Development of Sharp Flanging Technology for Aluminum Panels

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Abstract. 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. The process can be performed in two steps. At the first step, the metal is flanged conventionally with the larger radius of the die. In our experiments with 0.93mm 6111-T4 aluminum sheet, we used the first step radius of 2.5 mm. At the second step we applied a horizontal load, which can be produced using cams. Numerical simulation of flanging processes was conducted using the research code based upon solid elements and explicit integration procedure. The contact interaction between the blank and the die was simulated based upon mild contact approach. The results of numerical simulation explain the mechanism of flanging for both conventional and suggested process. Comparison of the newly developed and conventional flanging process indicated that the new process expands bendability of aluminum alloy 6111-T4 allowing additional prestrain of the panel in previous forming operations. The advantages of the new flanging operation can be transferred to hemming operation.

INTRODUCTION

Improving of fuel economy and reducing emissions are among the most important issues, which automakers are facing 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 powertrain, structural applications and body panels. However, implementation of aluminum alloys in production of outer body panels is often limited due to insufficient formability of these alloys compared to steel. 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 negative effect on the car exterior. In order to address these issues, new technologies of flanging and hemming have to be developed. Conventional flanging and hemming technology was studied in details in [1]. Some specific tentative results on formability of aluminum alloys for automotive applications are provided in [2]: aluminum sheet 6111-T4 can be bent 90° with 0.5t radius and down flanged with the radius of material thickness t; roped hem is appropriate for joining of interior and exterior panels. To expand the capabilities of conventional hemming technology, P.Weins proposed a modified flat hemming process [3]. Application of the compressive load on the tip of the hem allows formation of a sharper radius than it can be done with flat hemming, especially if the interior panel has significantly larger gauge. Potential risk of this technology is in producing a plastic hinge on the internal surface of the hemmed panel, which can propagate through the panels’ thickness. A.Braun and G.Reuber [4] proposed to thin the area of bending from the interior side of the future hem. Such measure allows decrease of metal thickness and increase of the actual radius of bending having the exterior view of such a hem similar to a flat hem. 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. P.Krajewski suggested a short retrogressive heat treatment of the area of bending [5] to achieve flat hemming of AA6111-T4. Even though the regimes proposed in [5]
did not produce a significant improvement in total elongation, which was evidenced by the results of the tensile tests, this procedure significantly increased the localization part of the stress-strain curve. According to [5], the developed heat treatment improved bendability of AA6111-T4 and allowed the successful flat hemming operation.

The approach disclosed in [6] is based upon phenomenon that elevated hydrostatic pressure can significantly increase material ductility by suppressing the microcracks development. To apply the hydrostatic pressure, a polyurethane insert was compressed in order to create a significant normal pressure on the stretched surface of the blank. However, the durability of the insert limits the application of this idea to low volume production. In this paper, we will describe a new technology of flanging appropriate for high-volume production, which allows to decrease the interior radii of flanged and hemmed panels made of common exterior panel aluminum alloy 6111-T4 to approximately ½ of the material thickness.

EXPERIMENTAL TECHNIQUE

The experimental tooling (Fig.1) used in this study was built on a standard die shoe including a steady lower plate and movable upper plate guided by four columns and attached to four nitrogen cylinders able to return the upper plate to its original position. The upper and lower steel blocks were attached to the corresponding plates with bolts and pins. The actual flanging tools designed as the punch and die inserts were attached with the screws to the upper and lower steel blocks. These inserts were fabricated from plates of oil-hardenable steel: machined, ground and heat treated to HRC60. In order to have both inserts parallel to each other and provide identical bending conditions along the bending line, the upper and lower steel blocks were mounted parallel to each other using special temporary block with accurately machined and ground parallel surfaces simulating the attached later inserts. Original samples were 25 mm wide and had the length of the flange of 12 mm.

CONVENTIONAL FLANGING PROCESS

Since the bending radius in flanging operation is less than 5t, where t is material’s thickness, the blank was considered as solid and normal stress was taken into account. Plane strain assumption was employed in numerical simulation. Previously similar model was used for the analysis of trimming technology [7]. However, blank-with-die contact interaction problem was solved using mild contact model [8]. The distribution of strains after conventional 90° flanging of aluminum sheet 6111-T4 with 0.5 mm internal radius is shown in Fig.2.

