

Analysis of Trimming Processes for Advanced High Strength Steels

Sergey F. Golovashchenko
Ford Research & Advanced Engineering

Andrey M. Ilinich, Nicholas M. Bessonov and Lorenzo M. Smith
Oakland University

Copyright © 2009 SAE International

ABSTRACT

Presented are analytical and experimental results for both the conventional trimming process and a recently developed robust trimming process, which involves dulling the upper trimming tool and providing elastic offal support. The robust process, which has strong potential to lower the requirements for the accuracy of trim die alignment, is analyzed. Material flow of the trimming process is modeled numerically using the commercially available LS-Dyna finite element program and an in-house finite element program, called Solid 2D. An experimental technique, which provides plane strain material deformation data as a function of hydrostatic pressure has been developed. Experimental results from the plane strain FLD test and a single interrupted trimming test were obtained in order to find agreement between analytical and experimental results. Analysis of the mechanisms of blank separation in conventional trimming and trimming with an elastic scrap support is also provided.

INTRODUCTION

Modern product design and manufacturing often utilizes a wide variety of materials. Where once low carbon steel predominated, a variety of new materials such as advanced high-strength steels (AHSS) and aluminum alloys are now being utilized. Although such alternative materials may provide a variety of benefits in product manufacturing and design, these same materials may present difficulties when subjected to manufacturing processes originally designed for low carbon steel. Burrs

are known to decrease the quality and accuracy of stamped parts and are the sources of potential splits in stretch flanging and hemming. Tolerances required by existing standards often exceed the capabilities of many trim dies, and can still result in the production of burrs. In order to satisfy the existing standards of quality and to meet customer satisfaction requirements, stamped parts frequently need an additional deburring operation, which is often accomplished as a metal-finish operation and conducted manually.

The quality of a trimmed surface for AHSS is defined by several factors. The higher strength of these materials compared to low carbon steel, the greater is the load on the trimming tool. This circumstance results in increased wear of the shearing edge and in some cases its failure, requiring expensive maintenance of the trim die.

Trimming dies for body panels require a clearance of approximately 0.06mm, (10% of the material thickness or even less) which is difficult to maintain along the trim line and requires significant alignment efforts. In addition, the trim die has to be sufficiently robust such that the opening of clearance between the shearing edges, remain within an acceptable tolerance. In case of small clearances, overlapping of the upper and lower shear edges can occur due to unbalanced forces in the trim die. This condition can lead to failure of the shearing edges, intensified wear, low quality trimmed surface and reduced trim die life. In addition, poor quality of the trimmed surface may reduce formability of the blank in flanging and hemming operations, especially in cases when a stretching load is applied along the trimmed surface.

Both conventional trimming process [1], schematically shown in Fig.1a, and robust trimming process [2] (Fig.2b) are under consideration in this study. The robust trimming process [2] demonstrated excellent results for aluminum alloys, resolving the issues of slivers, burrs and split of the trimmed surface [3]. Mechanisms of sheared surface formation generation of trimming defects were understood in [4]. Due to increased material ductility in compression compared to stretching [5,6], cracks in conventional trimming for both aluminum and AHSS usually start from the upper trim steel. Compared to the conventional process, robust trimming has the advantage of not producing burrs. Detailed discussion of how the quality of trimmed surface affects stretch flanging performance was provided in [7,8] for aluminum and AHSS. Very detailed studies of sheared surface stretching performance in hole expansion tests was also published in literature [9,10]. Issues of surface quality have been thoroughly addressed in these recent studies. The objective of this paper is to develop and validate a numerical model which simulates deformation of the blank in trimming processes and predicts the corresponding initiation of fracture.

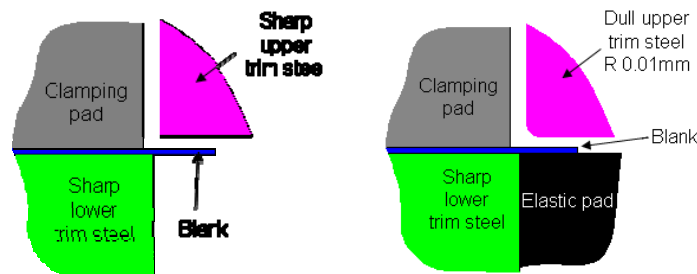


Fig.1. Schematics of the trimming processes: a) conventional trimming process; b) robust trimming process.

