

Improving the Rigidity of Sheet Metal by Embossing and Restoration Technique

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Abstract

Embossing and restoration technique is conducted as a simple method to strengthen sheet metals. Soft aluminum, mild steel and stainless steel sheets of different thickness are subjected to embossing and restoration at different sheet patterns and emboss height. Deflection tests are then conducted to evaluate the effects of the parameters considered on the increase in the rigidity of sheets. Experimental and numerical methods are both employed in the investigation. Results show that the restoration technique is effective in increasing the rigidity of thin sheet metals. By taking into considerations several important parameters, improvement in rigidity can be enhanced as shown in this study. Also, it should be emphasized that this technique can be used not only for increasing the rigidity of sheet metals but also for making decorative sheets without any special forming tools.

Keywords: sheet metal forming; restoration; embossing; FEM simulation; rigidity

1. Introduction

Sheet metal forming is one of the most important and commonly practiced fabrication processes in the manufacturing industry, ranging from the production of car body, outer panel of electric products and appliances, metal furniture and structural panels. Through the years, several efforts have been made in the sheet metal industry to improve efficiency and savings in energy and resources through reduction in weight and cost of the sheet metal product. For instance, in the automotive industry, the use of lighter gage high strength steel alloys, new density aluminum alloys and tailor-welded blanks (TWB) provide promising opportunities in reducing overall body weight and increasing mileage performance. The use of thinner sheets is a practical way for reduction of product cost and product weight. However, in utilizing a

lighter grade conventional sheet metal during press forming, some problems, such as increase in deflection due to its low rigidity and strength, arise. Moreover, the formability of the sheet also decreases with decreasing sheet thickness (Yamaguchi *et al.*, 1976 and Yamaguchi *et al.*, 1988). With the objective of overcoming these drawbacks, restoration technique (Yamaguchi *et al.*, 2002, Yamaguchi *et al.*, 2007, Namoco *et al.*, 2007, and Namoco *et al.*, 2006) has been proposed to strengthen sheet metals through simple means. The sheet metal is bulged by punch and then the embossed sheet is compressed between flat tools. As the sheet is subjected to these processes, the rigidity and strength are increased due to the unevenness of the metal shape which increases the section modulus and work hardening effect that is partially given to the sheet. Based on this interesting phenomenon, several parameters on how to enhance the mechanical properties of sheet metal through restoration process are investigated experimentally and numerically.

In the present investigation, the effects of embossing and restoration on the rigidity of sheet metals are investigated. Soft aluminum (Al-O), mild steel (SPCC) and stainless steel (SUS) sheets of different thickness are subjected to restoration process at different restoration patterns. The parameters considered are the number, position and pitch of emboss or restoration points. The emboss height is also varied. Deflection tests are then conducted to evaluate the effect of the parameters considered on the improvement in the rigidity of sheets. Both numerical (FEM) and experimental methods are employed in the investigation.

2. Experimental Methods

Soft aluminum (Al-O), mild steel (SPCC) and stainless steel (SUS) sheets of different thickness are used as specimens in the experiment. These specimens with dimension of 90mm x 115mm are subjected to embossing and restoration process of different patterns. By varying the number, position, and pitch of the emboss or restoration points, four (4) blank patterns are considered in this investigation. The experimental set-up of embossing and restoration is shown in Figure 1.

Embossing is conducted by some cycles of bulging process using fabricated dies (Figure 1(a)). The hemispherical punch used in embossing has a diameter of 6mm. After embossing, the specimens are compressed with the upper and lower platens as shown in Figure 1(b) to produce almost flat

sheets. A typical example of embossed and flattened sheets is shown in Figure 2. The details of the experimental conditions are shown in Table 1.