Experimental results indicate that with 7% of material prestrain, typical for automotive panels in drawing operation, conventional flanging with the radius of 0.5 t is not possible due to material fracture on class A surface, as it can be seen in Fig.3.

FIGURE 1. Experimental Flanging Die

FIGURE 2. Distribution of Plastic Strains after Flanging AA6111-T4 Sheet 0.93 mm Thick with Internal Radius of 0.5 mm.

FIGURE 3. Aluminum Sample Flanged to 0.5 mm Radius after 7% Prestrain: left- cross-section; right –outer surface.
Evidently, it is not possible to hem the outer panels with the radius of 0.5t since hemming requires even more bendability of the sheet than flanging. In our opinion this limitation can be expanded if plastic deformation can be distributed through a larger area reducing the level of maximum strain. New flanging process [9] based on this idea will be discussed in the next paragraph.

**NEW FLANGING PROCESS**

The process can be performed in two steps. At the first step, the metal is flanged conventionally with the larger radius of the die. In our experiments with 0.93mm 6111-T4 aluminum sheet, we used the first step radius of 2.5 mm. The variation of this parameter between 1 and 5 mm showed that this is about an optimal value of the parameter.

**FIGURE 4.** Schematic of Suggested Two-step Flanging Process

![Diagram](image)

At the second step, we employed the die with the final inner radius of 0.5 mm and applied horizontal force to earlier flanged to 2.5mm radius blank. The results of numerical simulation of the 1st step are shown in Fig.5. Since the 1st step is basically a conventional flanging process with the larger compared to Fig.2 internal radius, both distributions of strains are similar. However, the max level of strain in Fig.6 is 0.20 vs 0.51 in Fig.2. During the 2nd step, max strain is increased up to 0.44. Simple calculations indicate about 7% of additional strain allowed by the two-step process. However, this difference can be even underestimated due to the fact that the compressive forces are developed while compressing the arc during the second stage of the two-step process, and also the strain can be non-monotonic: original stretching of the outer surface can be followed by some compression due to the arc-straightening phenomenon. Application of additional compression is particularly important to the most stretched area of the class A surface where fracture is usually anticipated. Additional compression allows some increase of hydrostatic pressure which helps to increase material bendability [6]. The experimental results were obtained using an experimental fixture shown in Fig.1. In order to simulate the cam flanging operation at the 2nd step, the sample pre-bent at 1st step was then turned 90 degrees

**FIGURE 5.** Distribution of Plastic Strains after 1st Step of Flanging Internal Radius of 2.5 mm.

![Distribution](image)

**FIGURE 6.** Distribution of Plastic Strains after the 2nd Step of Flanging with Internal Radius of 0.5 mm.

![Distribution](image)
to make its horizontal part vertical and vice versa. Such experimental technique allows use of the same die insert with 0.5mm radius for comparison of conventional and suggested flanging processes. Experimental results in the form of samples flanged with suggested two-step process after 16% of material tensile prestrain are illustrated in Fig.7. These results clearly indicate a significant advantage of the suggested process compared to conventional flanging process: additional 9% of prestrain were applied to the sample and it still performed with no visible fracture.

**FIGURE 7.** Aluminum Sample Flanged in Two Steps to 0.5 mm Radius after 16% Prestrain: left- cross-section; right – outer surface.

The described flanging technique can be implemented in production environment as part of the stamping process and deliver a significant improvement for future hemming operation using standard hemming equipment in high-volume production conditions. With this strategy in mind, we conducted prehemming and final hemming experiments according to the traditional schemes [1]. The same die-set shown in Fig. 1 was employed for these experiments. According to the results of hemming after conventional flanging, flat hemming with the internal average radius of 0.5 mm, corresponding to the case when the interior panel has the same gauge as an exterior panel, is not possible for as low as 7% or even 4% of the sheet prestrain. These results are in agreement with the data provided by Aluminum Association [2], where roped hem is recommended for AA6111-T4. On the contrary, hemming of samples flanged according to the two-step process, produced positive result with acceptable level of orange peel for 7% and even 13% of prestrain.

**CONCLUSIONS**

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 it significantly expands bendability of aluminum alloy 6111-T4 allowing additional prestrain of the panel in previous forming operations.

The advantages of the new flanging operation can be transferred to hemming operation allowing additional prestrain through the whole sequence of forming and assembly operations. Employment of suggested flanging technology technology makes possible the flat hemming operation of panels stamped from AA6111-T4.

**REFERENCES**


