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Effects of the Rotary Embossing Process on Mechanical Properties in Aluminum Alloy 1050 Sheet

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Heat shields are designed to protect components from heat damage, and one method of producing heat shields is with the embossing process. The embossing process is a sheet metal–forming method that is utilised in strengthening sheet metals. This method also increases the surface area useful for heat transfer. In this paper, the effect of this technique on the yield load, tensile load, bending strength and buckling strength for different sheet thicknesses of aluminium alloy 1050 sheets is investigated. Furthermore, the efficacy of this forming technique as a method for strengthening the sheets is discussed.

Key words: embossing, mechanical properties, work hardening, deformation, buckling

1. INTRODUCTION

Sheet metal forming is one of the most important processes used in the automotive industry. In automotive manufacturing, for instance, sheet metal is widely used in the car body and in various parts inside of the car. Over the years, different manufacturing methods have been developed to increase productivity and save energy and resources by reducing the weight of sheet metal. In addition, the use of thin sheets represents a simple solution for making cars lighter. However, serious problems occur when forming thin sheets of metals. As the thickness decreases, the rigidity or formability of the sheet metal can decrease.

Another important issue to consider is the heating of car components. Abrasions and fractional deformations occur as a result of overheating. However, heating is inevitable, and heat shields are required to prevent overheating. Excess heat is dissipated inside of heat shields, thus protecting heat-sensitive components. Heat shields consist of sheet metals, and aluminium alloy is generally used in the automotive industry. Aluminium is an ideal heat shield material because it is light weight, strong and malleable.

During the assembly of heat shields for automotive use, some problems may be encountered. These problems include cracking, tearing and wrinkling deformations of the sheets. To prevent these problems, the mechanical properties of the materials applied for embossing need to be identified so that necessary precautions may be taken.

In this study, the embossing process, which is one of the cold forming processes used to form sheet metal, is investigated. The effects of embossing on the mechanical properties of sheet metals are examined. The materials produced by the embossing process are used as heat shields. Embossing increases the surface area of the sheet metal, allowing for increased heat transfer. During this process, the most critical problems are thinning and tearing. As a means of preventing these problems, the effects of the embossing process on the material need to be thoroughly understood.

There have been several previous studies that have focused on the embossing process [1-3]. In these studies, the embossing process was conducted through several cycles of bulging using fabricated dies, and restoration was performed by compressing an embossed specimen with plates to produce nearly flat sheets. Namoco *et al*. [1] investigated the effects of embossing on the yield strength, tensile strength, total elongation and bending strength of different aluminium alloy sheets. Another study focused on the application of embossing and restoration for deep drawing sheet metals [2]. Although Namoco *et al.* only focused on the restoration process, work has been done to investigate restoration behaviour using aluminium, mild steel and stainless steel sheet metals subjected to bulge deformation, both experimentally and through FEM simulation [3]. Namoco *et al*. [4] studied embossing and restoration techniques utilizing different hexagonal, diamond and hemispherical tools. The processed sheets were then subjected to flexural tests at different types of loading. Numerical simulations of the embossing and res-

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toration process of different sheet metals utilizing different geometry of embossing punches were also carried out using LS-DYNA3D.

There have been also several previous studies that have researched aluminium alloy 1050 [5-12]. Moon *et al*. [5] investigated the effect of tool temperature on the reduction of the amount of springback of aluminum 1050 sheet. To overcome this problem, they suggested using the combination of hot die and cold punch. Gavas [6] examined increasing the deep drawability of Al-1050 aluminum sheet using a multi-point blank holder. In the deep drawing process, the use of a multi-point blank holder was very effective in achieving better drawability and higher drawing height. Lang *et al*. [7] studied hydromechanical deep drawing with uniform pressure on the aluminum blank both numerically and experimentally. The drawing ratio improvement, the quality of the formed parts, the thickness distributions of the formed parts and the process window were also investigated. Keum and Han [8] experimentally researched the springback effect of Al 1050 sheet metals at various temperatures in the warm forming. Lang *et al*. [9] investigated the effect of pre-bulging on the hydromechanical deep drawing process. Pre-bulging included two parameters: pre-bulging height and pre-bulging pressure. The pre-bulging pressure and the pre-bulging height were built by using pure aluminium (Al1050-H0) and aluminium alloy. On the other hand, FEM was used to analyze the forming process to explain some results which were found in the experiment. Hydromechanical deep drawing (HDD) with uniform pressure onto the blank was proposed and investigated both primarily in experiments and simulation for soft aluminum (Al1050-H0) by Lang *et al*. [10]. Moon *et al*. [11] studied increasing the deep drawability of Al-1050 sheet. The deep drawability of Al-1050 was found to be strongly sensitive to the temperature of the die and punch. Demirci *et al*. [12] examined the effects of fixed blank holder forces on the wall thickness distribution and wrinkles of Al-1050 sheet by using non-linear explicit finite elements method. As a result of the analysis, for smooth drawings of blank holder, the required forces were determined. The results were evaluated and experiments were done with the forces which were determined earlier. As a result of the experiments, 90 % consistency between the experimental and theoretic results was seen.

