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Development of the sheared edge in the trimming of steel and light metal sheet Part 1—Experimental observations

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Abstract

Trimming experiments were conducted on sheet metals including two drawing steels, an aluminum alloy and a magnesium alloy, using a specially designed die in a mechanical press. The punch-die clearance was varied and data obtained on the rollover and burr height as a function of the clearance. Samples were also partially trimmed to examine crack initiation, the generation of the fracture surface profile and mechanism of burr formation. The results showed that while the burr height and rollover depth generally increased with increasing clearance for all examined materials, there were differences in the fracture surface profile shape, the burr shape, and the mechanism of burr formation, between the two steels and the two light alloys. The major cause of these differences appeared to be the rate of crack propagation through the sheet material.

Keywords: Shearing; Trimming; Burr; Rollover; Steel; Light metals

1. Introduction

Lighter sheet metals such as aluminum and magnesium alloys are currently being used, or investigated as potential replacements, for conventional low-carbon drawing sheet steels in the automotive industry as they allow for lighter vehicles to be manufactured. The shearing of sheet metal is an integral part of the automotive stamping process, and therefore are an important factor in maintaining part quality. Past research in shearing operations, such as blanking [1,2] and bar cropping [3,4], has focused mainly on the optimization of process measurables such as the maximum punch load and penetration at fracture as a function of variables including the cutting clearance and tooling geometry for different work-piece materials. More recently, the commercial usage of aluminum alloys in stamping has caused an interest in the influence of these same variables on the edge quality of the sheared part, specifically in the trimming operation.

In shearing, the work-piece, or material being sheared, is stressed in shear until fracture occurs. The work-piece consists of the part, which is the portion being used after shearing, and the scrap, which is the portion being cut off. While the general principles are the same between different shearing processes, slight differences exist in the tooling configurations and work-piece constraints. The majority of existing shearing literature relates to the blanking process [1,2,5,6], where both the part and the scrap are constrained with respect to the tooling. The main result of these constraints is that the metal on both sides of the cut remains perpendicular to the direction of punch travel; hence the shearing process is considered to be symmetrical. Trimming is a shearing process used to remove the scrap from a panel after it has been drawn from a flat metal sheet, or blank. Since there is little or no constraint on the scrap-side of the work-piece, significant bending occurs on this side during the operation, hence trimming is non-symmetrical [7]. Atkins has shown differences

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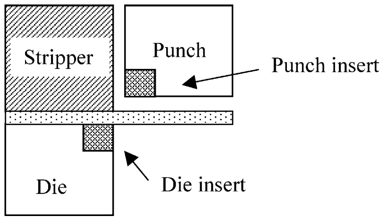

Fig. 1. Schematic drawing of the experimental die designed for the trimming investigation.

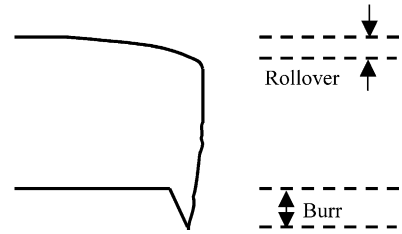

Fig. 2. Schematic drawing of the profile of a conventional sheared edge, showing the rollover and burr height.

exist between the blanking and trimming processes due to the difference in these constraints, such as the stress-state around the die tip [8].

While the main interest in the trimming quality of aluminum alloys has been mainly due to sliver defects (small metal fragments that detach from the panel or scrap during shearing), a recent study has highlighted other differences in the characteristic features of the sheared edge compared to conventional drawing steels [9]. These differences can be related to burr formation, which is the other major process defect besides slivers. Li and Fata [9] showed differing trends in burr formation of aluminum alloy and steel samples with changes in variables such as the angle of cut. These different trends highlight a difference in the fundamental metallurgical factors controlling the sheared part edge in the trimming process.

This paper examines the differences in fracture surface profile, including burr behavior, between two drawing steels, an aluminum alloy, and a magnesium alloy, over a range of cutting clearances. Mechanisms of burr formation are provided for all examined materials. A second paper [10] discusses the causes of these differences using results from finite element modeling and hardness contours of the deformed work-piece.

2. Methodology

2.1. Experimental apparatus

An open-fronted, mechanical press was used for the trimming experiments. The press has a maximum tonnage of 125 tonnes and punch velocity of ∼0.1 m/s at the point of contact with the sheet. The experimental die, shown schematically in Fig. 1, consisted of two identical mild steel blocks, the first acting as the punch, or upper tool, and the other as the die, or lower tool. Both steel blocks had removable inserts that acted as cutting blades. The top half of the die had a synthetic rubber stripper attached that led the punch and clamped the sheet in place before trimming. The stripper pressure was a constant value of approximately 1 MPa for all tests. The stripper was necessary to simulate a panel in a production die, which is generally tightly constrained on the die side. Blanks of size 900 mm × 400 mm were used, with the trimline along the longer dimension of the blank. Clearances were varied from approximately 3 to 35% of the sheet thickness from each material.

Brass shims were used to obtain the different punch-die clearances in the experiments. The shim was placed behind the bottom trim insert to adjust the distance between cutting blades. Steps could be made in 0.05 mm increments.

The materials examined were aluminum alloy 6111-T4, magnesium alloy AZ31 and two drawing steels, CA5 and HA3P. AA6111 is based on the Al–Mg–Si composition, and is the most common aluminum alloy currently used in the automotive stamping industry. Magnesium alloy AZ31 sheet is not currently used in the automotive industry, although it is being researched for such a purpose. CA5 is an ultra low-carbon (0.002–0.005 wt% C) cold-rolled, skin-passed critical drawing steel used for severely drawn components. HA3P is a low-carbon (0.04–0.07 wt% C), pickled, hot-rolled formable steel suitable for deep drawing. Tensile properties in the longitudinal direction for these four materials are listed in Table 1 and were obtained from samples with a 20 mm width and 110 mm gauge length using a screw-driven MTS testing machine at a constant crosshead speed of 5 mm/min.

2.2. Sample analysis

Measurements of the rollover depth and burr height for each sample were made using cross-sections of the trimmed sheet (Fig. 2). The rollover depth is the vertical distance between the original upper surface of the sheet and the start

Table 1
Tensile properties for investigated materials

Material	Y.S. (MPa)	U.T.S (MPa)	Total elongation (%)	Uniform elongation (%)	*n*-Value
6111-T4	190	310	23	21	0.19
CA5	150	280	44	27	0.22
HA3P	280	360	32	20	0.20
AZ31-B	250	290	23	12	–