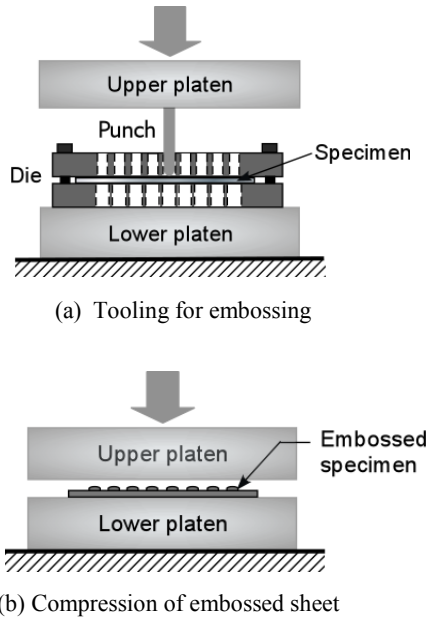


Figure 1. Experimental set-up of embossing and restoration

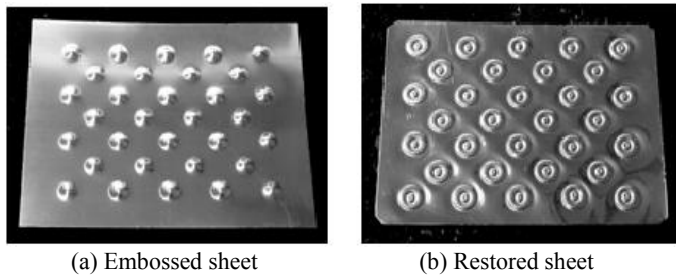


Figure 2. Typical example of specimens subjected to embossing and restoration

Table 1. Experimental conditions

Parameters	Dimension, mm
Specimen size	90 x 115
Sheet thickness	0.4, 0.8, 1.2
Punch diameter	6.0
Die diameter	8.0
Emboss height	1.0, 1.5, 2.0

Flexural experiments are then conducted to investigate the effect of embossing and restoration on the rigidity of sheet metals. The flexural test set-up is shown in Figure 3. During the deflection tests, two types of loading are being performed. In Type A loading, a concentrated load is applied by using a hemispherical punch in the center of the specimen supported at four points. On the other hand, in Type B loading, a distributed load is applied across the center in the direction normal to the longer width of the specimen using a cylindrical punch.

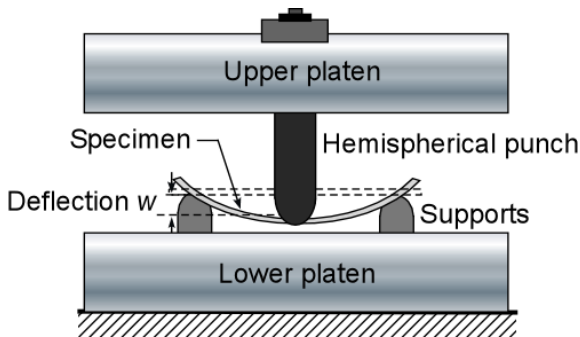


Figure 3. Flexural test set-up

3. Numerical Methods

Numerical simulations of embossing, restoration and deflection tests are conducted utilizing the explicit finite analysis code LS-DYNA3D (Hallquist, 2003). Throughout the simulations, symmetry is being taken advantage to reduce computational time and expense. Four blank patterns are created and modeled exactly the same with the experiment. These models are shown in Figure 4. During embossing, each punch is allowed to travel one at a time. Each emboss point corresponds to one punch. On the other hand, restoration is conducted by compressing an embossed specimen with upper and lower platens to produce almost flat sheets. The upper tool is allowed to slowly move downward while keeping the lower tool fixed. In Figure 5, the quarter models for the deflection tests are shown.

These two types of loading correspond to that of the experiment conducted. The sheet blank is modeled using the isotropic material model and is meshed using shell elements with Belytschko-Tsay element formulation and five integration points through the thickness. This material model is governed by the Hollomon power-law hardening rule defined as

