Journal of Materials Science Research; Vol. 5, No. 3; 2016
ISSN 1927-0585 E-ISSN 1927-0593
Published by Canadian Center of Science and Education

Development of Electrically Assisted Rapid Heating for Metal Forming of Hot-Stamping Process

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Received: May 31, 2016 Accepted: June 11, 2016 Online Published: June 6, 2016

doi:10.5539/jmsr.v5n3p66 URL: http://dx.doi.org/10.5539/jmsr.v5n3p66

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.

Keywords: 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 (Chao, Yisheng, XiaoWei, Bin, & Jian, 2012). 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 (Karbasian & Tekkaya, 2010).

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% (Zhu, Zhang, Li， Wang, & Ye, 2011). Therefore, such types of high strength steel but low ductile parts are not suitable especially for energy absorbing parts of automotive vehicles (Wang, & Liu, 2014). 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 (Liang, Wang, & Liu, 2014). 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 (Mori, Maeno, & Mongkolkaji, 2013). According to Hein and Wilsius (2008) have partially prevented quenching by reducing the cooling rate with partially heated tools. On the other hand, Erturk et al. (2011) 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, Maki, and Tanaka (2005) have developed warm and hot stamping process of ultra-high strength steel using resistance heating. Mori, Maeno, and Fukui (2011) have applied resistance heating to heat the side wall of a cup between two electrodes to decrease flow stress. Mori, Maeno, and Fuzisaka (2012) 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, electrically assisted (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.

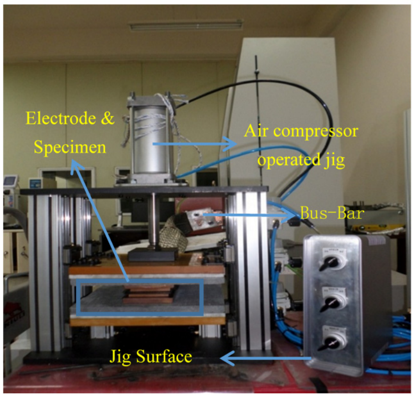
2. Experimental Setup

2.1 Materials

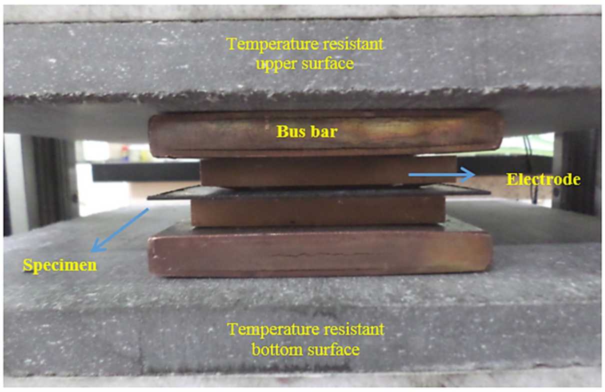
In this paper, the studied high strength steel belongs to specialized for hot stamping process, named BP4120B (HYSCO Steel, Korea). The thickness of the specimen was used in experiment was 1.0 mm. 1 mm thickness hot stamping material which was hot dip coated with a type 1 aluminized coating (87% Al - 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 Experimental Process

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 were prepared as the size of 65×95×1 mm^3. Custom made jig used for this experiment. Jig's upper plate was automatically moves by using hydraulic press. Figure 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 ~ 1000°C. Also two rectangular shapes (50×80×10mm^3) custom made electrodes with multi contact points designed/made to heat the blank locally for high temperature (Figure 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 Figure 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.



(a)



(b)

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

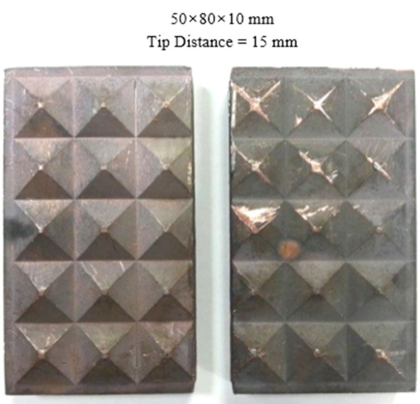


Figure 2. Multi contact points of electrode

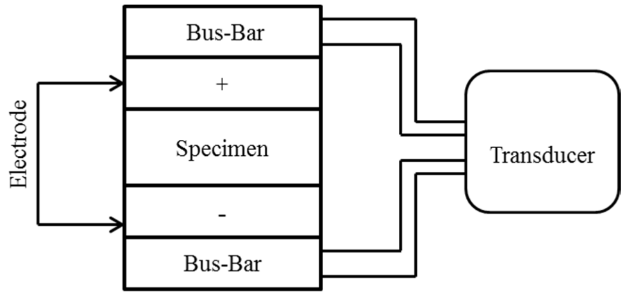


Figure 3. Schematic of electrical current connection

During experiment electrode's set up of both side of specimen was not parallel. The setup is schematically shown in Figure 4. By setting up electrodes of both side of specimen according to the Figure 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 infra-red 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°C.

