Experimental Study on Electromagnetic Forming of High Strength Steel Sheets with Different Dimensions of Aluminum Driver Plate*

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Abstract

Recently, the potential of the electromagnetic forming process has been introduced to form the shallow longitudinal reinforcement ribs in the lateral walls of roll formed parts, made of high strength steel sheets of 340MPa tensile stress grade [1]. However, it seems that the application may not be easy for high strength steel sheet because of its high tensile strength and low electric conductivity. In order to overcome this difficulty, aluminum driver plate could be considered to enhance the formability of high strength steel sheets in the electromagnetic forming process. In this paper, in order to investigate the effect of aluminum driver plate on forming height of high strength steel sheet in electromagnetic forming process, DP780 workpiece sheets were formed into a hemi elliptical protrusion shape with Al1050 driver plate of various thicknesses and sizes. Experiments were performed with a flat spiral coil actuator connected to an electromagnetic forming system. The results, the aluminum driver plate helps to increase the forming height of high strength steel sheets. In addition, the forming height of high strength steel sheet increases as the thickness and size of a driver plate increases.

Keywords

Electromagnetic forming, Flat spiral coil, High strength steel sheet, Aluminum driver plate, Reinforcement rib

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1 Introduction

There is a global trend nowadays of increasing the usage of high strength steel sheets in the automotive industry, aimed at producing lighter and safer cars. More specifically, high tensile steel sheets have been applied in the production of the impact energy absorbing member. Furthermore, to enhance their strength and rigidity more, the reinforcement ribs were often formed at the wall side of the members. Recently, Eguia et al. [1] showed the potential of the electromagnetic forming process to form the shallow longitudinal reinforcement ribs in the lateral walls of roll formed parts, made of high strength steels in a continuous manner.

Electromagnetic forming is a type of high speed forming where the electric current is induced on a specifically shaped coil to generate Eddy current, making a corresponding electric current on a conductive material and making an electromagnetic field on the coil, which generates the Lorentz force used to form the material [2]. It is widely renowned for its potential of formability improvement and springback reduction [3-5]. This technique can be easily used to form materials with a high electric conductivity, but has the disadvantage of requiring a driver plate to form materials with a low electric conductivity [6].

Although Eguia et al. successfully formed the reinforcement ribs with high strength steels sheets of 340 MPa tensile stress grade, it is not easy for high strength steel sheet of higher grade because of increasing tensile strength and decreasing electric conductivity. Therefore, aluminum driver plate might be used to enhance to formability of high strength steel sheets.

In this paper, It is experimentally demonstrated how the thickness and size of the aluminum used for driver plate affects the forming height of the high strength steel sheets. The high strength dual phase steel sheets, DP780 were utilized as a workpiece while aluminum alloy 1050-H16 sheet was used as a driver plate. Experiments were performed with a flat spiral coil connected to an electromagnetic forming system (EmFS) with the energy capacity of 119kJ. In order to consider forming the reinforcement rib, the hemi elliptical protrusions were formed by the open cavity die.

2 Experiments

2.1 Materials

Dual phase steel DP780 sheets with thickness of 1.4mm were utilized as workpiece sheet. The sizes of DP780 workpiece sheets were 200 x 200 mm^2. Aluminum Al1050-H16 sheets were chosen as driver plate because it has low tensile strength and high conductivity. The chemical compositions of DP780 workpiece sheet and Al1050 driver plate are listed in Table 1. The mechanical and electromagnetic material properties are summarized in Table 2.

Material							
Steel	**C**	**Mn**	**P**	**S**	**Si**	**-**	**Fe.**
DP780	0.070	2.26	0.012	0.0030	1.06	-	Bal.
Aluminum	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Al.**
A1050	0.25	0.40	0.05	0.05	0.05	0.05	Bal.