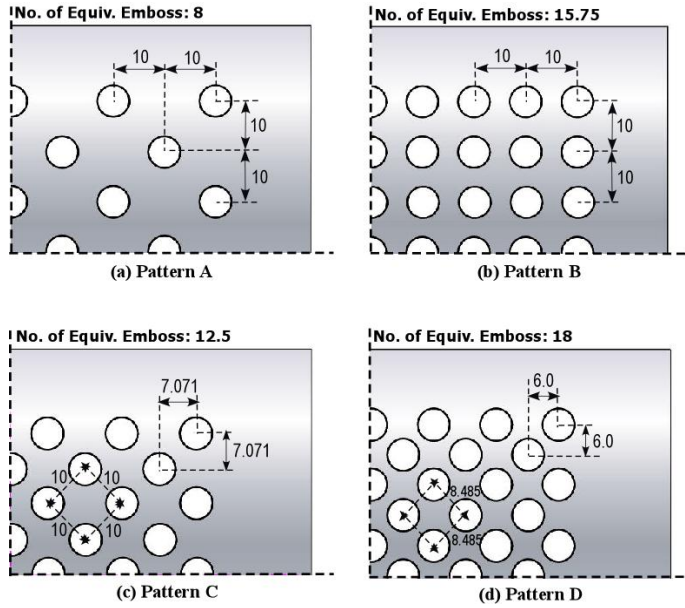


Figure 4. Quarter models of sheet blank patterns use in the simulation test (in mm)

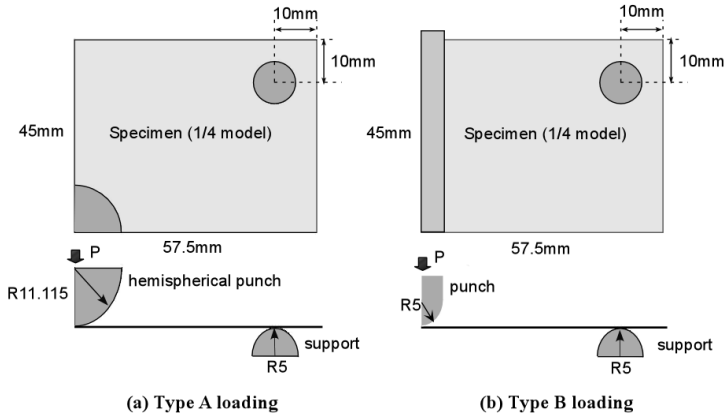


Figure 5. Quarter models used in deflection test simulations

$$\sigma = K \varepsilon^n \quad (1)$$

where K is the strength coefficient and n is the work hardening coefficient. The punch, die, holder, compression tools and support are created using rigid materials. The material properties used in the analysis which are derived from uniaxial tests are reported in Table 2.

Table 2 . Material properties used in the analysis

	Material		
	SPCC	Al-O	SUS
Young's modulus, E (GPa)	210	69	210
Poisson's ratio, ν	0.3	0.3	0.3
Plastic coefficient, K (MPa)	489	173	1641
Work hardening coefficient, n	0.21	0.24	0.47
Density, ρ (10^{-6} kg/mm ³)	7.8	2.7	7.8

The process conditions used in the finite element analysis are the same with that of the experiment in Table 1. The coefficient of friction used is 0.2 which corresponds to the no-lubrication condition. In the simulations of restoration and deflection tests, the restart input data method is used. The full deck restart has the capability to redefine contact surfaces, add new contact surfaces, replace or add parts, and many others. In the full restart analysis, the stresses, strains, displacements, and analysis time from previous analysis are carried over.

4. Results and Discussion

4.1 Effect of Blank Patterns on Rigidity

The number of equivalent emboss in the quarter model of sheet blank patterns A, B, C and D are respectively 8.0, 15.75, 12.5, and 18.0, as shown in Figure 4. Patterns A, C and D have similar emboss position with decreasing pitch value. On the other hand, in pattern B, the emboss points are positioned in such a way that they are directly aligned with each other. With this arrangement, a larger number of emboss points is needed for a given area.

Figure 6 shows the experimental results of load-deflection diagrams during flexural tests under Types A and B loading conditions. In both cases, a considerable increase in the rigidity of the sheet is being observed as the sheet is subjected to this technique. As the pitch is decreased, the amount of bending load is increased which means an increase in resistance to bending deformation. In Type B loading, the load is distributed along the width of the specimen.