In this study, an embossing method, distinct from those used in previous works, is used. The effects of embossing on the yield load, tensile load, bending strength and buckling strength of aluminium alloy 1050 sheets are investigated. Here, the mechanical properties of the material are measured using tensile, 3-point bending and buckling tests.

2. EXPERIMENTAL PROCEDURES

In this study, plain specimens were embossed. The aim of these experiments was to determine the effects of embossing on the mechanical properties of the material and to explain the effects of thickness and bulge height on the embossing behaviour of sheet metals. Tensile and 3-point bending and buckling tests were used to measure the material properties of the samples.

Table 1. Specimens are used in the experiments

Thickness of sheet metal (mm)	Bulge Height-h (mm)	Thickness of sheet metal (mm)	Bulge height-h (mm)	Thickness of sheet metal (mm)	Bulge height-h (mm)
0.4	0 (plain)	0.5	0 (plain)	0.8	0 (plain)
0.4	0.8	0.5	0.8	0.8	0.8
0.4	1.5	0.5	1.5	0.8	1.5
0.4	2.2	0.5	2.2	0.8	2.2

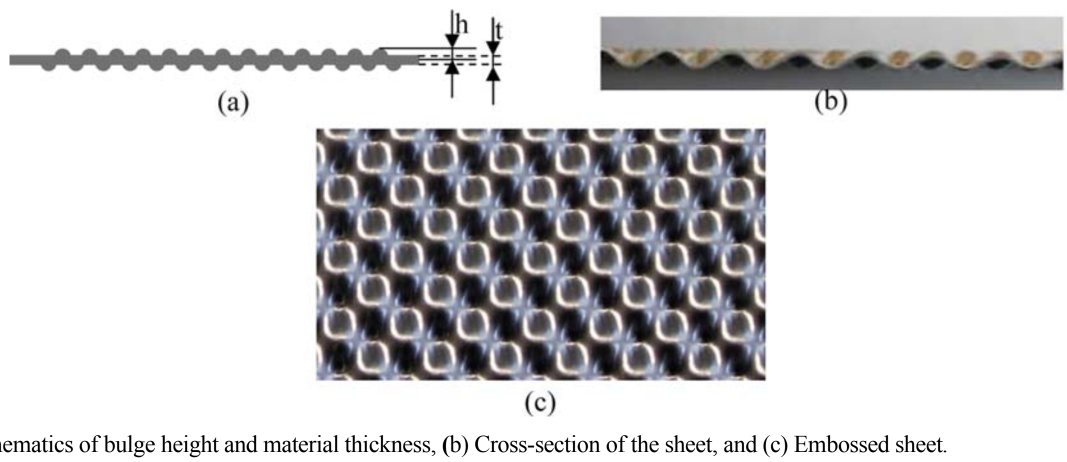

Fig. 1. (a) Schematics of bulge height and material thickness, (b) Cross-section of the sheet, and (c) Embossed sheet.

2.1. Material

Al 1050 alloyed aluminium of three thicknesses, 0.40 mm, 0.50 mm and 0.80 mm, was examined in these experiments. In addition, three different specimen bulge heights were also examined. The details of these specimens are given in Table 1 and Fig. 1.

2.2. Embossing process

Embossing is a method used to produce raised or sunken designs, using matched male and female roller dies. In this study, plain materials were embossed, and the distance between the two dies determined the thickness of the sheet metal. The rigid roller dies had a diameter of 700 mm and a length of 1300 mm and were driven at 21 rpm. The details of the embossing machine are shown in Fig. 2.

2.3. Tensile, 3-Point bending and buckling tests

Tensile and 3-point bending tests were applied to twelve different types of specimens, as described in Fig. 3. These tests measured the load values of each specimen. The gauge length was 30 mm for the tensile and 3-point bending tests and 80 mm for the buckling test.