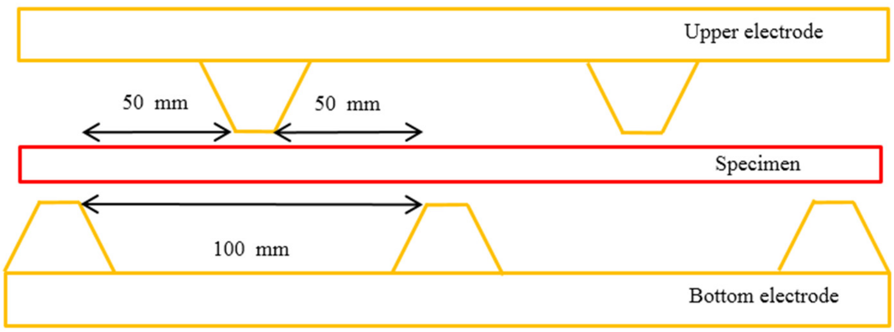


Figure 4. Electrode points position over specimen

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:

$$Q = I^2 Rt$$

The temperature increment (ΔT) is calculated from the adiabatic approximation:

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

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

Where, ΔT (^{0}C) 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.

Table 1. Experimental Parameters

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

3. Results

3.1 Temperature

The temperature rising rate of the blank by electrically assisted local heating is shown in Figure 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.

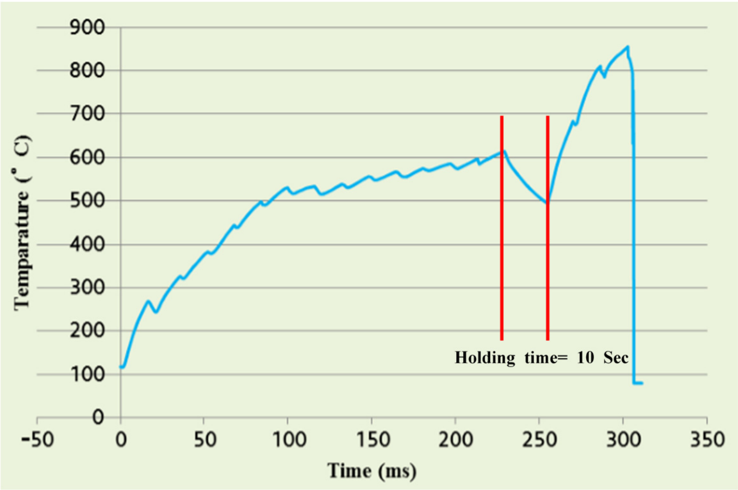


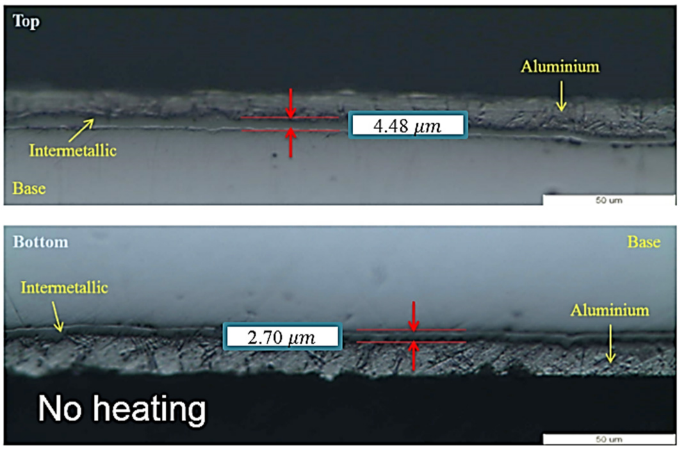
Figure 5. Temperature profile by multi pulsed electric heating