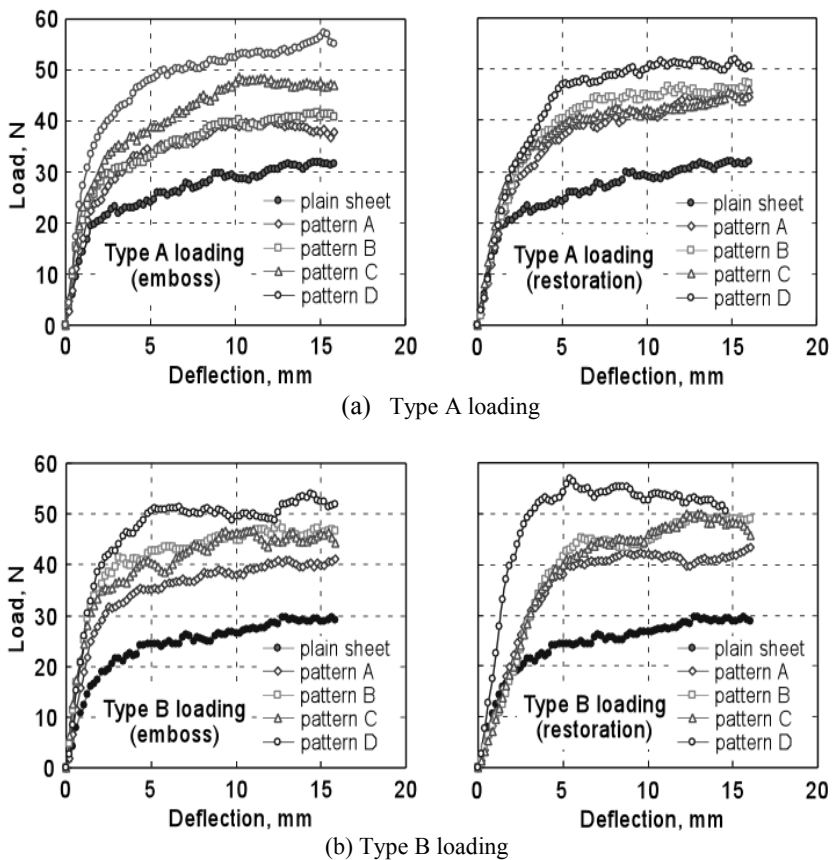
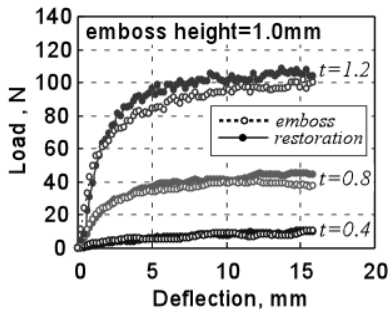


Figure 6. Experimental results of deflection test of different sheet patterns (Al-O; thickness=0.8mm; emboss height=1mm)

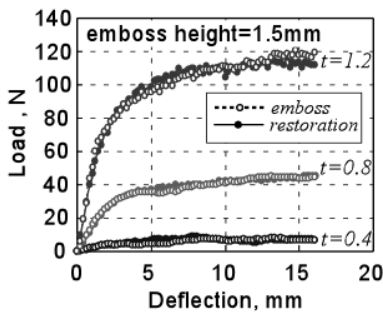
As shown in Figure 6 (b), the curves of Patterns B and C in either embossing or restoration are almost similar. This indicates that the rigidity of the sheet is more influenced by the positions of the emboss or restoration points. That is, the strengthening effect due to plastic deformation introduced during embossing and restoration process is more efficient in pattern C than in B.

4.2 Effects of Thickness and Emboss Height on Rigidity

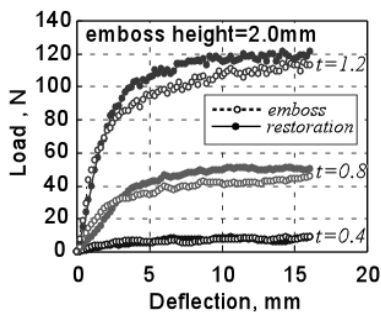
In Figure 7, the experimental results of flexural test of Al-O material with different sheet thickness and emboss height are shown. Results show that as the sheet thickness is increased, restored specimen requires higher loads to deform than embossed specimen. Results also show that the improvement in rigidity due to emboss height is not so pronounced.