EXPERIMENTAL TECHNIQUE

Dual phase steel DP500 $t=0.65\text{mm}$, which is very attractive for exterior automotive panel applications, was used in this study. Experiments were conducted for both the conventional trimming process [1] and the recently developed robust trimming process [2]. In both cases, perpendicular trimming was considered (a cutting angle equal to zero) as shown in Fig.1.

The blank was initially clamped to the lower trim steel and the upper trim steel moved down to trim the panel. The offal of the blank had an elastic support employing a polyurethane pad. The concept of trimming with the offal support eliminates its bending and makes the distribution of strains similar from the upper and lower shearing edges. In order to initiate crack propagation from the lower shearing edge, a small radius was fabricated on the upper edge lowering the maximum strain level in the area. Such trimming conditions are intended to reallocate burrs from the trimmed surface of the part to the sheared surface of the offal. The process

shown in Fig 1b is hereafter called the robust trimming process.

In order to analyze the trimmed surface quality, cross-sections of samples were mounted in epoxy, the polished and etched for 15-30 seconds by 4% nital acid. Samples were washed in water and dried by compressed air. To analyze crack propagation, partial trimming was employed. The trimming process was interrupted prior to final separation. The interruption process, which was conducted based upon the trimming force value in the force-displacement curve, was discovered to be very repeatable. Partially sheared samples were then polished and analyzed.

The tooling used in this experiment is shown in Fig.2. It was built on a standard die shoe (432mm long, 280 mm wide, 305 mm high) which included a fixed lower plate and a movable upper plate guided by four columns and attached to four nitrogen cylinders which were 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. Trimming steels with sharp shearing edges were attached to the upper and lower steel blocks.

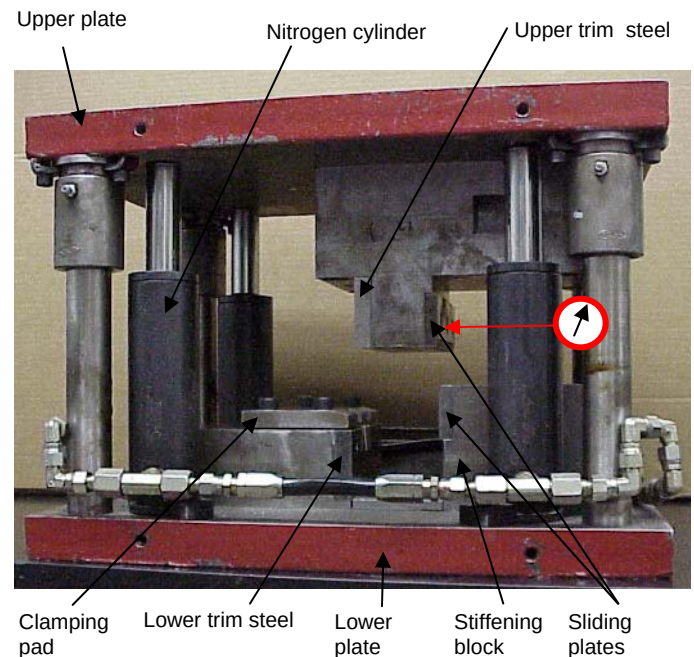


Fig.2. The experimental tooling.

These inserts were fabricated from plates of oil-hardenable steel: they were machined, ground and heat treated to HRC60. In preliminary experiments, the variation of clearance between shearing edges was explored by installing a micrometer indicator, as shown in Fig.2. These measurements illustrated that the clearance between shearing edges tends to expand by several percent. In order to increase the stiffness of the upper block and to prevent its horizontal movement, an additional stiffening steel block was attached to the

lower plate. To facilitate the upper block sliding along the surface of the stiffening block, special sliding plates were mounted on both blocks and accurately adjusted with shim stock. Great care was also taken in mounting to ensure that the upper and lower trim edges were parallel to each other.

