JMEPEG (2005) 14:508-515
DOI: 10.1361/105994905X56142

©ASM International
1059-9495/$19.00

Sharp Flanging and Flat Hemming of Aluminum Exterior Body Panels

Sergey F. Golovashchenko

(Submitted January 24, 2005; in revised form May 18, 2005)

Limitations of conventional flanging and hemming technologies require increased radii of flanges and roped hems when aluminum alloys are used for production of closure panels. A new process of flanging has been developed based upon the idea of redistributing plastic strains through the larger area, delivering additional metal into the bending zone, and creating an additional axial compression. Comparison of the newly developed and conventional flanging process indicated that the new process expands the bending ability of aluminum alloy 6111-T4 by allowing an additional 10% of prestrain to the panel compared with previous forming operations. The advantages of the new flanging operation can be transferred to the hemming operation by allowing an additional 10% of prestrain through the whole sequence of forming and assembly operations. Employment of suggested flanging technology makes possible the flat hemming operation of panels stamped from aluminum alloy 6111-T4 if the thickness of the interior panel is 1 mm or more.

Keywords aluminum blanks, flanging, fracture, radius

1. Introduction

Improving fuel economy and reducing emissions are among the most important issues facing automakers today. The increased interest in the production of lightweight vehicles to address these issues has resulted in an increased tendency in utilization of aluminum alloys for the power train, structural applications, and body panels. Between 1995 and 2000, the use of aluminum increased by more than 80% in automotive applications (Ref 1). However, implementation of aluminum alloys in the production of outer body panels brought a number of difficult technological problems. Most of them were the result of insufficient formability of these alloys compared with steel. Because plastic deformation accumulates in the deformed blank toward the end of the stamping and assembling process, difficulties in the form of cracks may arise. Flanging is often used as the last stage in the stamping process. Hemming is used either to improve appearance (to create a smooth edge rather than a razor edge with burrs) or to attach the exterior panel to the interior. In flanging and hemming operations, insufficient formability can result in splits on the class A surface. To eliminate these splits, the radii are in many cases significantly increased. However, this measure can produce a negative effect on the car exterior and customer satisfaction. To address these issues, new technologies of flanging and hemming have to be developed. In this paper, the new technology of flanging is described, which allows a decrease in the interior radii of flanged and hemmed panels made of common exterior panel aluminum alloy (AA)6111-T4 to approximately one-half of the material thickness.

Sergey F. Golovashchenko, Manufacturing and Processes Department, Ford Research and Advanced Engineering Scientific Research Laboratory, 2101 Village Rd., Dearborn, MI 48124. Contact e-mail: sgolovas@ford.com.

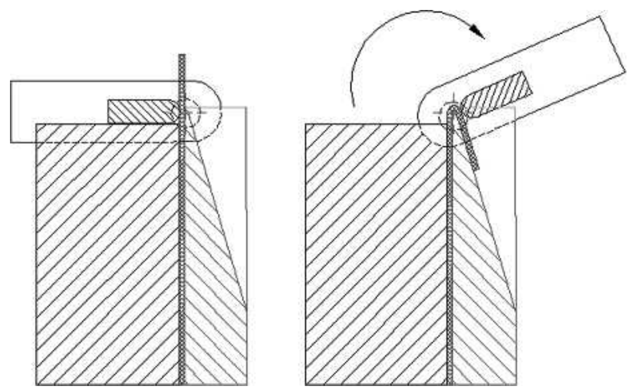


Fig. 1 Scheme of testing of material bendability. Left: at the beginning of the test; right: at the end of the test

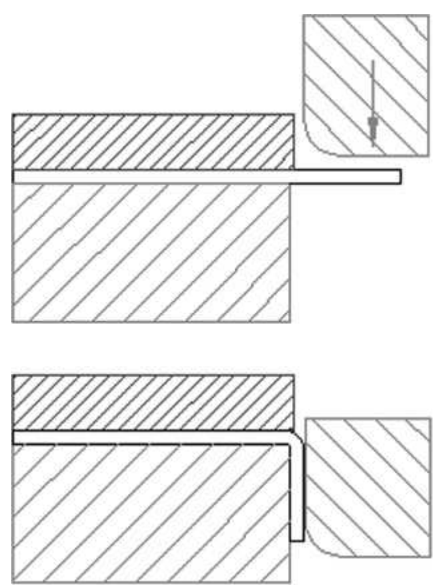


Fig. 2 Schematic of the conventional flanging process

2. Background

Conventional flanging and hemming technology is described in detail in the reference literature (Ref 2) and in a number of research publications cited in Ref 3-6. The mechanism of the hemming operation as simulated in 2D formulation is discussed in Ref 6. Some specific tentative results on the formability of aluminum alloys for automotive applications are provided in Ref 7. For example, sheet 6111-T4 can be bent 90° with a 0.5 *t* radius and down flanged with the radius of material thickness *t*. A roped hem is appropriate for joining interior and exterior panels. Insufficient formability of aluminum alloys accepted by vehicle designers for outer body panels motivated stamping engineers and researchers to look for nontraditional ways of conducting flanging and hemming operations. These approaches are mostly disclosed in the patent literature. Biernat et al. from Chrysler Corporation (Ref 8) suggested a combined prehemming and hemming operation, which also allows the application of the compression load in the zone of plastic deformation. Weins (Ref 9) proposed a modified flat hemming process, which can be conducted using either a press-hammer or a roll-hemmer (Ref 10). Application of the compressive load on the tip of the hem allows formation of a sharper radius than can be done with flat hemming, especially if the interior panel has a significantly larger gauge. The potential risk of this technology is in producing a plastic hinge on the internal surface of the hemmed panel, which can propagate through the panel thickness. A similar approach was undertaken by Klamser, Daimler Chrysler Corporation (Ref 11), who suggested the combined prehemming and hemming with compression of the radius. This may provide some additional improvement compared with earlier modified flat hemming procedures. However, the absence of control of the final radius on the tip of the hem at the end of the operation may produce similar difficulties (Ref 8).

