

Case Studies of Edge Fracture of Dual Phase Steel Stampings

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ABSTRACT

With the implementation of Advanced High Strength Steel (AHSS) becoming more common for automotive manufacturers to reduce mass and/or improve performance, special stamping considerations must be made. Certain production parts may split at trimmed edges where strain levels are well below the forming limit curve of the respective grade, which is more applicable to necking fractures/splits. Similar to the presence of hard inclusion stringers (i.e. MnS) that can cause edge fractures in high strength low alloy steels, AHSS steels most susceptible to this phenomenon typically consist of dual phase or multiphase microstructures containing both a hard phase (martensite) and a soft phase (ferrite). Specific examples of these parts will be discussed, including studies to determine the root cause of the edge fracture and to communicate the solutions for consideration in appropriate standards and specifications. The unexpected fractures at low strains were not limited to specific strength level, supplier or stamping plant but typically occurred when an edge was under tension in a stretch forming condition.

This paper will provide a review of various production case studies emphasizing the importance of the trimmed edge condition in edge fracture susceptibility. A comparison will be made between good and poor trim quality along with an updated definition for a good trimmed edge based on traditional shear face analysis. In addition, die design recommendations will be made for optimal trim conditions in both blanking and die trimming to help avoid unpredictable edge fractures. Finally, the paper will discuss one case study which emphasized the importance of material selection in eliminating an edge split issue in a component containing a flanged hole.

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INTRODUCTION

The usage of AHSS in the automotive industry is continuing to increase [1] based on its superior combination of strength and ductility versus conventional steels, which offers vehicle weight reduction potential. One such AHSS is dual phase steel, which consists of a microstructure containing a hard martensitic phase embedded in a soft ferritic matrix. When small amounts of bainite and/or retained austenite are also present, the grade is referred to as multi-phase (MP) or transformation-induced plasticity (TRIP) steel. Since the use of AHSS steel has increased, edge fracture has been observed as one of the major issues in stamping. If the steel is mechanically sheared, a shear-affected edge zone is created as a result of significant work hardening and possible void formation. Voids may form at the interface of the hard martensite and soft ferrite through a mechanism of strain partitioning, or strain localization. This occurs as a result of the inability of the hard and soft phases to deform coherently, and once strain localization is initiated, fracture can occur quickly in that localized zone by initiation, growth, and coalition of voids (decohesion at the interface). Additionally, fracture through the harder martensite phase may occur at low strain levels and propagate into the ferrite [2, 3]. Subsequent edge stretching

during part forming may lead to lower fracture strains than expected. Microstructural variation in the steel has been shown to have a large effect on forming performance and is critical in both bending under tension and stretch forming [4]. The steel industry continues to focus on optimization of the phase constituents, phase distribution and hardness gradients within a steel microstructure. In addition, mechanical shear process optimization should be considered to reduce edge damage and retain edge ductility to improve edge stretch conditions when forming a part.

Traditional methods to characterize a sheared edge in a mechanical trimming process typically include analysis of the rollover zone, burnish zone, fracture and burr along a shear face, typically reported as a function of the material thickness. These parameters are dependent upon material strength and ductility, die clearance and die configuration in the shearing process. Previous studies have provided in depth analysis to fully understand and characterize the level of damage during the shearing process [5, 6]. To best understand edge stretch performance, the magnitude and depth of damage/work hardening from the shearing process, referred to in literature as the shear affected zone, has been shown to be more important than the

shear face itself [7]. This information, however, is not typically obtained in a plant production environment as the issue is often resolved with a change in the stamping process or in die maintenance.

Auto manufacturers typically employ multi-stage forming processes (progressive or transfer die forming) which include an edge flanging process. Uniaxial or biaxial tension pre-straining has shown in a laboratory set-up to have a minimal effect on the edge flanging performance (which can be evaluated through hole expansion). Rather, the damage from the mechanical punching of the holes in the samples dominated the edge stretch performance [8]. This has been verified in other studies by comparing various methods to prepare the holes (i.e. milling, laser cutting, water jet cutting, etc.) in hole expansion tests intended to quantify the edge stretch performance of a material [9, 10].