3.2 Intermetallic Developement

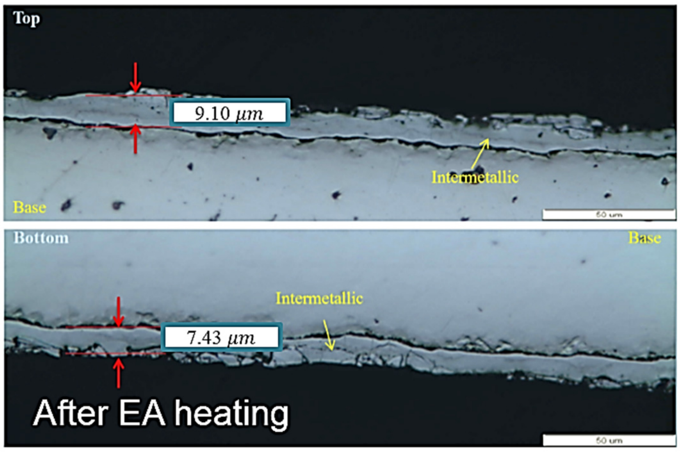
By using holding time during rapid heating of Al-Si coated steel at room temperature, the Al matrix and the Si distribution cannot be distinguished because of their equivalent atomic weights. Comparing with base materials, the intermetallic layers of heated specimens are thicker due to the reaction of the coating with the substrate steel. As can be summarized in Figure 6 that electrically assisted (EA) heating specimen achieved the highest result of 5.04 ± 0.66 µm of intermetallic layer while it was 3.75 ± 0.13 µm in case CH and 3.24 ± 0.58 in case of induction heating. Figure 6 (a) and (b) show the OM view of development of intermetallic after heating the blank with respect to no heat treatment. Use of electric current for heat treatment obtained result in intermetallic evolution which includes thin layer of Fe_2Al_5 phase constituent close to the Fe substrate and thick layer of Fe_4Al_{13} & FeA_{l3} phase constituents.

3.3 Temperature Distribution

The steady temperature variation in the blank is shown in Figure 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 Figure 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 Figure 7 (a) (300°C) between two points we can see unsteady temperature distribution of heating that is marked with red box. Furthermore, in Figure 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 Figure 7(c) we see the uniform temperature distribution of blank.

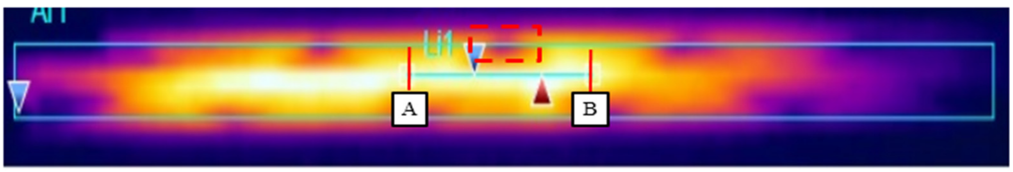


(a)



(b)

Figure 6. Development of intermetallic due to the effect of EA rapid heating (a) & (b)



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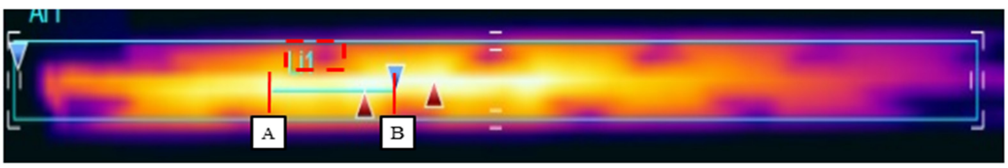

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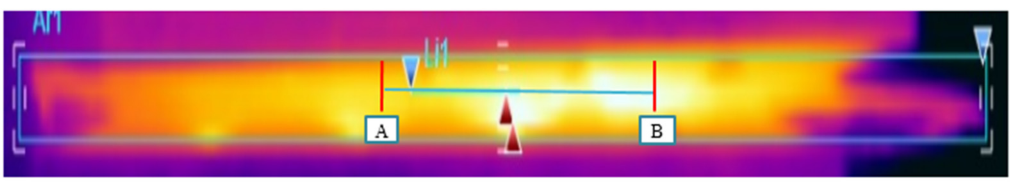

(c)

Figure 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 Figure 8 (a). Discolored parts inside the heated are 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 Figure 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 Figure 8 (b).

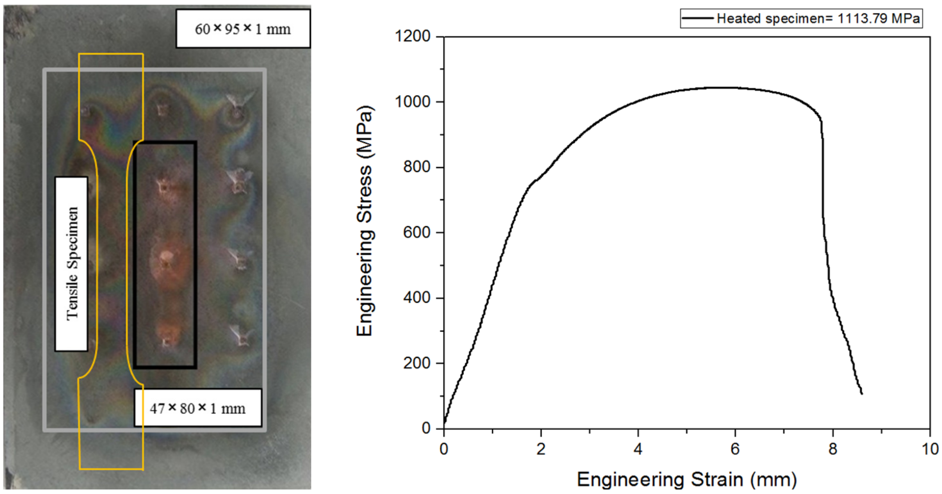

Figure 8. (a) Heated specimen and schematic of tensile specimen for the heated zone; (b) Tensile test after rapid heating