Braun and Reuber (Ref 12) proposed to thin the area of bending from the interior side of the future hem. Such a measure allows for a decrease of metal thickness and an increase of the actual radius of bending, having the exterior view of such a hem similar to a flat hem. The described approach enables significant reduction of stretching of the exterior surface and therefore allows for bending of less ductile materials. However, producing such local gauge reduction may be labor-intensive and requires an additional manufacturing operation.

Table 1 Results on bending of prestrained sheet 6111-T4 in fixture shown in Fig. 1

	Radius, inches (mm)							
Angle	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.040 (1.02)	0.050 (1.27)	0.060 (1.52)	Pre-strain
112°	···	+	+	+	+	+	+	7%
123°	−	+	+	+	+	+	+	7%
139°	−	?	+	+	+	+	+	7%
150°	−	?	+	+	+	+	+	7%
112°	−	−	?	+	+	+	+	10%
123°	−	−	?	+	+	+	+	10%
139°	−	−	?	?	+	+	+	10%
150°	−	−	?	?	+	+	+	10%
112°	−	−	−	?	?	+	+	15%
123°	−	−	−	?	?	+	+	15%
139°	−	−	−	−	?	+	+	15%
150°	−	−	−	−	?	+	+	15%

Krajewski from General Motors Corporation suggested a short retrogressive heat treatment of the area of bending (Ref 13) to achieve flat hemming of AA6111-T4. Even though the regimes proposed in Ref 13 did not produce a significant improvement in formability, as evidenced by the results of the tensile tests (Ref 14), this procedure significantly increased the localization portion of the stress-strain curve. According to Krajewski (Ref 14), the heat treatment improved the bending ability of AA6111-T4 and allowed a successful flat hemming operation to be accomplished.

The approach disclosed in Ref 15 and later explained in detail in Ref 16 is based upon the fundamental study on material ductility under different stress states (Ref 17). In this study external pressure was applied to the sample during a tensile test. It was discovered that increasing the hydrostatic pressure can elevate material ductility many times by suppressing the microcrack development. In this study external pressure was applied to the sample during a tensile test. To apply hydrostatic pressure, a polyurethane insert was compressed to create a significant normal pressure on the stretched surface of the blank. Such an approach also allowed the flat hemming of a 7% prestrained aluminum blank. However, the durability of the insert limits the application of this idea to low-volume production. The objective of this paper was to develop the technology of sharp flanging in steel tools, which will be appropriate for high-volume production and will enable the flat hemming operation of stamped aluminum panels.

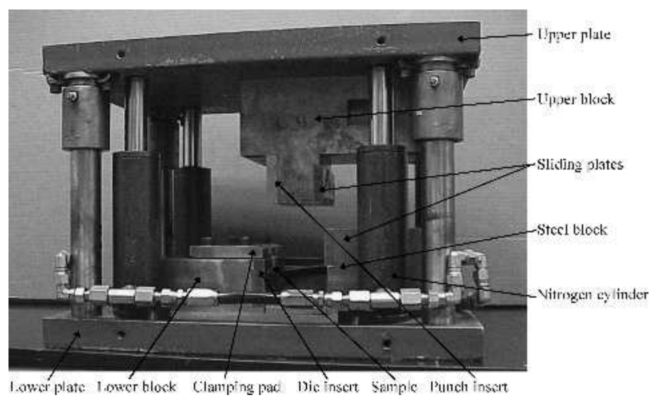


Fig. 3 Photograph of the experimental tooling used in flanging and hemming experiments

