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Effect of an aluminum driver sheet on the electromagnetic forming of DP780 steel sheet

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ABSTRACT

Some experimental studies have proved that materials with low electrical conductivity and even nonconductive materials can be formed using driver sheets with high electrical conductivity. This study investigated the effect of an aluminum driver sheet on the forming peak height of advanced high-strength steel sheet (AHSS) in the electromagnetic forming (EMF) process. DP780 workpieces were formed into a hemi-elliptical protrusion shape, analogous to a reinforcement rib, with various thicknesses, sizes, and material types of the aluminum driver sheets. These experiments were performed with a flat spiral coil actuator connected to the EMF system with a high energy capacity. In addition, three-dimensional coupled electromagnetic-mechanical finite element (FE) simulations were conducted to analyze the effect of the aluminum driver sheet on the forming peak height of the high-strength steel sheets and to predict the proper configuration of the aluminum driver sheet.

1. Introduction

There is a recent global trend in the automotive industry of increasing the use of high-strength steel sheets aiming at producing lighter and safer cars. More specifically, advanced high-strength steel (AHSS) sheets have been applied in the production of impact energy-absorbing members. To enhance their strength and rigidity further, reinforcement ribs are often formed at the side walls of the members. Recently, Eguia et al. (2010) showed the potential of the electromagnetic forming (EMF) process to form shallow longitudinal reinforcement ribs in the lateral walls of roll-formed parts, made of conventional steels with a tensile strength of 340 MPa in a continuous manner.

The EMF process is a high-speed forming technique that uses electromagnetic force to deform workpieces (Boulger and Wagner, 1960). In the EMF process, high-density electric current generated by discharging a capacitor bank on a conductive coil causes a transient magnetic field on the coil, and the magnetic field induces an electric current on the nearby workpiece. This induced electric current is called the eddy current. The interaction of the magnetic field and eddy current generates a Lorentz force that forms the workpiece (Psyk et al., 2011). The EMF process offers several advantages compared to the traditional quasi-static metal forming process. First, its high velocity is known for its potential of formability improvement (Balanethiram et al., 1994) and springback reduction (Correia et al., 2008). Additionally, the cost of the forming process can be reduced because the contactless application eliminates the necessity of a male punch and lubricant. However, this technique has the disadvantage of requiring the workpiece to be electrically conductive where the eddy current is generated. Although Eguia et al. (2010) successfully formed reinforcement ribs in conventional steels with a tensile strength of 340 MPa, it is not easy to accomplish this in higher-grade AHSS sheets because of their higher yield strength and lower electrical conductivity.

In order to form a workpiece with low electrical conductivity, the additional use of a highly electrically conductive material, so-called a driver sheet, was alternatively considered. Many experimental studies have proven that materials with low electrical conductivity, even nonconductive materials, can be formed using a driver sheet with high electrical conductivity. Weimar (1963) first introduced the basic concept of forming materials with low electrical conductivity. By placing a driver sheet with high

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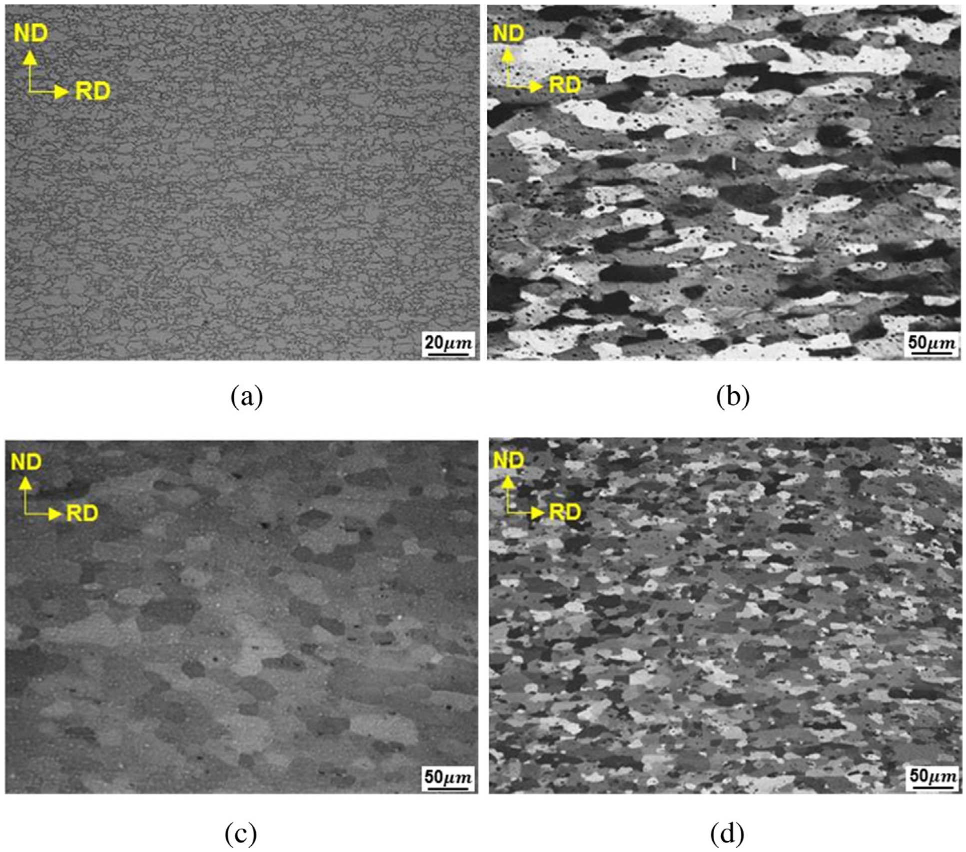

