

Cold Roll Forming of Circular Tube Section for Wrought Magnesium Alloy Sheet

Hisaki Watari, Hidemitsu Hamano, Shi-ichi Nishida, and Shun-suke Kanai

Abstract—The growing demand for light weight products for automotive industries has been increased due to global trend of environmental preservation. In recent several years, although production of magnesium has risen dramatically, production of magnesium alloy sheet remains still at a very low level in practical use. The major barrier to greatly increased magnesium alloy use has been in still primarily high manufacturing cost as well as poor workability of wrought magnesium sheet alloys. One of the author has investigated in cold roll forming of magnesium alloy, however detailed forming characteristics of the wrought magnesium alloy sheets has not been clarified. The aim of our study is to establish a guideline for roll design in the roll forming for wrought magnesium alloy sheet. A three dimensional elasto-plastic analysis by finite element method (FEM) has been conducted to examine the shapes of cross section, springback characteristics, bending strains and longitudinal membrane strain of magnesium alloy sheet comparing to cold rolled steel sheet during cold roll forming.

Keywords—cold roll forming, finite element simulation, sheet metal forming, wrought magnesium alloy

I. INTRODUCTION

THE growing demand for light weight products for automotive industries has been increased due to global trend of environmental preservation magnesium alloys that are lighter than aluminium alloys have a specific gravity of 1.8, which is 2/3 of aluminium alloys. In recent several years, although production of magnesium has risen dramatically, production of magnesium alloy sheet remains still at a very low level in practical use.

The major barrier to greatly increased magnesium alloy use has been in still primarily high manufacturing cost as well

Hisaki WATARI has been working as a full time professor at the Department of Mechanical System Engineering, Graduate School of Science and Technology, Gunma University, 29-1 Hon-cho, Ota, Gunma 373 0057 Japan. (e-mail: watari@gunma-u.ac.jp).

Hidemitsu HAMANO is a senior researcher of JFE Technology Research Centre, 1-9-1 Edobori, Nishi-ku, Osaka 550 0002 Japan, (e-mail: hidemitsu_hamano@yahoo.co.jp).

Shi-ichi Nishida, Department of Mechanical System Engineering, Graduate School of Science and Technology, Gunma University, 29-1 Hon-cho, Ota, Gunma 373 0057 Japan..

Shun-suke Kanai, Department of Mechanical System Engineering, Graduate School of Science and Technology, Gunma University, 29-1 Hon-cho, Ota, Gunma 373 0057 Japan

The research topics are manufacturing technology for light weight metals, such as aluminum and magnesium alloys.

as its poor workability of wrought magnesium sheet alloys.

The process of cold roll forming has been an established industrial process for manufacturing long sheet metal products with constant sections. Roll formed products are widely used in the building industry today. Many researchers of the cold roll forming process has investigated computer-aided design or numerical simulation of the cold roll forming process in order to manufacture products while increasing the productivity and maintaining the accuracy of the resulting products [1]-[4].

One of the author has investigated in cold roll forming of magnesium alloy [5]-[6], however the details for forming characteristics of the wrought magnesium alloy sheets has not been clarified.

The aim of the study is to establish a guideline for roll design in the roll forming for wrought magnesium alloy sheet. A three dimensional elasto-plastic finite element analysis was conducted to examine differences of cross section shapes and bending strains of magnesium alloy sheet comparing to cold rolled steel sheet (SPCC in Japanese industrial standard) during cold roll forming process.

II. ANALYTICAL PROCEDURE

Figure 1 shows analytical model of finite element method. PAM-STAMP was used in the cold roll forming analysis. In the analysis, a roll forming process with a six stands has been performed. Table 1 shows analytical conditions in the FEM simulation. The analyzed strip width was 42 mm, the pipe diameter was 14mm, and roll clearance was 0.64 mm. Also shell element was 1mm × 1mm mesh and integration point of thickness direction was five. In the analysis, von Mises yield criterion was used. Fig. 2 shows a W bend type roll design that was chosen in the simulation as well as in the experiment. Table 1 shows mechanical properties of the material properties of the tested magnesium alloy.