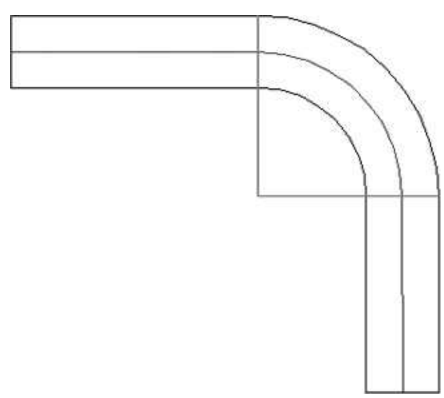


Fig. 4 Bent sheet with zone of plastic deformation limited with two radii

3. Limitations of the Conventional Process

Before the development of new technology, the limits of the conventional bending process were defined. The investigated material was AA6111-T4, widely used for outer body panels in the automotive industry. The thickness of the original sheet was 0.93 mm. The line of bending was perpendicular to the rolling direction. The influence of three parameters was subsequently analyzed: the radius of the die, the level of material prestrain, and the angle of bending. The semiguided wrap bend tooling (built by ALCAN) was used in these experiments. A similar bending procedure was described in Ref 18. The scheme of testing is shown in Fig. 1. The results of experiments are shown in Table 1, where "–" indicates cracking on the outer surface, "?" means that severe orange peel was observed, and "+" is a sign of acceptable quality of the bent surface. Four different angles of bending were used (112°, 123°, 139°, and 150°) in conjunction with three levels of material prestrain (7, 10, and 15%). A set of bending experiments was also conducted, which simulated the flanging process according to the scheme shown in Fig. 2. These processes are very similar; however, they have some points of difference such as bending with the moment and bending with the force. The deforming force in Fig. 2 is applied vertically, whereas in Fig. 1 it follows the sample and is applied perpendicularly to the sample surface. Accordingly, for the flanging process in Fig. 2, the friction force generated by the punch sliding along the blank surface can be a source of additional material stretching. The experimental tooling used in the experimental program, and for all other tests discussed below, is shown in Fig. 3. It was built on a standard die shoe (i.e., 432 mm long, 280 mm wide, and 305 mm high), including a steady lower plate and movable upper plate guided by four columns. It is attached to four nitrogen cylinders thus allowing the upper plate to return to its original position. The upper and lower steel blocks are attached to the corresponding plates with bolts and pins. The actual tools designed as the punch and die inserts are attached with the screws to the upper and lower steel blocks. These inserts are fabricated from plates of oil-hardenable steel. The inserts are machined, ground, and then heat treated to Rockwell hardness HRC60. To have both inserts parallel to each other and to provide identical bending conditions along the bending line, the upper and lower steel blocks were mounted parallel to each other using a special temporary block with accurately machined and ground parallel surfaces that simulate the inserts. This allowed the positions of pins to be located for the upper and lower steel blocks in such a way that after removing the temporary block and mounting the die and punch inserts, they were parallel to each other. To increase the stiffness of the upper block and to prevent its horizontal movement by forces generated by the blank reaction, an additional steel block was attached to the lower plate. To facilitate the upper block sliding along this block surface, special sliding plates were mounted on both blocks and accurately adjusted with shims.

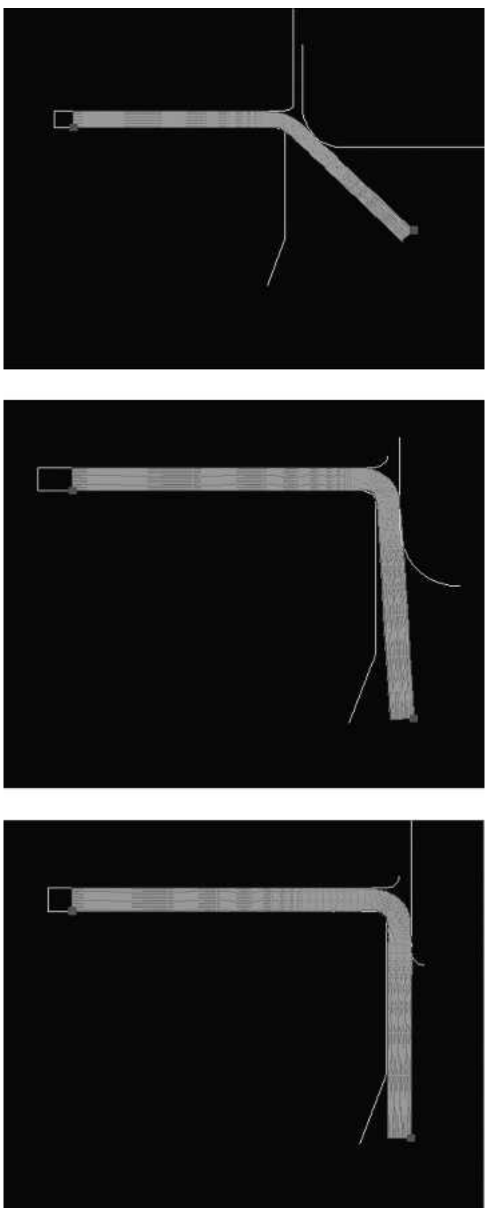


Fig. 5 Mechanism of bending in conventional flanging process

Table 2 Results on bending of prestrained sheet 6111-T4 in fixture shown in Fig. 2

Angle	Radius, inches (mm) 0.015 (0.38)	0.020 (0.51)	0.030 (0.76)	0.040 (1.02)	0.050 (1.27)	0.060 (1.52)	Prestrain
90°	···	–	+	+	+	+	7%
90°	–	–	?	+	+	+	10%
90°	–	–	–	?	+	+	15%