Fig. 1. Optical microstructures: (a) DP780, (b) AA1050, (c) AA3003 and (d) AA5052.

electrical conductivity between the workpiece and the electrically conductive coil, a large amount of Lorentz force is generated on the driver sheet. Because of the contact between the driver sheet and the workpiece, the Lorentz force is mechanically transferred to the workpiece. Sano et al. (1986) obtained a United States patent regarding the EMF method using a driver sheet. Dengler and Glomski (1991) as well as Desai et al. (2011) claimed that an aluminum sheet should be favored as a driver sheet material, because of its high electrical conductivity and low yield stress. Furthermore, Desai et al. (2011) investigated a comparison between aluminum and copper driver sheets using numerical simulation. Li et al. (2013) investigated the numerical simulation method of EMF for low electrically conductive metals with a driver sheet. Recently, Gies et al. (2014) experimentally determined the optimum thickness of copper and aluminum driver sheets and concluded that it depends on the conductivity of a workpiece and on the yield stress of a driver sheet. Furthermore, the effect of the driver thickness has been investigated by the aforementioned experiments and simulations. See Gies et al. (2014) for reviews of the current literature on the effect of the driver sheet thickness. They lead to the conclusion that the optimum thickness of the driver sheet is determined by interaction of the increasing Lorentz force and increasing consumed force as the driver sheet becomes thicker. Meanwhile, when the eddy current is generated on the workpiece by the magnetic flux density, its strength depends on the depth of the penetration, called skin depth. Note that the skin depth is defined as

$$\delta = \frac{1}{\sqrt{\pi \kappa \mu f}} \tag{1}$$

where f is the frequency of the electric current, and κ and μ are the electric conductivity and magnetic permeability of the workpiece, respectively. Tillmann et al. (2008) as well as Sano et al. (1986) recommended a driver thickness equal to the skin depth. Belyy et al. (1996) claimed that the optimum driver thickness is same to half of the skin depth. The numerical results of Desai et al. (2011) showed that the optimum thickness of an aluminum driver is $0.83{\cdot}\delta$mm, whereas a driver made of copper should have a thickness equal to the skin depth.

Studies on the EMF process for AHSS sheets having a tensile stress of 780 MPa with a driver sheet are limited (Kim et al., 2016). In order to properly form a reinforcement rib on AHSS member parts with a driver sheet, it is necessary to investigate the following questions on the configuration of the driver sheet: What is the best material for the driver sheet, and what is its optimum size and thickness? Therefore, this study experimentally and numerically investigated how the thicknesses, sizes, and material types of the aluminum driver sheet affect the forming peak height for the AHSS sheets. Some experimental results of this study have been partially presented previously with additional details presented here (Park et al., 2014). Advanced high-strength, dual phase (DP) 780 steel sheets were utilized as workpieces, and aluminum alloy sheets were used as driver sheets. To account for the effect of the configuration of aluminum driver sheets, several thicknesses and sizes and material types of aluminum alloy were considered. Experiments were performed with a flat spiral coil actuator connected to an EMF system. In order to consider the reinforcement rib forming, hemi-elliptical protrusions were formed by an open cavity die. In addition, three-dimensional coupled electromagnetic-mechanical finite element (FE) simulations were conducted to analyze the effect of the aluminum driver sheet on the forming peak height of the DP780 steel sheets and to predict the proper configuration of the aluminum driver sheet.