

Study of Trimming Behavior of Automotive AZ31 and ZEK100 Sheet Materials

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Abstract. The trimming behavior of AZ31 and ZEK100 automotive magnesium sheet materials was investigated using lab-based experiments. The effects of trimming process parameters; trimming speed, clearance and tool setup configuration, on quality of trimmed edge were analyzed. Experimental results indicated strong dependence of trimmed edge quality on trimming process conditions. Clearance between punch and die had the most significant influence on the trimming behavior of AZ31 and ZEK100, both the punch load peak and quality of trimmed edge decreased with increase of clearance. The larger is the clearance, the later the crack initiates. ZEK100 was more sensitive to smaller clearance compared to AZ31. Trimmed edge quality of AZ31 and ZEK100 Mg sheets improved with increase in trimming speeds up to 5 mm/sec. The tool setup configuration with cushion consistently resulted in better trimmed edge quality and especially help with burr height reduction which is a key parameter for assessing the quality of the trimmed edge.

1. Introduction

Two potential wrought magnesium alloys, AZ31 and ZEK100 in sheet form are becoming increasingly attractive for forming applications. While much progress has been made towards formability enhancement of these alloys, few studies have been undertaken to investigate their trimming behavior, a widely used process of material separation that is typically applied at room temperature. Present work is an attempt to characterize the trimming behavior of AZ31 and ZEK100 magnesium sheet materials. Trimming is a process in which part(s) of a formed or un-deformed region of a component, referred to as offal, is cut away to yield the desired part. A typical tool configuration for trimming process consists of punch, die, blank-holder and sometimes an optional cushion as shown in Figure 1. The sheet is clamped between the blank-holder and die and held stationary while the punch and cushion (if applicable) are moved perpendicular to the sheet plane to trim the sheet. A clearance between the punch and die, a small fraction of sheet thickness, exists to allow the punch to pass through the clamped sheet to cut. Trimmed edge of part is typically characterized in terms of four different quantities: rollover, burnish zone, fracture zone and burr. The different zones determine profile and quality of the trimmed edge.



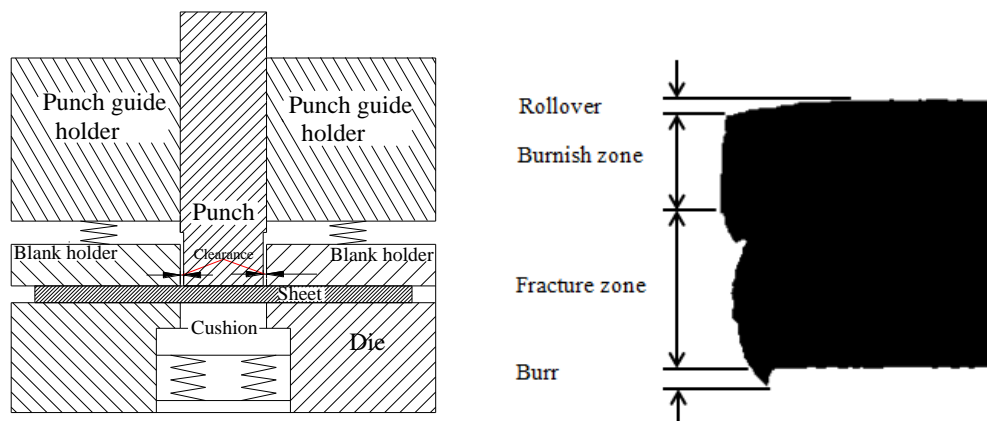


Figure 1. Trimming process and typical profile of trimmed edge.

Trimmed edge shape and quality are typically related to material properties (mechanical and thermal properties, microstructure, geometry), operation parameters (trimming speed, clearance), friction (lubrication) and tooling (tool setup configuration, tool geometry and wear). Many experiments on factors affecting the trimmed edge quality have been conducted by researchers on ductile sheet materials such as steel, copper and aluminum. These studies indicate higher blanking speeds can improve the part edge quality, resulting in smaller burr height and rollover, and a larger shear zone [1]. Clearance was identified as a critical factor that affects the crack path and governs the quality and profile of the trimmed edge (burnish, burr size and fracture shape) in many cases regardless of which material is blanked or what cutting speed is used [2-6]. For aluminum sheet, an optimal clearance of about 5% to 10% of thickness has been reported[8]. The improved trimming tool configurations by adding a support pad underneath the offal prevents the offal's bending and excessive rotation, eliminates burrs and prevents the generation of slivers from the trimmed surface and gives a better cut edge quality for aluminum alloy AA6111-T4 [5, 6].