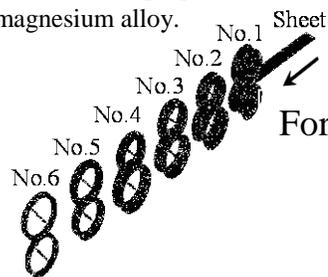


Fig. 1 Example of analytical model for cold roll forming of wrought magnesium alloy

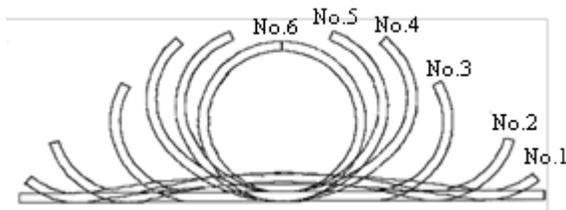


Fig. 2 Roll forming process for magnesium alloy sheet

TABLE I

DIMENSIONS OF FORMING MACHINE AND MATERIAL

Type of forming roll	W bend type
Number of forming stand	6
Distance between stands [mm]	180
Roll clearance [mm]	0.66
Pipe diameter [mm]	13.6
Sheet thickness [mm]	0.60

$$e_x = \frac{1}{2}(e_{x1} + e_{x2})$$

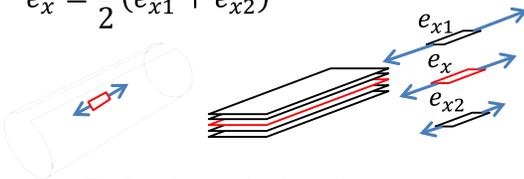


Fig.3 (a) longitudinal membrane strain

$$e_y = \frac{1}{2}(e_{y1} - e_{y2})$$

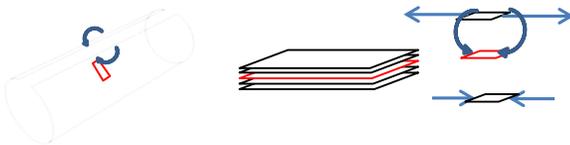


Fig.3 (b) longitudinal bending strain

Results obtained by analysis of cold roll forming are shaped section, curvature, longitudinal membrane strain and bending strain of longitudinal and width direction. The measurement position was 90 mm from the top of the strip. Fig. 3 indicates measuring method of (a) longitudinal membrane strain and (b) bending strain of width direction.



Fig.4 (a) Formed magnesium tube



Fig.4 (b) Formed cold rolled steel tube

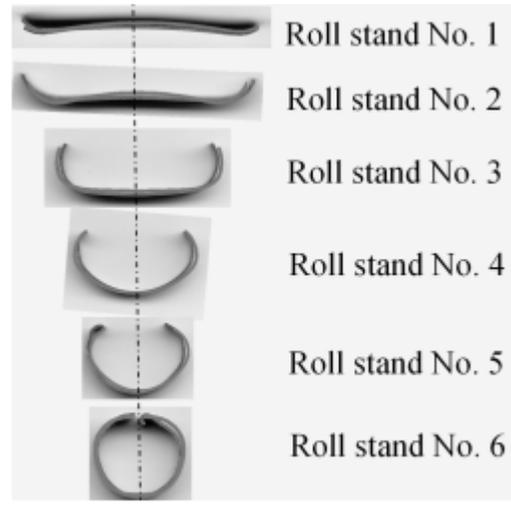


Fig.5 Cross section shapes of formed products of cold rolled steel obtained by analysis and experiment

III. RESULTS AND DISCUSSION

Figure 4 shows formed products obtained by experiments. The gap between the top of the edge of the formed products was 11.14 mm in the case of AZ31 and 2.85 mm for cold rolled steel, respectively. The gap between the edge of the formed pipe at stable domain in the 90 mm length was 7.01 mm for AZ31 and 1.21 mm for cold rolled steel. Magnesium alloy, AZ31 has larger springback characteristic comparing to the cold roll steel. It has been clarified that manufacturers should decrease the large springback of the wrought magnesium alloys. Such springback may cause another problems in the welding process of the formed pipe. Roll designers should decide overbend process during roll forming in order to remove opening of the seam of the pipe. Next step is to estimating the exact magnitude of the springback as well as roll pass schedules. Figure 5 shows the cross section shape of cold rolled steel obtained by analysis and experiment. Both results show approximately the same result. Fig. 6 shows longitudinal membrane strain of analysis for cold rolled steel and wrought magnesium alloy sheet, AZ31. As a previous experiment, the strains during cold roll forming were measured by strain gages that were bonded on the surface of the cold rolled sheets. The experimental result and analytical shows approximately same tendency. After that it is concluded that prediction of strain by analysis was possible. The strain of cold rolled steel sheet during forming was obtained by using strain gages that were bonded at the bottom and edge of the sheet. We can see that the peak of the longitudinal membrane strains was less than 1.0 %. It is confirmed that any shape defects were not observed in the experiment condition. In order to examine in detail the result obtained in the experiment, a three dimensional elasto-plastic analysis by finite element method has also been performed to investigate into differences of magnesium alloy sheet and cold rolled steel sheet during forming.