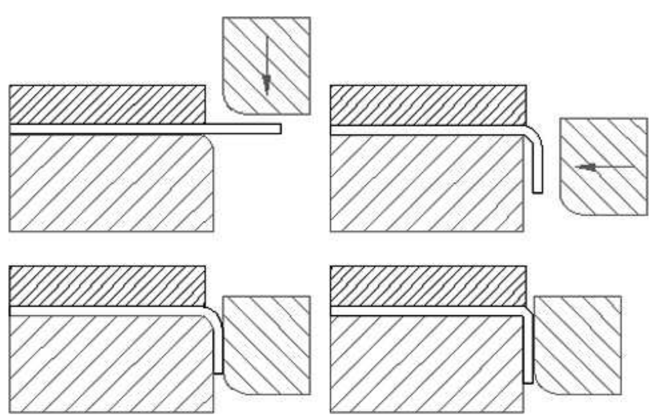


Fig. 6 Schematic of the two-step flanging process

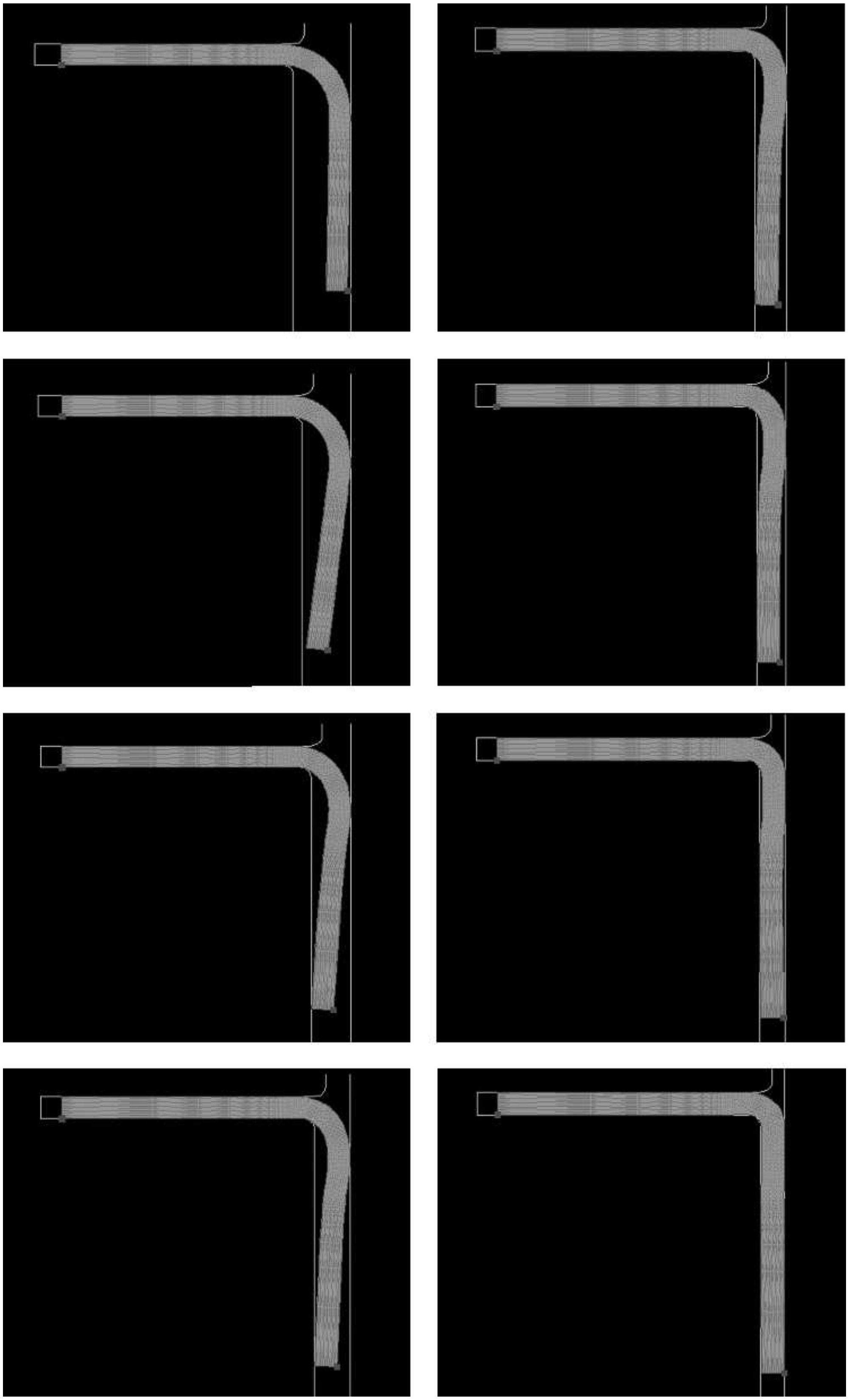


Fig. 7 Results of numerical simulation of step 2

Results of the flanging tests are shown in Table 2 for the 90° bending angle and the three levels of prestrain used in the previous set of experiments. The original samples were 25 mm wide and had a flange length of 12 mm. Despite some difference in testing procedures, shown schematically in Fig. 1 and 2, the results were similar. They indicated that even with the lowest level of material prestrain (i.e., 7%), flanging with a radius of 0.5 *t* was not possible with the conventional flanging