The study of trimming behavior of magnesium alloy sheet is a relatively new subject, so the objective of this study was to investigate the trimming characteristics of two recent magnesium sheet materials, AZ31 and ZEK100. The effects of various trimming process parameters including tool setup configuration, trimming speed, clearance between the punch and die, sheet thickness and sheet orientation (along rolling and transverse directions) were analyzed through lab-based experiments and FE simulations.

2. Experimental Procedure

Trimming tests were conducted on a computer-controlled screw-driven Instron mechanical test system of 10 kN load capacity (see Figure 2). A trimming test rig, fabricated for the above test system, included two tool setup configurations, (i) a conventional tool setup consisting of punch, blank-holder and die (see Fig. 3(a)), and (ii) an alternative tool setup consisting of punch, blank-holder, die, and a two-part steel and elastic (polyurethane foam) cushion (dynamic stiffness in compression of about 4 MPa), the latter was located directly below the clamped test specimen (see Fig. 3(b)). The trimming tool setup was mounted on the base plate while a compression platen was attached to the load cell and positioned directly above the punch of trimming tool setup. The punch was kept unattached but guided in a housing at the top of the die. When the cross-head was moved downward, and the compression platen with it, the latter came in contact with the punch. The punch then delivered a quick downward blow to the sheet metal clamped between the die and the blank-holder to perform the trimming process. During the trimming process, the punch load and displacement were continuously recorded.

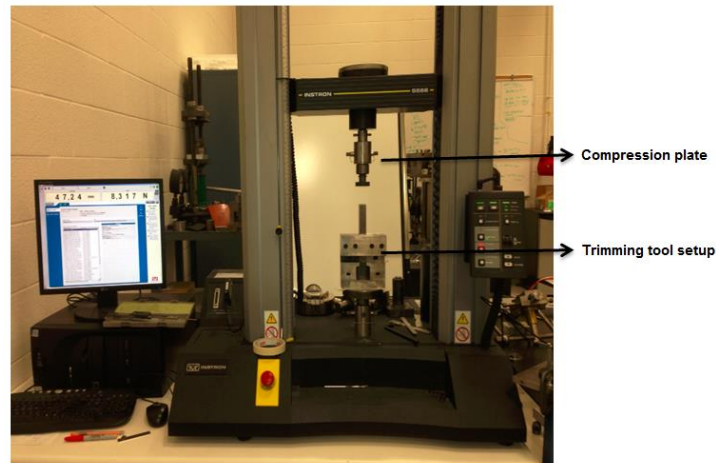


Figure 2. Instron 10 kN mechanical test system for trimming test.

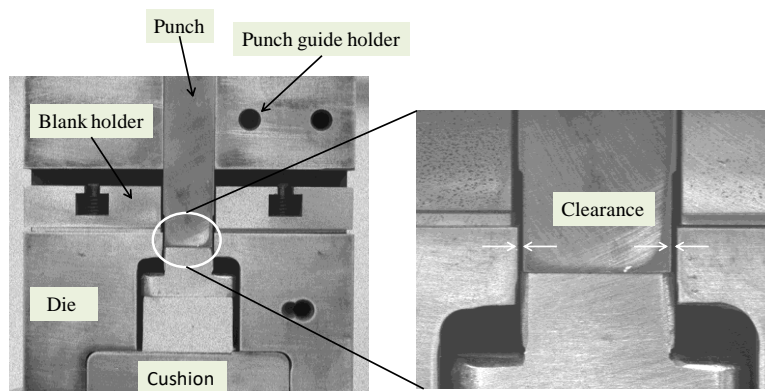


Figure 3. Tool setup configurations for trimming tests.

The materials studied in this research were commercial grade rolled AZ31 and ZEK100 magnesium sheets. The specimens for trimming test were annealed at a temperature of 300°C for 15 minutes, and then furnace cooled to room temperature of 20°C. The dimension of specimen for trimming test was chosen as 75 mm in length and 15.8 mm width while keeping the original sheet thickness of 1.58 mm for AZ31 and 1.53 mm for ZEK100. Trimming process parameters considered included speed, clearance and tool setup configuration. The test matrix is presented in Table 1. To obtain more representative experimental results, test for each test condition was repeated 4 or 5 times. The tests were conducted at room temperature (20°C).