This paper will provide examples of real-world production issues, where edge fracture occurred. Parts utilizing a variety of different dual phase or multiphase steels encompassing a number of different steel suppliers are included. The effect of trim edge quality and key indicators of edge fracture susceptibility will also be summarized.

EXPERIMENTAL METHOD

Materials and Part Selection

A list of ten production parts that have exhibited edge fractures is listed in [Table 1](#). This list includes current production parts made of Dual Phase (DP) or Multi-Phase (MP) Advanced High-Strength Steel (AHSS) grades. The parts are stamped at various GM Stamping plants including Lansing, Flint, Parma and Marion, and at one outside supplier. Ultimate Tensile Strength (UTS) of these materials ranged from 590 to 980 MPa. Most of the incoming material is hot dip galvanized, but one part has no zinc coating. In addition, the production materials are supplied by five different steel suppliers.

Table 1. List of production parts with edge fractures.

Part	Grade (UTS/YS)
Front Compartment Rail	DP780/420
Torque Box	DP980/550
Rear Rail Inner	DP590/340
Center Pillar Inner	MP980/700
Lock Pillar Inner	DP780/420
Hinge Pillar Outer	DP590/340
Front Body Hinge Pillar	DP590/340
Sill – Underbody #2 Cross Bar	DP590/340
Rocker Inner	DP780/420
Front Rocker Inner	DP980/700

During production, when issues arise unrelated to material quality, Manufacturing Engineering Die & Stamping Group is contacted for assistance. The parts for this study were grouped together when it became apparent there were multiple production problems with seemingly similar descriptions. Each part consisted of an AHSS material grade and exhibited edge fractures of unknown origin.

Edge Fracture Evaluation

It was always assumed press and die set-up were correct for each part and no changes were made between production runs, so the first step investigating these stamping issues was to confirm the mechanical properties. The material supplied for each part in this study was verified to meet the respective GMW3399 specification requirements. The evaluation included chemistry, microstructure and tensile properties (0.2% offset yield strength, ultimate tensile strength, total elongation and uniform elongation, as required).

The production parts were photographed showing the edge fracture area(s), then sectioned to remove smaller pieces of the part so the local area of fracture could be evaluated with a stereo microscope at 8 - 12 X magnification. These areas were often compared to similar areas on a matching part, that is left-hand verses right-hand, to compare edge quality with no edge fractures. The edges were photographed at these magnifications to document differences in surface appearance. The sections were then cut perpendicular to the surface so the profile of the edges could be evaluated and documented using the same technique.

RESULTS

The evaluation in this study shifted from material interaction to the tooling since there was no particular combination of steel grade or supplier that was causing the issues. All of the steels met GM Requirements, and the fractures were not confined to a particular part design, press type or stamping location. Since most fractures were prevalent on one side of a left-hand and right-hand part, the investigations proceeded by comparing and contrasting the steel/tooling interactions. This paper focuses on three of the ten parts highlighted in [Table 1](#) to best demonstrate the findings of all the parts in this study.

Front Compartment Rail

The first example shows both the importance of the trim operation and blank nesting in solving multiple fracture locations on a front compartment rail of a current model mid-size sedan utilizing a DP780 grade. The fractures were intermittent but resulted in an average of 20% production scrap in 2013. The stamping plants were unable to discern any problems with the press or die set-ups and thus requested support to identify the root causes of the edge fractures.

Production schedules allowed for these parts to be stamped once a week on the same day so additional support could be organized to help gather data during the stamping run. Data was gathered weekly on the amount of scrap and specific locations of the edge cracks. Representative samples of each crack location were gathered and delivered to the lab for analysis as described earlier.