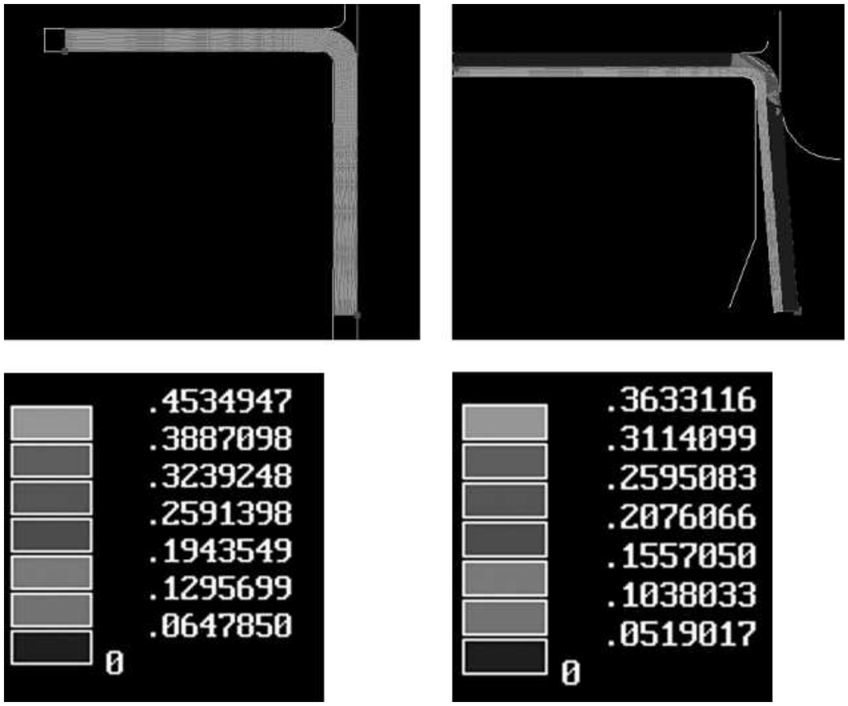


Fig. 8 Distribution of effective strains in the stretched area of the blank after conventional flanging (left) and at the end of the suggested two-step flanging process (right)

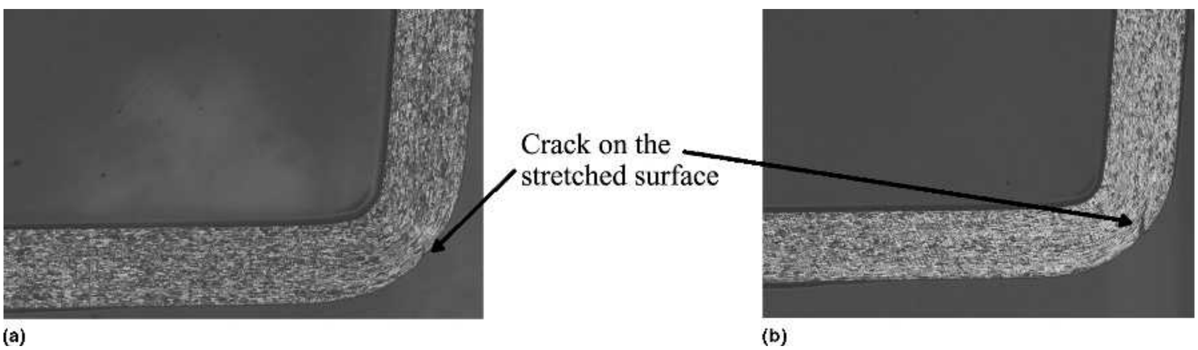


Fig. 9 Prestrained samples after conventional flanging. (a) 7%, (b) 10%

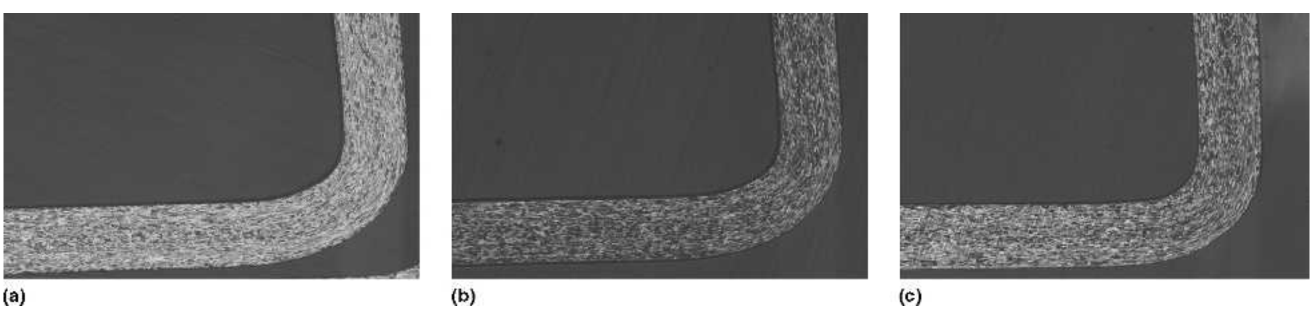


Fig. 10 Prestrained samples after suggesting flanging. (a) 10%, (b) 13%, (c) 16%

technique. Evidently, it is not possible to hem the outer panels with a radius of 0.5 t because hemming requires even more bending ability of the sheet than does flanging. Table 1 indicates that larger bending angles require the increase of the die radius to provide an acceptable quality of bending. In stamping and assembling practice, such limitation results in increased radii of flanges and the employment of roped hemming designs (Ref 2). However, improvement in the craftsmanship of aluminum panels requires decreasing the flanging and hemming radii, which motivates the development of a new flanging method (Ref 19).