Table 1. Experimental matrix for trimming tests.

Materials and thickness (mm)	AZ31(1.58), ZEK100 (1.53)
Tool setup configuration	1. Die, punch, blank-holder
	2. Die, punch, blank-holder, cushion

Clearance/thickness (%)	4, 11, 20, 26
Trimming speed (mm/sec)	0.1, 1, 3, 5

The burnish depths of trimmed specimens were observed and measured using a stereoscope. Trimmed specimens were also cold mounted in a cylindrical container and filled with epoxy resin and epoxy hardener in proper proportion. Epoxy mounted specimens were also observed using a microscope equipped with a camera to record the trimmed edge profile and measure the burr height, rollover and fracture depths along the cross section. A typical trimmed edge is shown in Figure 4.

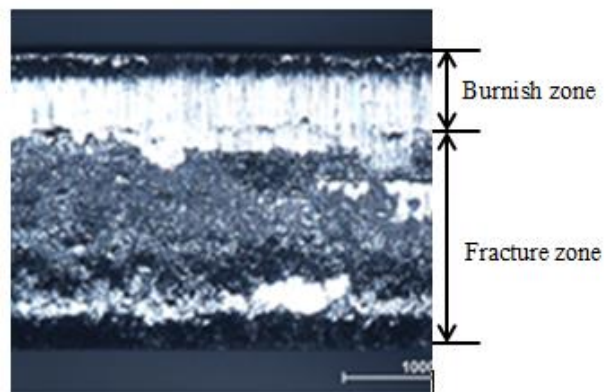
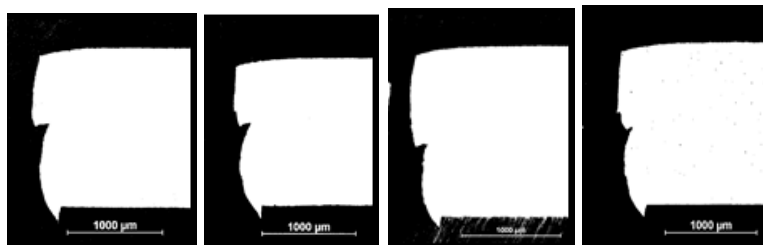


Figure 4. Fracture surface of cross section.

3. Results

Figure 5 shows profiles of trimmed edges at different trimming speeds for AZ31 and ZEK100 specimens. In general, for both materials, the quality of trimmed edge improves with increase in trimming speed. Both AZ31 and ZEK sheets show the same general trend of increase in burnish depth with increase in trimming speed. Since trimmed edge is mainly composed of the burnish zone and fracture zone, the fracture depth usually shows an opposite trend to the burnish depth. As for rollover and burr height, they remain almost constant with increase in trimming speed (see Figure 6). A comparison of trimmed edge quality between AZ31 and ZEK100 reveals that the rollover depth for both AZ31 and ZEK100 are almost the same, but the burnish depth for ZEK100 is higher than that for AZ31. The burr height for ZEK100 is also slightly lower than that for AZ31 in the range of higher trimming speeds. Therefore, it can be concluded that the trimming quality of ZEK100 is generally better than that of AZ31.



AZ31:

0.1 mm/sec

1 mm/sec

3 mm/sec

5 mm/sec

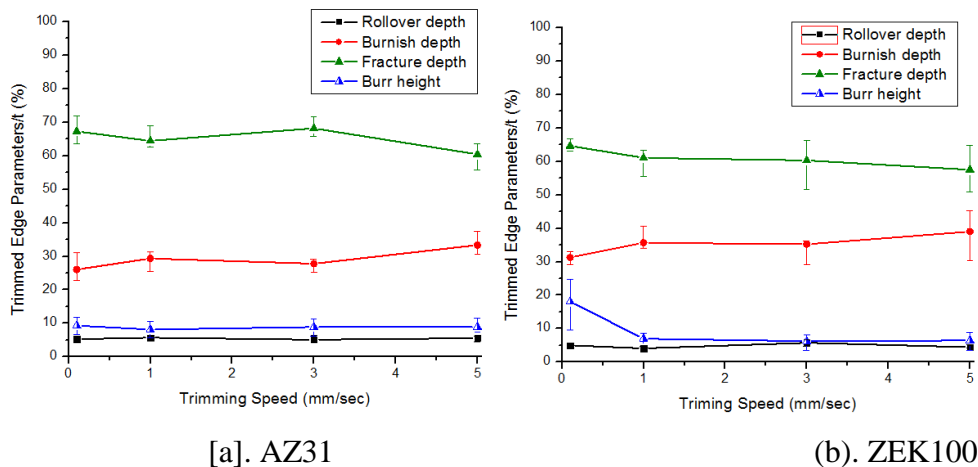
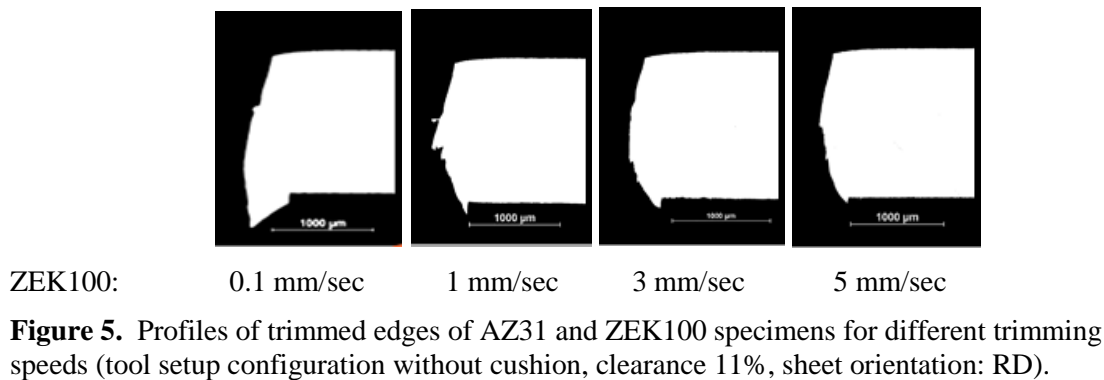


Figure 6. Plots of trimmed edge parameters as a function of trimming speed. (edge data is normalized by material thickness), (a). AZ31, (b). ZEK100.

Figure 7 shows the profiles of trimmed edge of AZ31 and ZEK100 with respect to different clearances. Trimmed edge parameters as a function of clearance are plotted in Figure 8. The quality of trimmed edge progressively decreases with an increase in clearance for both materials. For rollover, both materials show the same trend; the rollover depth decreases with increasing clearance, and for identical clearance, there is no significant difference between AZ31 and ZEK100 sheets. The burnish depth for ZEK100 is much higher than that for AZ31 in the range of small clearance (up to 11%), but for clearances above 11%, the burnish depth for both AZ31 and ZEK100 tend to evolve to a similar value. The fracture depth exhibits an opposite trend to burnish depth. Lastly, for the burr height, ZEK100 remains almost constant within the entire range of clearances while the burr height increases with increase of clearance for AZ31. Especially, at large clearances, the trimming zone is wider and this region will encounter more bending. Consequently, the burnish zone is reduced while fracture zone is increased, the burr height and size becomes larger, and the precision and quality of trimmed edge decreases. From a comparison of results between AZ31 and ZEK100 for different clearances, one can conclude that the trimming quality of ZEK100 is better than that of AZ31. Moreover, there is dramatic change of trimmed edge quality for ZEK100 in the range of small clearance, this is because the ZEK100 is more ductile and thus sensitive to small clearances compared to AZ31 sheet.