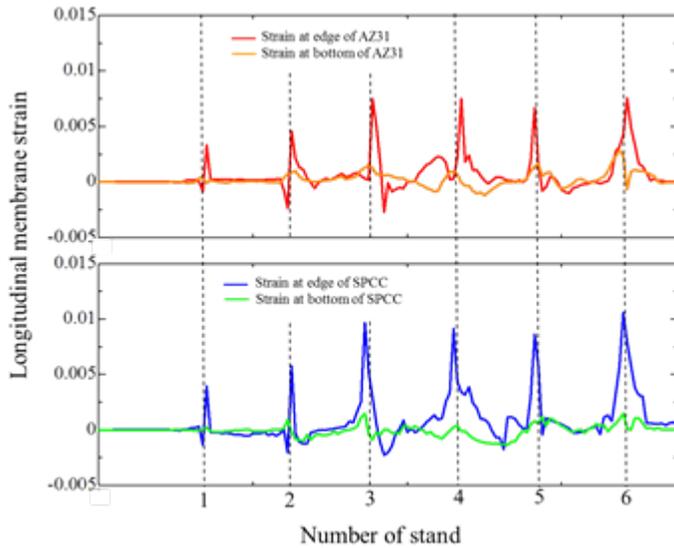


Fig.6 Longitudinal membrane strain of analysis for cold rolled steel and wrought magnesium alloy sheet

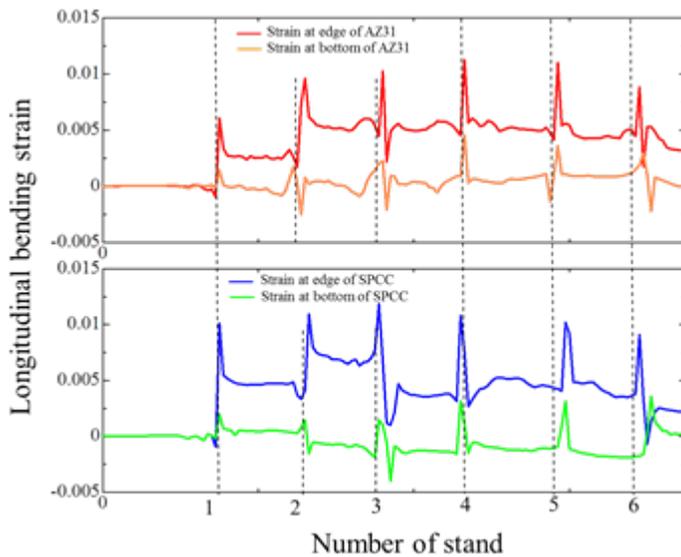


Fig.7 Longitudinal bending strain of analysis for cold rolled steel and wrought magnesium alloy sheet

Figure 6 shows longitudinal membrane strain obtained by analysis of cold rolled steel (SPCC) and wrought magnesium alloy sheet (AZ31). We can see that the peak of the longitudinal membrane strains was less than 1.0 %. It is confirmed that any shape defects were not observed in the manufacturing condition.

Figure 7 shows longitudinal bending membrane strain of AZ31 and SPCC. The bending strains at bottoms were smaller than that of edge. The maximum strain in bending was about 0.4 %, no edge waves were seen in SPCC as well as AZ31 in the same roll forming condition. In the longitudinal direction, sheet was subjected to small bending in the case of AZ31 as well as SPCC.

Figure 8 shows cross-sectional shapes of AZ31 and SPCC obtained by finite element analysis. From the Fig.8, it is found