From these experimental results, it is clear that 6111-T4 does not have enough formability to be flat hemmed and flanged with the inner radius of $t/2$. This limitation can be

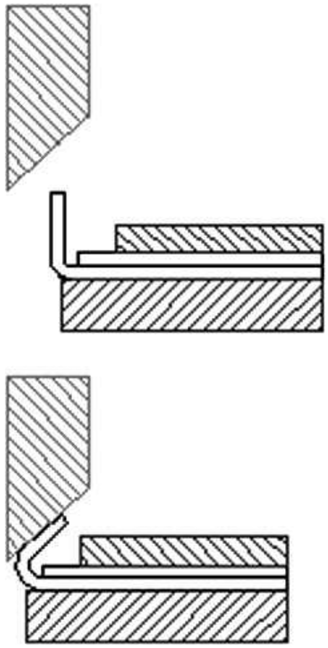


Fig. 11 Prehemming process

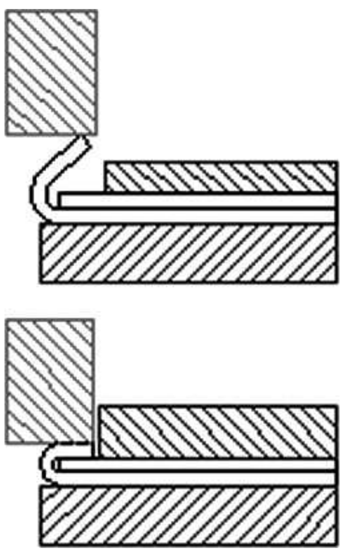


Fig. 12 Final hemming process

expanded if the mechanism of bending is modified. In conventional bending, the area of plastic deformation can be defined as shown in Fig. 4. The results of simulation of conventional flanging, illustrating the mechanism of bending, are shown in Fig. 5. If plastic deformation can be distributed over a larger area, this may allow a reduction in the level of maximum strain. The new flanging process (Ref 19) is based on this idea.

4. New Flanging Process

The new flanging process can be performed in two steps. During the first step, the metal is flanged conventionally with the larger radius of the die. In experiments with 0.93 mm 6111-T4 aluminum sheet, an initial step radius of 2.5 mm is used. The variation of this parameter between 1 and 5 mm showed that 2.5 mm is the optimal value. For the second step, a horizontal load was applied, using cams. The schematics of the process are shown in Fig. 6 for both steps. Evidently, during the first step the area of plastic deformation is distributed through a significantly larger area (i.e., a factor of five larger). However, the key element of the new process is step 2. The results of numerical simulation of step 2, shown in Fig. 6, serve to illustrate the mechanism of flanging. The numerical results were obtained using solid 2D formulation, an elastic-plastic model of the material, and the explicit integration procedure (Ref 20).

It can be seen from Fig. 7 that at the final stage of step 2, the blank is moving upward to the area where conventional bending would occur by compressing the radius with cam flange die. While compressing the arc, some increment of compressive stress is developed. In addition, while straightening the prebent aluminum blank, an opposite stress state is applied to the blank with compression on the exterior surface of the blank and tension on the inner surface facing the die. Comparison of strain distribution in the stretched area of the bending zone for the conventional process is shown in Fig. 8. It can be seen that the level of equivalent strain for the conventional process is 0.45. These results are in good agreement with approximate estimation of the strain on the outer surface using an analytical equation from bending theory:

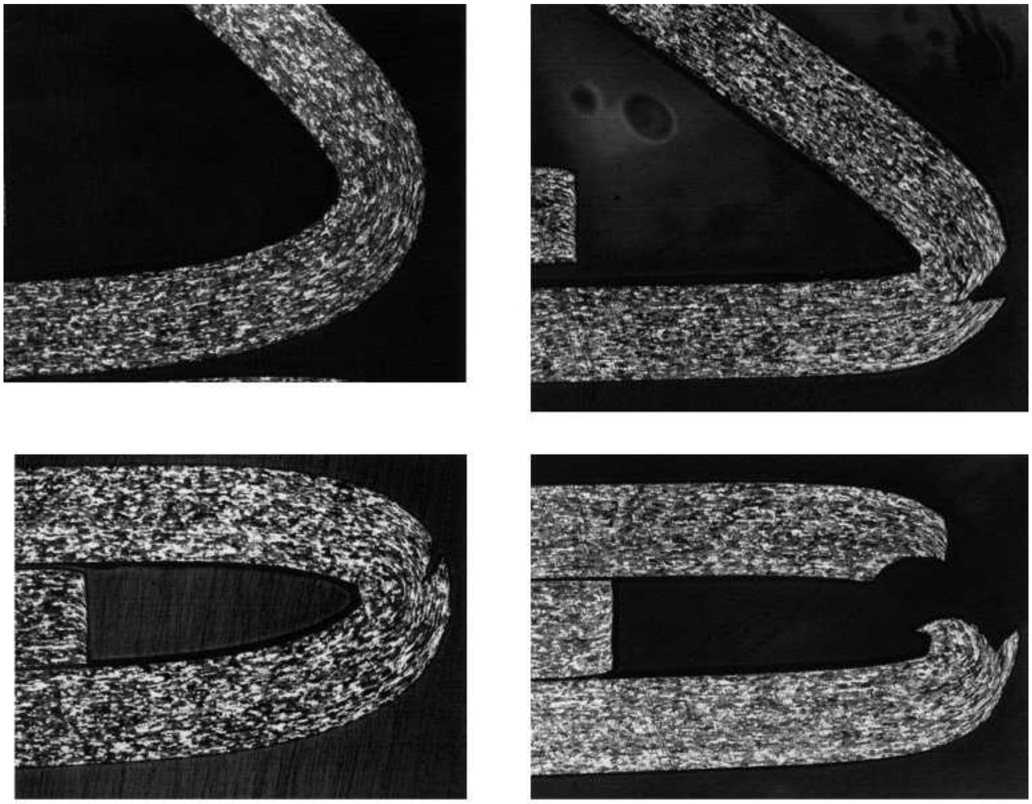
$$\varepsilon = \frac{t}{2r + t} \cdot 100\%$$