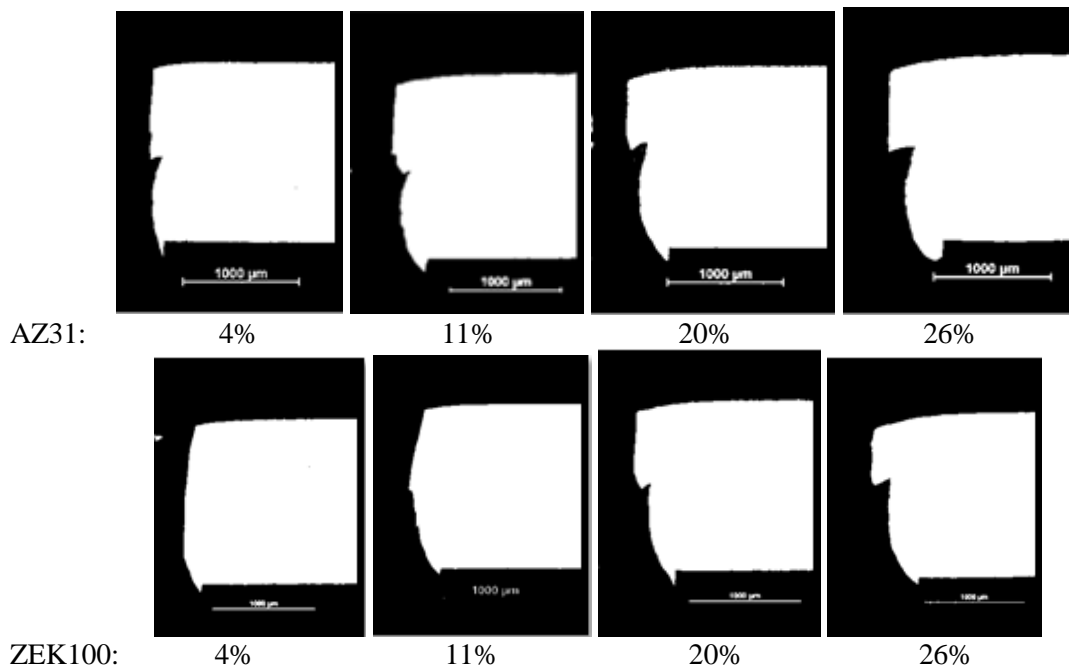


Figure 7. Profile of trimmed edge of AZ31 and ZEK100 for different clearances (tool setup configuration without cushion, trimming speed 5 mm/sec, sheet orientation: RD).

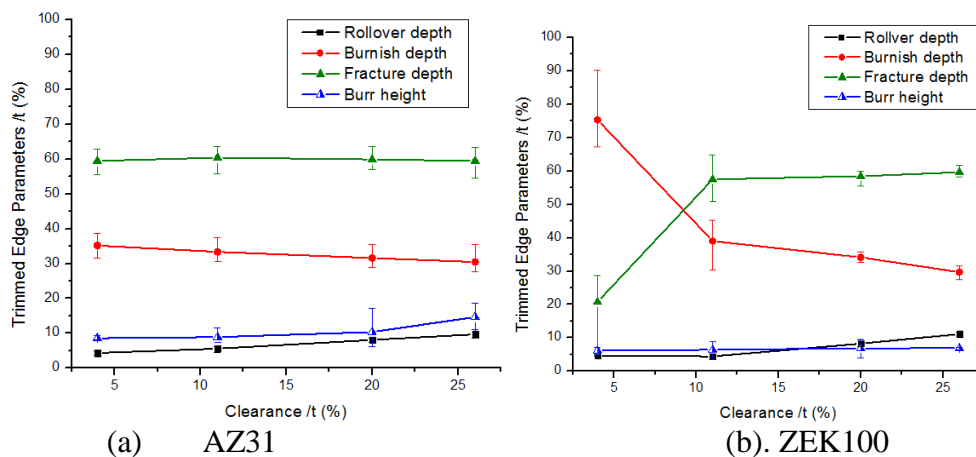


Figure 8. Plots of trimmed edge parameters as a function of clearance, (a). AZ31, (b). ZEK100.

Figures 9 and 10 show the profiles of trimmed edges of AZ31 and ZEK100 and bar charts of trimmed edge parameters from two different tool configurations respectively. Burr is clearly more visible for the conventional tool configuration (i.e., without cushion) than with cushion. Also, for both materials, the rollover depth for trimming with cushion is slightly larger than without cushion. This is because more punch penetration is required to overcome resistance of cushion, and correspondingly, there is more compression and tension in the trimmed zone that can possibly contribute to larger rollover depth. The burr height, on the other hand, decreases with the use of cushion because the cushion prevents the offal from rotation and bending at the bottom area of the trimming zone. Lastly, the burnish and fracture depth appear to be almost the same for AZ31 and ZEK100. In general, comparing the overall quality of the trimmed edge from the 2 different tool configurations (Figure 10), the use of

cushion not only keeps the burnish depth to same extent, but also can effectively reduce the burr size and improve the quality and precision of trimmed edge. Also, in majority of the test conditions involving two different tool setup configurations, the rollover depth, fracture depth and burr height of ZEK100 is smaller than that of AZ31, so, in general, ZEK100 sheet shows better trimming quality than AZ31.