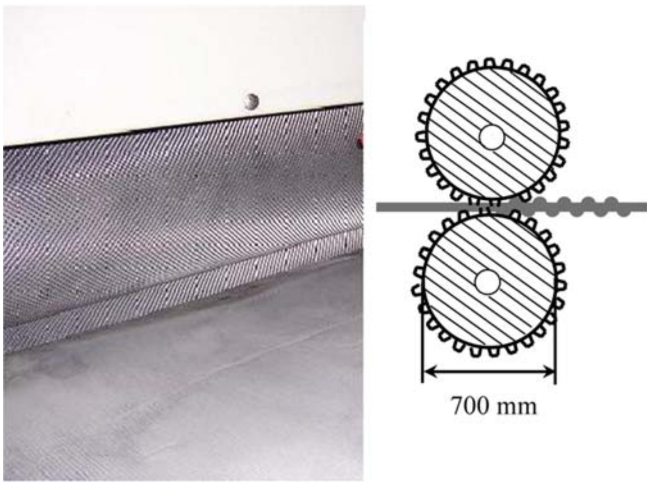

Fig. 2. Schematics of roller dies.

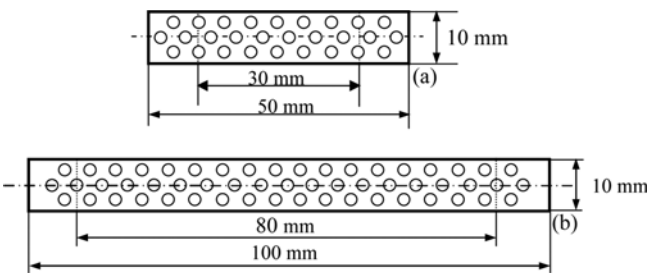

Fig. 3. (a) Schematic of tensile and 3-point bending specimen and (b) schematic of buckling specimen.

3. RESULTS AND DISCUSSION

3.1. Effects of the embossing process on yield load

Maximum yield load results are shown in Fig. 4 and Table 2. As shown in the figure and table, the yield load of the 0.4 mm, 0.5 mm and 0.8 mmthick sheets that were embossed changed considerably, compared to that of the plain sheet specimen. For all sheet thicknesses, the yield load became higher than that of the plain sheet because of the strain hardening effect. Furthermore, this effect was strongest for a bulge height of 1.5 mm in sheets with the same thickness. The 0.8 mm thick sheet had the highest maximum yield load, whereas the 0.4 mm thick sheet had the lowest yield load. These findings are a result of increased material yield load in thicker samples.

3.2. Effects of the embossing process on tensile load

Figure 5 and Table 3 show the effect of bulge height on tensile load for all sheet thicknesses. As shown in Fig. 5, the tensile load of 0.4 mm, 0.5 mm and 0.8 mm thick sheets changed considerably when compared after embossing.

Table 4 shows the maximum (%) thinning values of the bulged area in the tensile specimen. The propagations of fracture in the tensile specimens are also shown in Fig. 6.

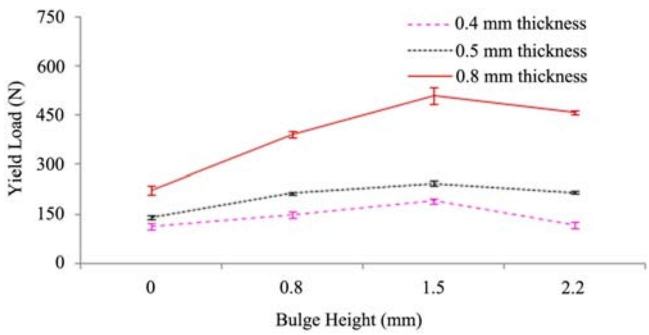

Fig. 4. Diagram of Yield Load-Bulge Height.

Table 2. Maximum Yield Load Values of Embossing Process

Sheet metal thickness (mm)	Bulge Height (mm)	Yield Load (N)
0.4	0 (plain)	112
	0.8	149
	1.5	191
	2.2	117
0.5	0 (plain)	140
	0.8	214
	1.5	245
	2.2	217
0.8	0 (plain)	224
	0.8	394
	1.5	510
	2.2	460

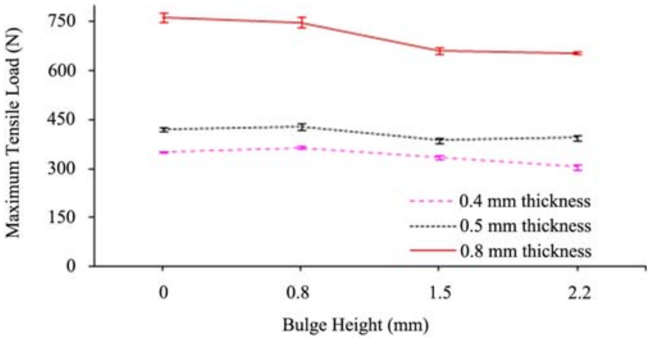

Fig. 5. Diagram of Maximum Tensile Load-Bulge Height.