where r is the radius of the die corresponding to the interior radius of the blank before spring-back occurs and t is the thickness of the blank. This analytical formula predicts an engineering strain of 48%, resulting in a true strain of 0.392 and an equivalent strain of 0.452.

For the two-step process the predicted equivalent strain is 0.36. This difference signifies a difference in maximum strain, which is confirmed by experimental results. This difference can even be underestimated because the compressive forces developed during the second stage of the two-step process and the strain can be nonmonotonic, i.e., the original stretching of the outer surface can be followed by compression caused by the arc-straightening phenomenon. To simulate the cam flanging operation, the sample that was prebent at step 1 is then turned 90° to make the horizontal part vertical and the vertical horizontal. This approach allows the use of the same die insert with a 0.5 mm radius for comparison of the conventional and the new flanging processes. Comparison of samples flanged with the conventional process and the two-step process is illustrated in Fig. 9 and 10 with the flanged areas facing upward (later the samples will be positioned at the beginning of the prehemming operation). To simulate the deformation prior to the flanging operation, strips of aluminum were prestrained to 4, 7, 10, 13, and 16%. It is clear from Fig. 9 that for prestrains as low as 10% or even 7%, flanging is not possible with a die radius of 0.5 mm because cracks on the outer surface are produced. However, using the suggested two-step process, the sheet can be flanged with initial prestrains of 10, 13, and 16%.

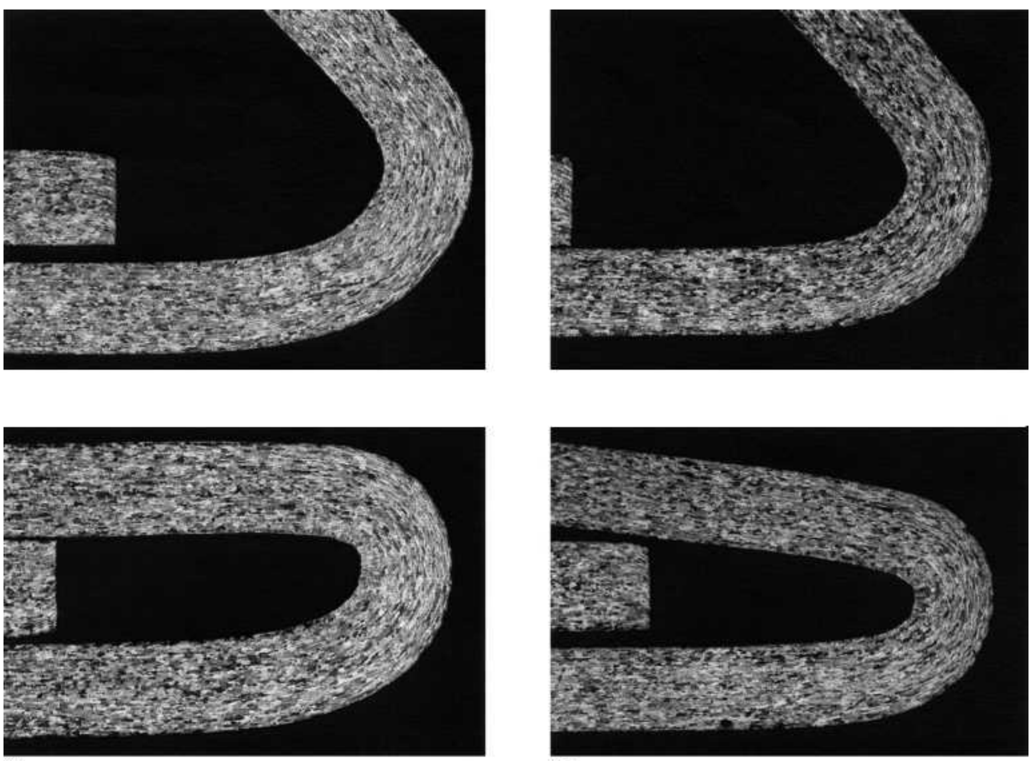
5. Effect of the Flanging Technique on Results of the Hemming Operation

The new two-step flanging technique can be implemented in the production environment as part of the stamping process and



(a) (b)

Fig. 13 Prestrained samples after conventional prehemming and hemming processes. (a) 4%, (b) 7%



(a) (b)

Fig. 14 Prestrained samples after suggested flanging, conventional prehemming, and hemming processes. (a) 7%, (b) 13%

delivers a significant improvement for future hemming operations using standard hemming equipment in high-volume production conditions. With this strategy in mind, prehemming and final hemming experiments were conducted according to the schemes shown in Fig. 11 and 12. The same die set shown in Fig. 3 was used for these experiments. According to the results of hemming after conventional flanging (Fig. 13), flat hemming with an internal average radius of 0.5 mm, corresponding to the case in which the interior panel has the same gauge as an exterior panel, is not possible for sheet prestains as low as 7% (or even 4%). These results are in agreement with the data provided by the Aluminum Association (Ref 7), where a roped hem is recommended for AA6111-T4. On the other hand, hemming of samples flanged according to the two-step process produced positive results with an acceptable level of orange peel for 7% and even 13% prestrain levels (Fig. 14). For 16% prestrain, some cracking was observed on the stretched surface, but it was less pronounced than that observed in Fig. 13.