Even though the tensile test data indicated that total elongation in the longitudinal and transverse direction was almost identical, the influence of the trimming line orientation to the rolling direction was studied thoroughly. In this paper, focus was placed upon the comparison of trimming methods. Therefore, this investigation is limited to orientation of the trimming line parallel to the rolling direction.

Both trimming and tensile tests were conducted using an Instron testing machine (Model 1125). For the trimming experiments, a ram speed of 0.5mm/sec was imposed. For partial trimming, however, the speed was decreased to 0.1mm/sec.

NUMERICAL MODELING OF TRIMMING PROCESSES

Analysis in LS-DYNA was carried out using 2-D plane-strain solid elements layered through the thickness of the blank and an elasto-plastic material model with piecewise linear plasticity (MAT_024). All tools were modeled as rigid bodies. Two dimensional automatic surface-to-surface penalty contact algorithm was used. In this algorithm, the Coulomb friction model was applied with the friction coefficient of 0.1 and a maximum surface shear stress of $\sigma_y/\sqrt{3}$. The remeshing technique was not used in this study. This model setting limited the depth of shearing edge indentation into the blank body to a smaller value compared to observed indentation in experimental samples.

Another limiting factor was penetration of nodes of the blank into the die body. The attempts to address this issue by increasing the stiffness of the contact layer resulted in excessive deformation of the elements adjacent to the blank surface. Obviously, more work is still necessary to address more fully this issue.

The two-dimensional, finite element simulation of the trimming process using the internally developed research code, Solid 2D, was also conducted. The Solid 2D governing equations of motion are identical to those featured in LS-Dyna. Model settings and assumptions for the Solid 2D model are as follows:

- Material Properties: Isotropic
- Hardening: Piecewise linear
- Yield Surface: von Mises with Isotropic Hardening and plastic strain dependent yield stress
- Constitutive Relationship: Prandtl-Reuss

- Time Integration: Explicit
- Discretization: Triangular mesh with no adaptive meshing

The most popular method of modeling contact interaction is based on the geometrical analysis of mutual position of boundary nodes of each mesh [3]. At every integration step, nodal penetration into the die boundary mesh is investigated. If such penetration exists, then the appropriate geometric correction is enforced. Due, in part, to time step limitations, some penetration will occasionally prevail. As soon as the blank's node penetrates into the die's surface, it is unable to return back to its geometrically correct location; subsequent calculations will not correct the problem. Therefore, a different approach was employed based on the idea of a mild contact formulation for which the contact force is in inverse proportion to the distance between the interacting surfaces. From a mathematical point of view, the mild contact is a variable boundary of unknown shape, where satisfaction of the non-penetration condition and equilibrium of forces between both surfaces is sought. This idea is based on the introduction of local forces repelling the surface nodes which are likely to violate prescribed contact conditions. As a result, the two surfaces do not coincide locally, but stay at some very small distance from each other. The force is localized in a small neighborhood of mesh elements, and increases to infinity when the distance between them approaches zero. The absolute value of the force F is given by

$$F = \begin{cases} k \left(\frac{1}{h} - \frac{1}{h_0} \right) & \text{at } h < h_0 \\ 0 & \text{at } h \geq h_0 \end{cases}, \quad (1)$$

where h_0 is the thickness of the contact layer, and h is the normal distance between the two surfaces in a local region. In the absence of technical memory and trial and error analysis, the value of h_0 is arbitrary. The value for $h_0 = 0.01$ mm defined for the current analysis is based upon calibration with respect to a large number of case studies. The mild contact algorithm allows for the prescription of Coulomb's friction effects, for which friction force directions are defined by relative velocity vectors.

Comparison of results on plastic strain distribution obtained by Solid 2D and LS Dyna for a conventional trimming process for the same penetration depth of the upper shearing edge is shown in Fig.3. Modeling results from both codes produced about the same maximum strain near the contact area of the blank with the upper shearing edge and similar boundaries of the plastic zones.

Similar modeling results were obtained for the robust trimming process (Fig.4). Since the upper trimming edge has a larger radius than the lower edge, higher level of