(a) emboss height=1.0mm



(b) emboss height=1.5mm



(c) emboss height= 2.0mm

Figure 7. Deflection test results of Al-O (Pattern A) at different sheet thickness and emboss height

Figure 8 shows the relationships between emboss height and bending loads at various deflections, w , for SPCC and SUS materials (Pattern A; $t=1.2\text{mm}$). Experimental and numerical results are provided. The experimental results are somewhat lower than the simulation results, but both results show similar tendency. The discrepancy may be attributed to the material model and assumptions being considered in the study. Owing to its high strength

and higher n -value, SUS material shows higher rigidity among the materials tested in this study.

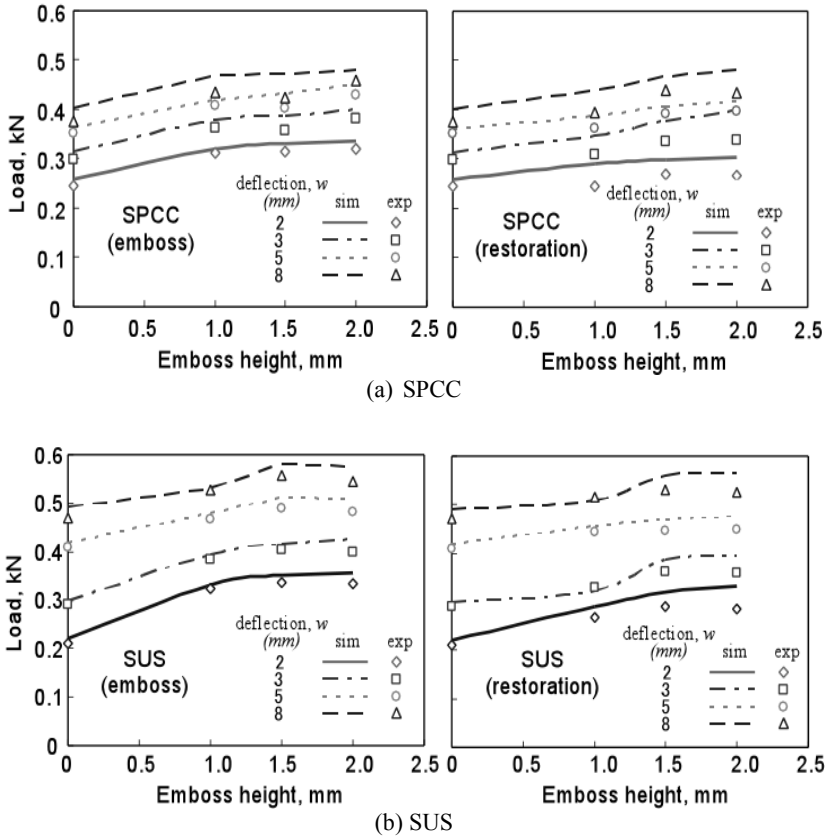


Figure 8. Relationship of emboss height and bending load at various deflection values, w , for SPCC and SUS materials (Pattern A; thickness=1.2mm; Type A loading)

4.3 Application to Production of Decorated Sheets

This proposed method has very unique features. In addition to the increase in rigidity of sheet metals by a very simple process, it has a unique characteristic that when the embossed specimen is compressed to a flat sheet, various wrinkle patterns appear automatically on the sheet surface due to buckling at the embossed portions as shown in Figure 2(b). The formation of wrinkle pattern is dependent on the sheet thickness, emboss height, and material properties (Namoco *et al.*, 2006b). This is an interesting finding in

the restoration process. Therefore, embossing and restoration technique can be used not only for strengthening of sheet metals but also for a sheet metal forming process to make decorative sheets, panels, doors and other metal coverings and other parts.

5. Conclusion

Experimental and numerical investigations are conducted to various sheet metals subjected to embossing and restoration. Results show that the proposed technique is an efficient way to improve the rigidity of thinner sheet metals, which leads to the reduction of formed parts. Furthermore, the improvement can be enhanced by taking into considerations several parameters such as number, position and pitch of emboss or restoration points as what has been done in this study. It should also be emphasized that this technique can be used not only for increasing the rigidity of sheet metals but also for making decorative sheets without any special forming tools.

6. References

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