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. After electrically assisted rapid heating the area under heated zone became full martensite that represents the hardness value in graph. While the hardness of transition area varies from 453 HV20 to 643 HV20. Actually in transition region mixsturcutre was found and that's why fluctuation was observed in hardness value calculation. Finally the unheated area hardness was measured and the value is 149.5 HV. Unheated are had no effect of heat conduction even and the values are checked even after heating experiment. Every hardness value was measured by double checking with its repeatability value. These results demonstrated the hot stamping blank with tailored properties was realized by means of local resistance heating. Hardness value is shown in Table 2/Figure 9.

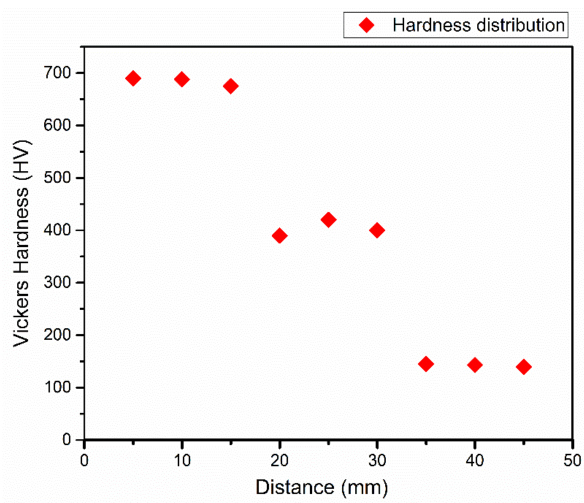

Figure 9. Hardness distribution of heated blank of different regions

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

This work is supported by Ulsan University fund.

References

Chao, W., Yisheng, Z., XiaoWei, T., Bin, Z., & Jian, L. (2012). Thermal contact conductance estimation and experimental validation in hot stamping process. *Scientia Sinica Tech., 55*(7), 1852. http://dx.doi.org/10.1007/s11431-012-4871-0

Erturk, S. (2011). Simulation of Tailored Tembering with a thermo-mechanical metallurgical model in autiform. *AIP-Proceedings, 1383*, 610. http://dx.doi.org/10.1063/1.3623664

Hein, P., & Wilsius, J. B. (2008). Status and innovation trends in hot stamping of USIBOR 1500 P. *Steel Research Int., 79*, 85-91.

Karbasian, H., & Tekkaya, A. E. (2010). A review on hot stamping. *J. of Mat. Process. Techn., 210*(15), 2103-2118.

Liang, W., Wang, L., & Liu, Y. (2014). Hot stamping parts with tailored properties by local resistance heating. *J. of Tech. of Plasticity., 81*, 1731-1736. http://dx.doi.org/10.1016/j.proeng.2014.10.222

Mori, K., Maeno, T., & Fukui, Y. (2011). Spline forming of ultra-high strength gear drum using resistance heating of side wall of cup. *CIRP Annals - Manuf. Tech., 60*, 299-302. http://dx.doi.org/10.1016/j.cirp.2011.03.144

Mori, K., Maeno, T., & Fuzisaka, S. (2012). Punching of ultra-high strength steel sheets using local resistance heating of shearing zone. *J. of Mat. Process. Techn., 212*, 534-540. http://dx.doi.org/10.1016/j.jmatprotec.2011.10.021

Mori, K., Maeno, T., & Mongkolkaji, K. (2013). Tailored die quenching of steel parts having strength distribution using bypass resistance heating in hot stamping. *J. of Mat. Process. Techn., 213*, 508-514. http://dx.doi.org/10.1016/j.jmatprotec.2012.10.005

Mori, K., Maki, S., & Tanaka, Y. (2005). Warm and hot stamping of ultra-high tensile strength steel sheets using resistance heating. *CIRP Annals - Manuf. Tech., 54*, 209-212. http://dx.doi.org/10.1016/S0007-8506(07)60085-7

Wang, Z., & Liu, P. (2014). Hot stamping of high strength steel with tailored properties by two methods. *J. of Tech. of Plasticity., 81*, 1725-1730. http://dx.doi.org/10.1016/j.proeng.2014.10.221

Zhu, B., Zhang, Y., Li, J., Wang, H., & Ye, Z. (2011). Simulation research of hot stamping and phase transition of automotive high strength steel. *Mat. Researc. Innov., 15*, 426-430. http://dx.doi.org/10.1179/143307511X12858957675435