***Table 1**: Chemical composition of DP780 workpiece sheet and Al1050 driver plate.*

Material	Young's modulus (GPa)	Yield stress (MPa)	Tensile stress (MPa)	Total strain (%)	Electric conductivity (S/m)	Magnetic permeability (H/m)
DP780	210	546.9	832.4	23.89	7.04×10^{6}	8.75×10^{-4}
Al1050	71	90.78	108.1	8.07	3.55×10^{7}	1.26×10^{-6}

Table 2*: The mechanical and electromagnetic properties of DP780 workpiece sheet and Al1050 driver plate*

In order to investigate the effect of thickness of aluminum driver plate on forming height of high strength steel sheet, the DP780 workpiece sheets were formed into hemi elliptical protrusion shape in electromagnetic forming process without and with aluminum driver plate having thickness of 0.4, 0.6, 0.8 and 1.0mm. In this case, the size of Al1050 driver plate was fixed as 200 x 200 mm^2. On the other hand, the aluminum driver plate having sizes of 100x200, 150x200 and 200x200 mm^2 are adapted to investigate the effect of size of aluminum driver plate. In this case, the thickness of Al1050 driver plate was fixed as 1.0mm.

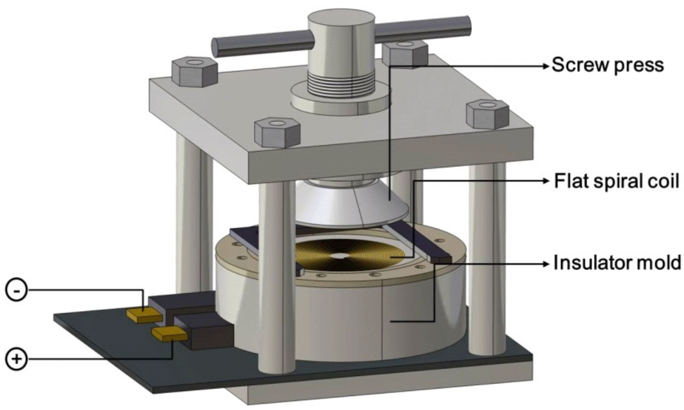


Figure 1: *Configuration of the flat spiral coil actuator*

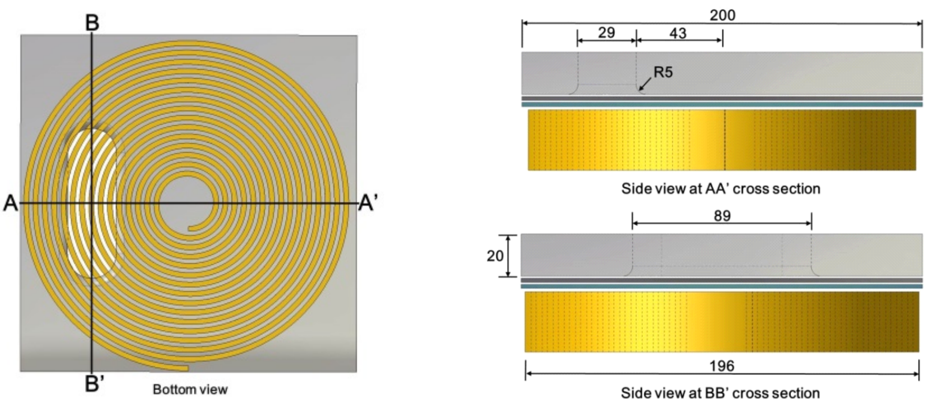


Figure 2: *(a) Bottom view and (b) side view of the flat spiral coil and the open cavity die (unit: mm).*

2.2 Electromagnetic forming

In order to form a hemi elliptical protrusion shape on the workpiece sheet with open cavity die, the flat spiral coil actuator was used as shown in Figure 1. The copper strip with cross sectional area 30 x 3 mm^2 was wound into spiral coil with fifteen turns. The gap between coil turns was 2.5mm. The flat spiral coil was insulated and fixed by epoxy resin inside of the insulator mold. The hole of open cavity die was machined at mean radius of the flat spiral coil to avoid the dead zone that occurs at the center of the winding [7-8] as shown in Figure 2 (a). Detailed dimension of the open cavity die is shown Figure 2 (b). The flat spiral coil actuator was connected to the electromagnetic forming system having a maximum stored energy of 119kJ for maximum working voltage of 17kV.

In this paper, all experiments were performed with charge voltage of 7.3kV. The representative current profile measured by an oscilloscope and a Rogowski flexible coil is shown in Figure 3.

