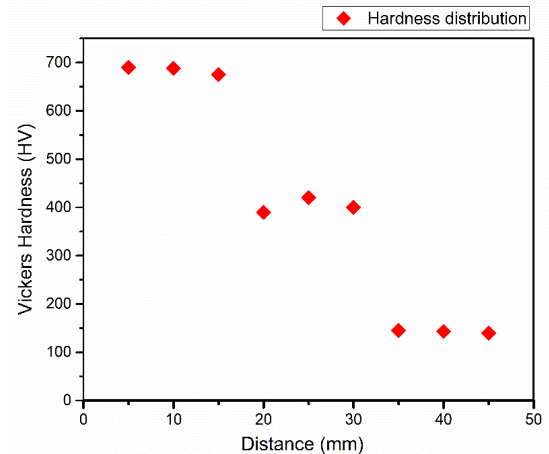


Fig. 9. Hardness distribution of heated blank of different regions

tailored properties was realized by means of local resistance heating. Hardness value is shown in Fig. 9.

## 4 CONCLUSIONS

The effect of hot stamping processes by using point contacts electrode local resistance heating of steel was studied. The processes included hot stamping and cooling by quenching. It was concluded that:

- The temperature rising profile was even at highest temperature.
- Temperature profile can be achieved more smooth and uniform without or less interval during electrical pulse.
- Partial local heating was properly done.
- Hardness of different region of heated specimen shows better result to get better mechanical properties.
- Tensile tests satisfied for better tailored properties.
- Intermetallic was observed by the effect of electric pulsed current.

## ACKNOWLEDGMENTS

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