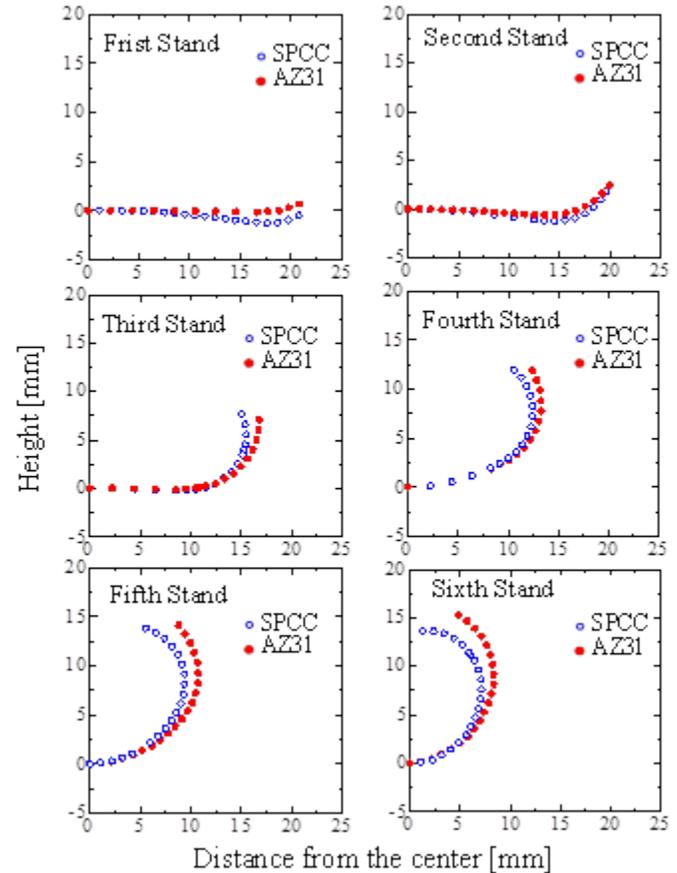


Fig.8 Cross sectional shapes of formed cold rolled steel and wrought magnesium alloy sheet obtained by analyses

That bending was not sufficient in the case of magnesium alloy (AZ31) comparing to the cold rolled steel (SPCC) in the first and second stage due to large spring back characteristics of AZ31. After three stages, the insufficient bending has been remaining, so that large gap of the pipe edge of final formed product has been observed.

In the forming process of AZ31, the W bend rolls were used to obtain better edge curvature, however it is cleared that a new guideline for wrought magnesium alloy is needed. More detailed research work to reduce large springback of AZ31 should be necessary.

Figure 9 shows bending strains of AZ31 and SPCC in width direction. The large differences bending strains were observed in the case of AZ31 and SPCC. We see that strong bending points were at the 19 millimeters apart from the center point of the formed sheet in the first stage. The peak value of the bending strain was about 0.04 for AZ31 and SPCC which is the exact magnitude of the designed value of the desired pipes. In the second stage, the peak point of bending was shifted into inner point at 16 or 17 millimeters. In the third stage forming, we see the peak bending strains of about 0.04 at 13 and 17 millimeters, however the sheet apart from 3 millimeters the edge could not

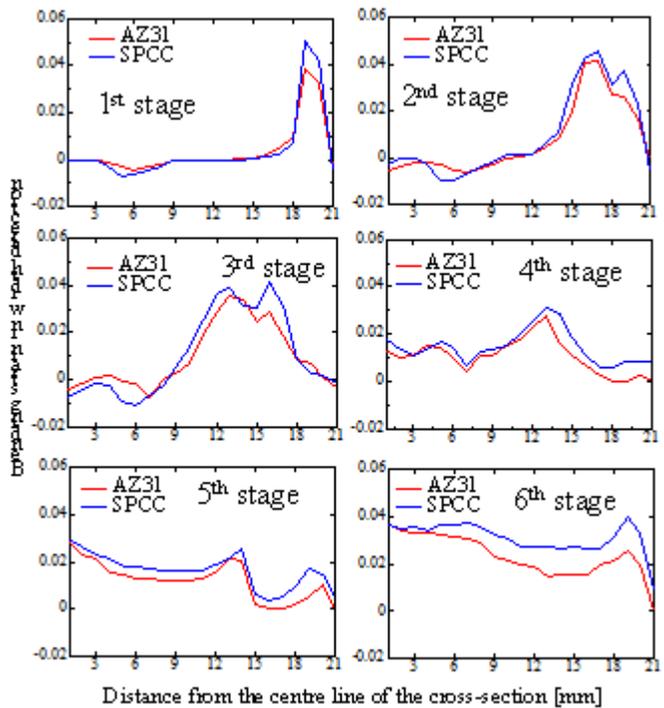


Fig.9 Bending strains of magnesium and cold rolled steel sheet in width direction

be bent though one, two and three stages. In the fourth stage, the strain of the bent portion at the 12 millimeters in the previous three stages which had 0.04 of designed strain, was reduced to about 0.03. In the fifth stage, the magnitude of the strain of the bent portion was reduced to 0.02, which is about half of the desired strain for no reason. At the last sixth stage, we can see about the peak strain of 0.03 around the edge portion, however it is seen that the shortage of bending strains between eight and sixteen millimeters in the case of AZ31. It is considered that insufficient bending in width direction between eight and sixteen millimeters has remained. For the successfully manufacturing pipe in the sixth stage forming, more detailed research work is necessary to predict the accurate amount of springback with shapes of over bend rolls.

Figure 10 shows contact situation between roll and material which are obtained by finite element method. The differences of contact between lower roll and strip were significant as shown in Fig. 10.

