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A local heating method by near-infrared rays for forming of non-quenchable advanced high-strength steels

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ABSTRACT

A forming process by local heating using near-infrared rays (NIRs) is proposed to reduce springback of non-quenchable advanced high-strength steels, such as dual-phase steels, that are not suitable materials for hot stamping. NIR lamps show outstanding cost performance, and the width of the heating area can be controlled by designed reflectors. To confirm the advantages of NIR local heating, DP980 sheets were heated by two methods – NIR local heating and furnace heating, which heats the whole material. V-bending and 2D-draw bending were conducted with heated DP980 sheets. Results showed that NIR local heating has advantages over furnace heating in both shape accuracy and hardness.

1. Introduction

With the increased concerns of environmental and safety issues, industries have paid closer attention to advanced high-strength steels, but the high degree of springback in advanced high-strength steels has been an obstacle to their widespread use. Hot stamping is appropriate for forming quenchable advanced high-strength steel parts, such as boron alloyed steels, because of the hardenability of the materials. Merklein and Lechler (2006) studied the thermo-mechanical properties for hot stamping steel, and details of hot stamping are well described by Karbasian and Tekkaya (2010). Kolleck et al. (2009) proposed a two-step induction heating method for hot stamping. However, non-quenchable advanced high-strength steels, such as dual-phase steels, do not have sufficient hardenability to take advantage of hot stamping. Therefore, other warm-forming methods have been studied in order to reduce springback of non-quenchable advanced high-strength steels. Mohammad and Mahdi (2011) used chamber heating for warm forming of DP600 sheets. Mori et al. (2005) applied resistance heating to high-strength sheets with a tensile strength of 980 MPa. Because generally only a limited area of the material is deformed in sheet metal forming processes, heating of the whole die or the material will result in a waste of energy. As a solution to this drawback, local heating methods that heat the area where plastic deformation occurs have been proposed. Park et al. (2011) proposed an incremental induction heating method for incremental bending of DP590 sheets, and Romero et al. (2010) conducted laser-assisted conical spin forming of dual-phase steels. Neugebauer et al. (2009) studied the effect of local laser heat treatment on the microstructure and mechanical properties of dual-phase steels. This study indicates that local laser heat treatment results in the decomposition of martensite, which then leads to reduction in yield stress and tensile strength, and an increase in elongation. Their results imply that the decomposition of martensite results in a reduction of springback in dual-phase steels. This occurs because a high degree of springback in dual-phase steels is due to its high yield strength and tensile strength, as documented by Bekar et al. (2011).

Mori et al. (2013) described the advantages and disadvantages of laser and induction heating. Although laser heating methods provide rapid heating, the heating zone is too narrow with high investment. Induction heating has to have a large inductor system for homogeneous heating when forming sheet metal. Furnace heating has the advantage of homogeneous heating. However, this heating method consumes a lot of energy and involves inconvenient handling. Near-infrared ray (NIR) lamps are inexpensive compared to other heating devices, and with the help of designed reflectors, the heating performance of NIR lamps can be enhanced and the width of the heated area can be controlled. In the present work, both elliptical and parabolic reflectors were used with an NIR lamp in order to control the width of the heating area when heating DP980 sheets. Unvala and Maries (1973) obtained a concentrated heating zone by using a halogen lamp in an ellipsoidal

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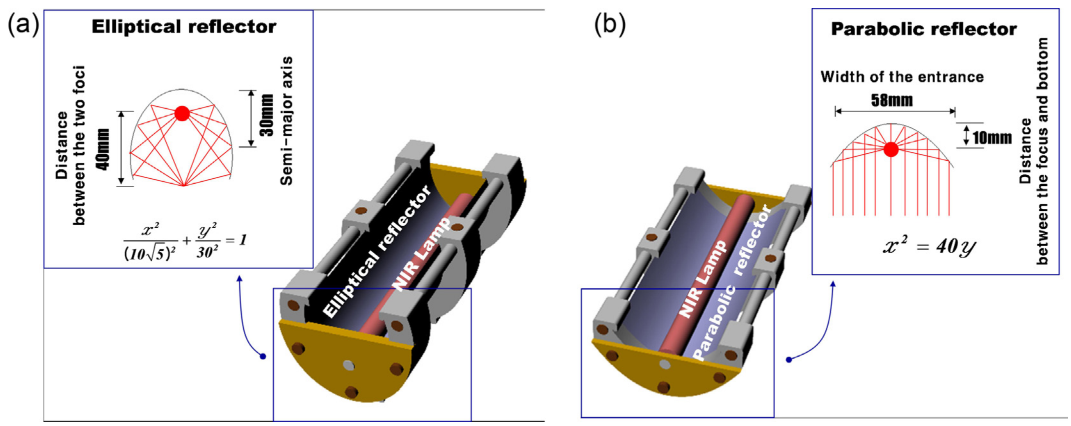

Fig. 1. NIR heating devices: (a) elliptical heating device and (b) parabolic heating device.