6. Conclusions

- A new process of flanging has been developed based upon the idea of redistributing plastic strains through a larger area. This approach delivers additional metal into the bending zone and creates additional axial compression.
- Comparison of the newly developed and conventional flanging processes indicates that the new process expands the bending ability of AA6111-T4, allowing an additional 10% prestrain of the panel compared with previous forming operations.
- The advantages of the new flanging operation can be transferred to the hemming operation, also allowing an additional 10% prestrain throughout the whole sequence of forming and assembly operations. Employment of this flanging technology makes possible the flat hemming operation of panels stamped from AA6111-T4 sheet.

References

1. W.S. Miller, L. Zhuang, A.J. Wittebrood, P. De Smet, A. Haszler, and A. Vieregge, Recent Development in Aluminum Alloys for Automotive Industry, *J. Mater. Sci. Eng.,* Vol A280, 2000; p 37-49
2. D.A. Smith, *Die Design Handbook*, Society of Manufacturing Engineers, 1990, p 81-86
3. A. Muderrrisoglu, M. Murata, M. Ahmetoglu, G. Kinzel, and T. Altan, Bending, Flanging, and Hemming of Aluminum Sheet: An Experimental Study, *J. Mater. Process. Technol.,* Vol 59, 1996, p 10-17
4. H. Livatyali, A. Muderisssoglu, N. Akgerman, G. Kinzel, and T. Altan, Improvement of Hem Quality by Optimizing Flanging and Prehemming Operations Using Computer-Aided Design, *J. Mater. Process. Technol.,* Vol 98, 2000, p 41-52
5. H. Livatyali and T. Altan, Prediction and Elimination of Springback in Straight Flanging Using Computer-Aided Design Methods, *J. Mater. Process. Technol.,* Vol 117, 2001, p 262-268
6. H. Livatyali, G. Kinzel, and T. Altan, Computer-Aided Design of Straight Flanging Using Approximate Numerical Analysis, *J. Mater. Process. Technol.,* Vol 142, 2003, p 532-543
7. *Automotive Aluminum Crash Energy Management Manual*, Publication AT5, The Aluminum Association, 1998, p 1-76
8. D. Biernat, G. Wagner, A. Kalson, D. Davidson, and R. Shaffer, Method of Forming a Sealed Edge Joint Between Two Metal Panels, U.S. Patent 6,000,118, Dec 14, 1999
9. P. Weins, Modified Flat Hem Apparatus and Method, U.S. Patent 6,257,043, July 10, 2001
10. P. Weins, Sheet Metal Hemming Method and Apparatus, U.S. Patent 2001,0,029,766,A1, Oct 18, 2001
11. M. Klamser, Falzverbindung zwischen einem Aussenblech und einem Innenblech, Patent EP,0,988,906,A2, Germany, March 29, 2000
12. A. Braun and G. Reuber, Verfahren zum Umbiegen und Falzen von Blechen, Patent DE,41,13 719,A1, Germany, Oct 29, 1992
13. P. Krajewski, A Method for Improving Hemmability of Age-Hardenable Aluminum Sheet, U.S. Patent EP,0,996,760,B1, Sept 24, 2003
14. P. Krajewski, "Retrogression Heat Treatments in AA6111," Presented at Aluminum: Building a Better Car, Aluminum Association Aluminum Design and Fabrication Seminar, Oct 23, 2002
15. S. Golovashchenko, A. Vlasov, S. Kolesov, and L. Chappuis, New Flanging and Hemming Processes with Radial Compression of the Blank Stretched Surface, U.S. Patent 2004,0,187,535,A1, Sept 30, 2004
16. S. Golovashchenko and A. Vlasov, Flanging of Aluminum Panels, *Proceedings of TMS Symposium Aluminum 2004,* p 43-52
17. P.W. Bridgeman, *Studies in Large Plastic Flow and Fracture,* Harvard University Press, Cambridge, MA, 1964, p 38-86
18. G. Oehler, *Das Blech und seine Prufung,* Springer-Verlag, 1953, p 1-282 (in German)
19. S.F. Golovashchenko, A.V. Vlassov, S.S. Kolesov, and V.G. Kondratenko, Flanging Process with Radial Compression of the Blank Stretched Surface, U.S. Patent 2004,0,187,542,A1, Sept 30, 2004
20. S.F. Golovashchenko, R.G. Davies, and W.S. Stewart, "Influence of Tooling Geometry on Quality of Aluminum Sheets Shearing Surface," SAE Technical Paper 970716, 1997 SAE Annual Congress Proceedings, Society of Automotive Engineers, Inc. (Warrendale, PA) (reprinted from *Sheet Metal Stamping: Development and Application),* p 139-146