Table 3. Maximum Tensile Load Values of Embossing Process

Sheet metal thickness (mm)	Bulge Height (mm)	Maximum Tensile Load (N)
0.4	0 (plain)	350
	0.8	365
	1.5	335
	2.2	306
0.5	0 (plain)	421
	0.8	428
	1.5	386
	2.2	395
0.8	0 (plain)	764
	0.8	748
	1.5	661
	2.2	654

According to Table 4 results, the bulge height was increased as the maximum (%) thinning value increased. If the bulge height increased as the tensile load decreased, it would show that the effect of decreased sheet thickness in the bulged area dominated the work hardening effect. On the other hand, if the bulge height increased as the tensile load increased, the work hardening effect would be dominant.

Depending on this result, for the 0.8 mm bulge height of 0.4 and 0.5 mm sheet thicknesses, the work hardening effect was more pronounced than the effect of decreased sheet thickness in the bulged area. At a bulge height of 1.5 and 2.2 mm in 0.4 and 0.5 mm thick sheets, the tensile load became lower than that of plain sheet. This was because the thickness in the centre of the bulge area was reduced.

Table 4. Maximum Thinning Values After Tensile Test in The Bulged Area

Sheet metal thickness (mm)	Bulge Height (mm)	Maximum Thinning (%)
0.4	0.8	14.5
0.4	1.5	17
0.4	2.2	19
0.5	0.8	15.6
0.5	1.5	18
0.5	2.2	22.8
0.8	0.8	10.75
0.8	1.5	13.25
0.8	2.2	13.75

In the 0.8 mm thick sheet, the tensile stress decreased as the bulge height increased. In this case, the effect of decreased sheet thickness in the bulged area dominated the work hardening effect, resulting in a reduced tensile load.

A comparison of the effect of embossing on all bulge heights showed that the 0.8 mm bulge height had the highest tensile load for all sheet thicknesses. This was because the 0.8 mm bulge height had the smallest decrease in embossed metal. Conversely, at a bulge height of 2.2 mm in 0.4 and 0.8 mm thick sheets, the tensile load was at a minimum. This was due to decreased thickness in the bulged portion.

3.3. Effects of embossing on 3-Point bending strength

According to the 3-point bending test results in Fig. 7 and

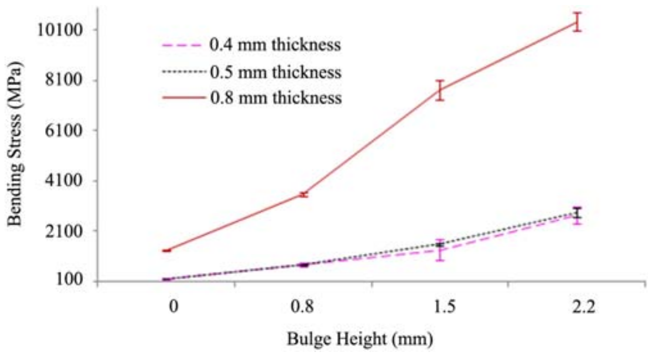

Fig. 7. Diagram of Maximum Bending Stress-Bulge Height.

Fig. 6. Propagations of fracture in tensile specimens. (a) 0.8-1.5- and 2.2-mm bulge height of 0.4-mm- thick sheet, (b) 0.8-1.5- and 2.2-mm bulge height of 0.5-mm- thick sheet, and (c) 0.8-1.5- and 2.2-mm bulge height of 0.8-mm- thick sheet.

Table 5. Maximum Bending Load Values of Embossing Process

Sheet metal thickness (mm)	Bulge Height (mm)	Bending Stress (MPa)
0.4	0 (plain)	187
	0.8	731
	1.5	1353
	2.2	2735
0.5	0 (plain)	203
	0.8	755
	1.5	1582
	2.2	2865
0.8	0 (plain)	1341
	0.8	3582
	1.5	7739
	2.2	10453

Table 6. Maximum Buckling Load Values of Embossing Process

Sheet metal thickness (mm)	Bulge Height (mm)	Maximum Buckling Load (N)
0.4	0 (plain)	3.12
	0.8	3.95
	1.5	4.87
	2.2	7.43
0.5	0 (plain)	6.54
	0.8	7.79
	1.5	10.14
	2.2	10.48
0.8	0 (plain)	21.12
	0.8	28.24
	1.5	28.96
	2.2	32.54

Table 5, specimens subjected to embossing exhibited bending strength increases as the bulge height was increased. This is because, during the bending process, neighbouring embosses come into contact with one another. This caused the moment of inertia to decrease with the increasing bending strength. In addition, it may be related to stress distribution near the embosses.