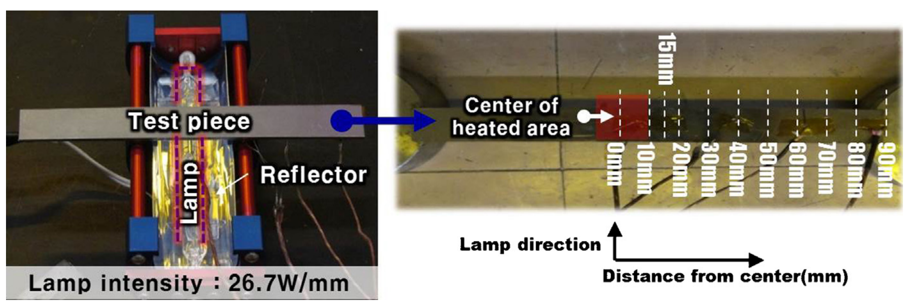

Fig. 2. Temperature measurement in the heating experiment of the NIR heating device.

reflector. Gutzeit and Kushch (2006) studied the intensity of collimation beams made by each quasi-parabolic reflector with an electrodeless lamp.

The purpose of this work is to confirm the reduction of springback without considerable change in mechanical hardness of DP980 due to heat treatment by NIR local heating. By using NIR local heating devices, DP980 sheets were locally heated to a temperature below the austenization temperature (Ac3 temperature) in order to minimize hardness changes induced by phase transformation. V-bending and 2D-draw bending experiments were then carried out under various temperature conditions to analyze springback and hardness changes corresponding to temperature. The results showed that NIR local heating has sufficient potential for non-quenchable advanced high-strength steels. A comparison of the results with those of furnace heating, which heats the whole material, has shown that NIR local heating bends sheets more accurately and does not appreciably reduce hardness at the same temperature. Since bending and drawing are important forming mechanisms in sheet metal forming, the results of this study provide an indicator to judge the applicability of NIR local heating for sheet metal forming.

2. NIR local heating methodology

Two kinds of NIR local heating devices were made, as shown in Fig. 1. One was an elliptical heating device, which was composed of an NIR lamp and an elliptical reflector. The other was a parabolic heating device, which was composed of an NIR lamp and a parabolic reflector. The shape of the elliptical reflector made in this work is expressed as (Stewart, 2001)

$$\frac{x^2}{(10\sqrt{5})^2}+\frac{y^2}{30^2}=1 \quad (1)$$

The distance between the two foci was 40 mm, and the length of the semi-major axis was 30 mm. The heat intensity per unit length of the NIR lamp was 267 W/mm. The shape of the parabolic reflector used in this work can be depicted as (Stewart, 2001)

$$x^2=40y \quad (2)$$

The distance between the focus and bottom of the parabolic reflector was 10 mm, and the width of the entrance was 58 mm.

To analyze the heating characteristics of these heating devices, a heating experiment was conducted. The test piece was placed perpendicular to the longitudinal direction of the heating device, and temperature was measured at 11 locations, as shown in Fig. 2. For measuring temperature, K-type thermocouples were welded at each point. The dimensions of each experimental piece were 180 mm × 20 mm × 12 mm. Since the sheet thickness was 12 mm, there was little difference in temperature distribution in the through-thickness direction. The center of the experimental piece was heated to 1073 K, which is below the Ac3 temperature, about 1120 K. The value of Ac3 temperature has been provided by the supplier, and confirmed by another calculation which uses the

Table 1
Chemical composition (wt%) of the DP980 used in this work.

Chemical composition (DP980)	C	Si	Mn	P	S	Cr	Ni	Mo	Cu
	0.150	1.280	2.230	0.016	0.003	0.023	0.019	0.009	0.016