As shown in Fig. 10, it is considered that the shortage of bend in AZ31 was caused at the beginning stage of cold roll forming. To gain successful cross section by cold roll forming, it is necessary for roll designers should set over bend rolls in the beginning stage of forming. Also, in the proposed roll pass schedules, the decrease in bend was seen as shown in Fig.9 in the four and five stage. It is also considered that the decrease of bend was caused over stretch of edge when in forming of four and five stage. Over bend rolls for springback as well as small increment of bend in the final forming process will be necessary by consideration obtained by finite element simulation.

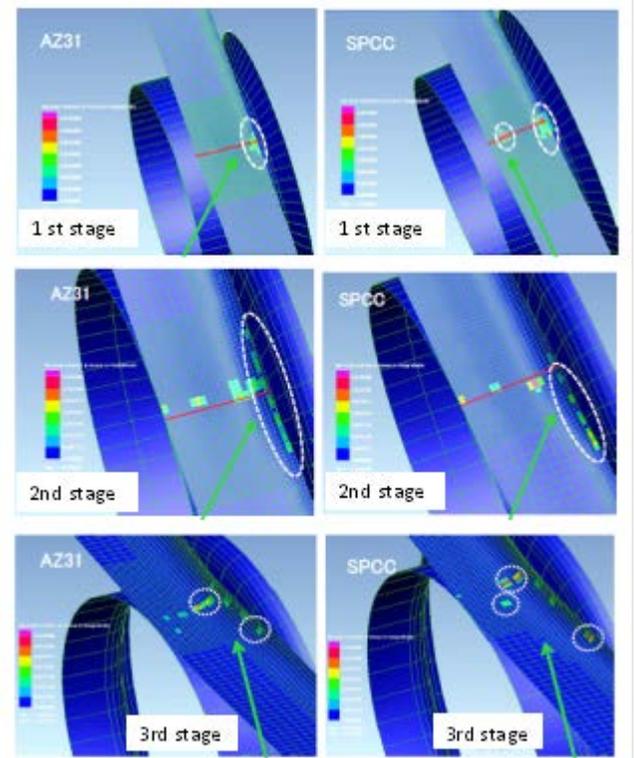


Fig.10 Contact situation between lower roll and strip of AZ31 and SPCC obtained by finite element simulation

As shown in Fig. 10, it is considered that the shortage of bend in AZ31 was caused at the beginning stage of cold roll forming. To gain successful cross section by cold roll forming, it is necessary for roll designers should set over bend rolls in the beginning stage of forming. Also, in the proposed roll pass schedules, the decrease in bend was seen as shown in Fig.9 in the four and five stage. It is also considered that the decrease of bend was caused over stretch of edge when in forming of four and five stage. Over bend rolls for springback as well as small increment of bend in the final forming process will be necessary by consideration obtained by finite element simulation.

IV. CONCLUSION

The following results were obtained in experiment as well as analytical research work.

The strains of magnesium alloy strip were smaller than the case of the cold rolled steel sheet. It is suggested that a new roll design for forming of magnesium alloys is necessary to give appropriate magnitude in bending at each stand. For designing for successfully manufacturing wrought magnesium alloy pipes, over bend roll is effective to prevent shortage of bending in the beginning stage of forming. Also, roll designers should be careful to set small bending increment especially in the final stage of roll forming.

More detailed research work will be needed with establishing a prediction method of magnitude of springback as well as shapes of over bend rolls which prevent from a large spring back in roll forming process.

REFERENCES

- [1] M. Kiuch, T. Koudabashi, F. Eto, "Development of simulation model of roll-forming processes", Journal of Japan Society for Technology of Plasticity, Vol. 27, 306, 1986, pp. 874–881
- [2] Y. Onoda, T. Nagamachi, "Finite element simulation of extroll-forming process of heavy gauge square steel pipe", Journal of Japan Society for Technology of Plasticity, Vol. 30, 345, 1989, pp. 1441–1446.
- [3] E. Doege et. Al., Journal of materials processing technology, Vol. 105, 2001, pp.14-19.
- [4] H. Watari et. al., Proc. of the European Metallurgical Conference, EMC2003, 2003, pp. 437-446.
- [5] T. Hiroki and H. Watari, Analyses of cold roll forming for magnesium alloy sheet, the 29th Mathematical Science Conference, 2010, Vol. 29, pp.69-70 (in Japanese)
- [6] T. Hiroki and H. Watari, Characteristic features of cold roll forming of wrought magnesium alloys sheet,, the 30th Mathematical Science Conference, 2010, Vol. 29, pp.69-70 (in Japanese)