On the other hand, plain sheet metals had the lowest bending strength, and therefore, it can be said that the embossing process increased bending strength overall. The bending rigidity of the embossed specimens was higher compared to that of the plain sheet materials. In addition, the plastic deformation that was introduced into the formed area also caused an increase in the bending strength and a decrease in the moment of inertia.

The 0.8 mm thick sheet had the highest bending stress value, whereas the 0.4 mm thick sheet had the lowest. These findings were a result of increased material bending strength in the thicker samples.

3.4. Effects of embossing on buckling strength

In Fig. 8 and Table 6, the buckling test results show that the maximum buckling strength was measured for the 0.8 mm thick sheet. Furthermore, the buckling strength for the 0.5 mm thick sheet was higher than that for the 0.4 mm. In addition, the maximum buckling load increased as the bulge height increased. This shows that the embossing process had a positive effect on buckling strength. During the buckling process, buckling strength increased as a result of increases in thickness.

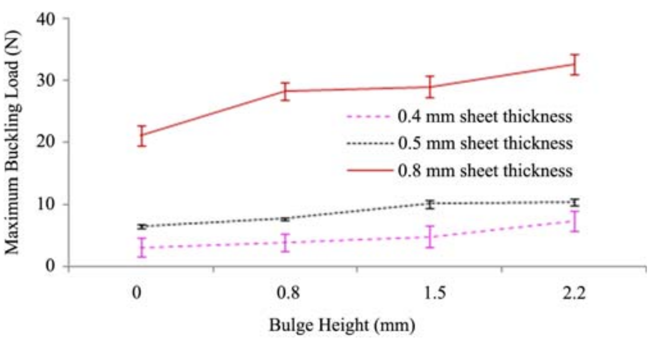

Fig. 8. Diagram of Maximum Buckling Load-Bulge Height.

4. CONCLUSIONS

In this study, the effects of the embossing process on the mechanical properties of Al 1050 alloy sheets were examined.

The experimental results showed that embossed sheets, for all sheet thicknesses and bulge heights, had higher yield loads than that of plain sheets. The tensile load of the embossed specimens was generally lower than that of the plain sheets.

According to the 3-point bending test results, specimens subjected to embossing exhibited increases in bending strength with increases in bulge height.

The buckling test results showed that the maximum buckling load increased as the bulge height increased.

According to these experimental results, the embossing process increases yield load, bending and buckling strength, and decreases tensile load. When forming and using embossed parts for heat shielding, steps must be taken to strengthen pin connection zones to improve tensile load, like a restoration process. Additional research based on these results is required.

REFERENCES

1. C. S. Namoco Jr., T. Iizuka, N. Hatanaka, N. Takakura, and K. Yamaguchi, *Mater. Processing Technol.* **192-193**, 18 (2007).
2. C. S. Namoco Jr., T. Iizuka, R. C. Sagrado, N. Takakura, and K. Yamaguchi, *Mater. Processing Technol.* **177**, 368 (2006).
3. C. S. Namoco Jr., T. Iizuka, K. Narita, N. Takakura, and K. Yamaguchi, *Mater. Processing Technol.* **187-188**, 202 (2007).

4. C. S. Namoco Jr., T. Iizuka, N. Hatanaka, and N. Takakura, *Mater. Forum* **31**, 194 (2007).
5. Y. H. Moon, S. S Kang, J. R. Cho, and T. G. Kim, *Mater. Processing Technol*. **132**, 365 (2003).
6. M. Gavas, *Metalurgija* **45**, 109 (2006).
7. L. Lang, J. Danckert, and K. B. Nielsen, *J. Eng. Manufacture* **218**, 833 (2004).
8. Y. T. Keum, and B. Y. Han, *Ceramic Processing Research* **3**, 159 (2002).
9. L. Lang, J. Danckert, and K. B. Nielsen, *Int. J. Machine Tools & Manufacture* **44**, 649 (2004).
10. L. Lang, J. Danckert, and K. B. Nielsen, *Int. J. Machine Tools & Manufacture* **44**, 495 (2004).
11. Y. H. Moon, Y. K. Kang, J. W. Park, and S. R. Gong, *Int. J. Machine Tools & Manufacture* **41**, 1283 (2001).
12. H. I. Demirci, M. Yaşar, K. Demiray, and M. Karalı, *Mater. and Design* **29**, 526 (2008).