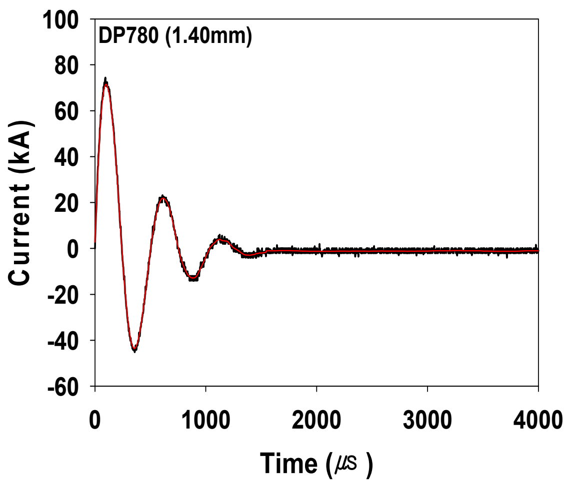
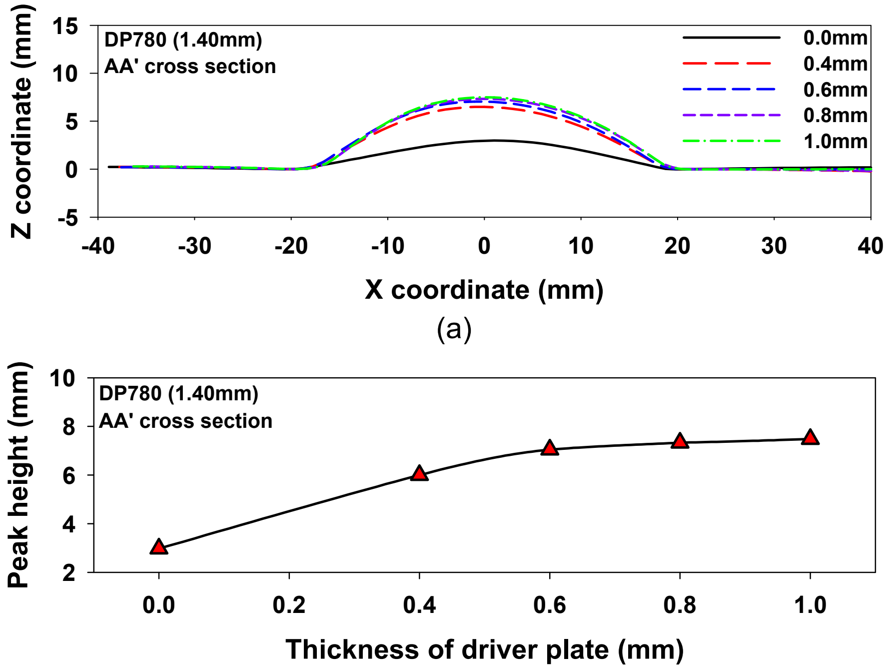


Figure 3: *Primary current profile measured for charge voltage of 7.3kV*



(b)

Figure 4: *(a) Forming shape in AA' cross section, (b) peak height of DP780 workpiece sheet with different thicknesses of Al1050 driver plate at charge voltage of 7.3kV.*

3 Results

3.1 Effect of thickness

Forming shape in AA' cross section and peak height of DP780 workpiece sheet after electromagnetic forming with different thicknesses of Al1050 driver plate are shown in Figure 4 (a) and (b), respectively. In these experiments, the size of driver plate was fixed as 200 x 200 mm^2. The peak height of DP780 workpiece sheet was remarkably increased when Al1050 driver plate was used as expected. In addition, the peak heights of DP780 workpiece sheet increase as the thickness of Al1050 driver plate increase and are gradually saturated while the thickness of Al1050 driver plate is approaching to 1.0mm.

3.2 Effect of size

Figure 5 shows the deformed shapes of the DP780 workpiece sheet and Al1050 driver plate after electromagnetic forming with the different sizes of Al1050 driver plate.

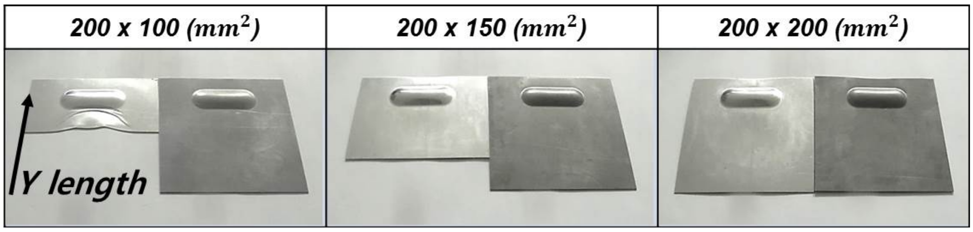


Figure 5: *Deformed shape of DP780 workpiece sheets after electromagnetic forming with the different sizes of Al1050 driver plate.*

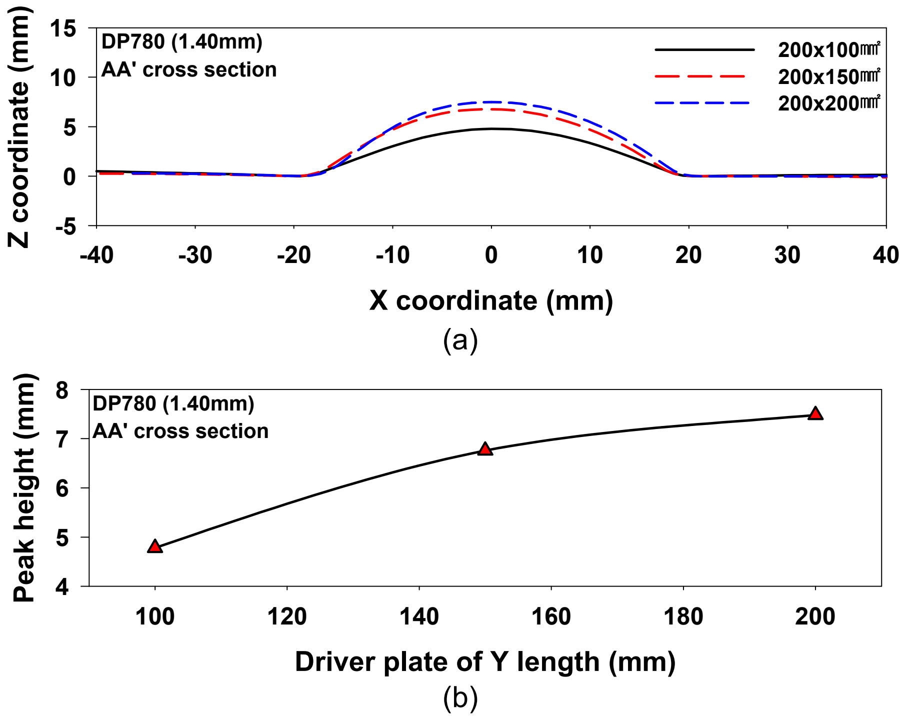


Figure 6: *(a) Forming shape in AA' cross section and (b) peak height of DP780 workpiece sheet with different sizes of Al1050 driver plate at charge voltage of 7.3kV.*

Forming shape in AA' cross section and peak height of DP780 workpiece sheet after electromagnetic forming with different sizes of Al1050 driver plate are shown in Figure 6 (a) and (b), respectively. In these experiments, the thickness of driver plate was fixed as 1.0mm. The peak heights of DP780 workpiece sheet decrease as the size of Al1050 driver plate decrease.

4 Summary

The effect of an aluminum driver plate has been investigated on electromagnetic forming of high strength steel sheet DP780 workpiece sheets were formed into hemi elliptical protrusion shape with Al1050 driver plate of various thicknesses and sizes in electromagnetic forming process. As results, the aluminum driver plate helps to increase the forming height of high strength steel sheet. In addition, the forming height of high strength steel sheet increases as the thickness and size of driver plate increases. The aluminum driver plate might be indispensable for electromagnetic forming of high strength steel sheets because of their low conductivity. It is expected that these results can be utilized to select proper dimensions of an aluminum driver plate.

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