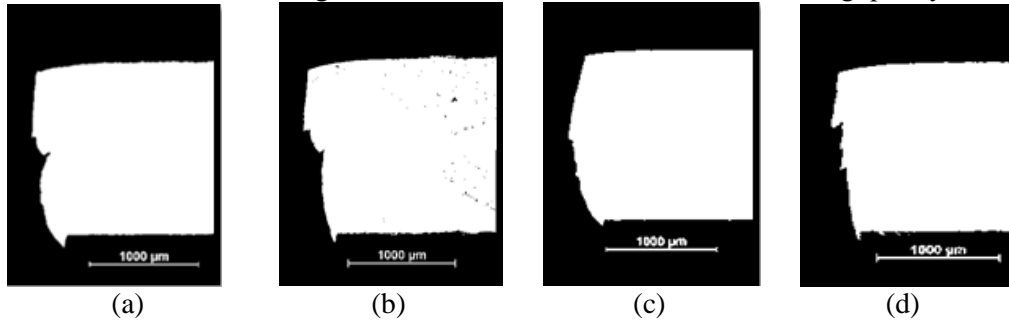


Figure 9. Profiles of trimmed edges of AZ31 and ZEK100 specimens obtained using different tool setup configuration, (a). AZ31 without cushion, (b). AZ31 with cushion, (c). ZEK100 without cushion, and (d). ZEK100 with cushion (trimming speed: 5 mm/sec, clearance 11%, sheet orientation: RD).

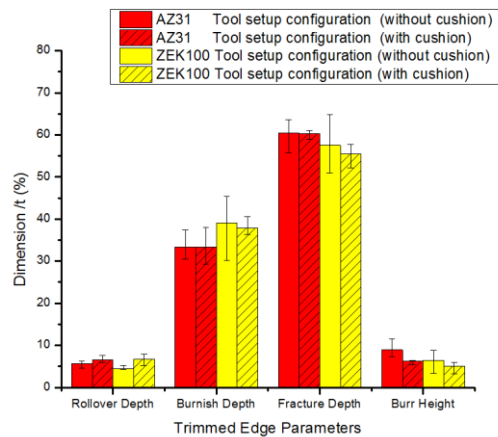


Figure 10. Comparison of effect of tool configuration on trimmed edge quality.

The punch load-displacement curves for AZ31 and ZEK100 sheets with different orientation are presented in Figure 11 (a-b). Both materials exhibited very similar features with respect to the peak load which remains independent of the specimen orientation (with respect to the trimming line). However, a rather large plateau or load saturation was observed for the transverse (or TD) specimens compared to the rolling direction (RD) specimens. This means that crack initiation and fracture was delayed in the transverse specimens and more plastic work was required to complete the trimming process. Both AZ31 and ZEK100 sheets exhibited significant anisotropy, the flow stress-strain curves and work-hardening capacity along RD and TD were different, and that is why the response of the punch load-displacement curves was also quite different.

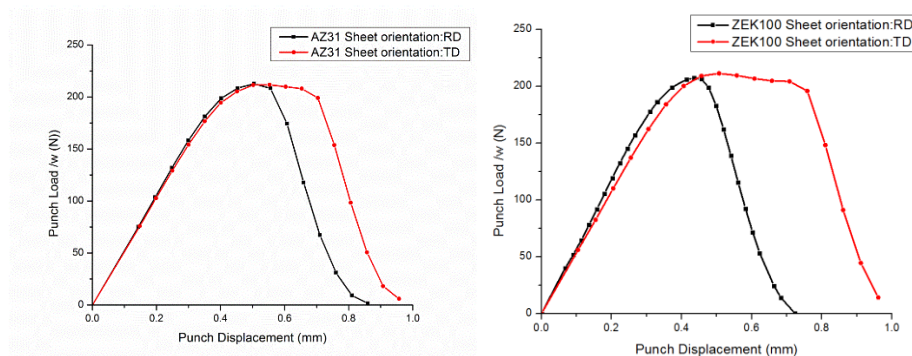


Figure 11. Effect of sheet orientation on punch load-displacement curves (tool setup configuration without cushion, clearance: 11%, trimming speed: 5 mm/sec).

4. Conclusions

The effect of various process parameters such as trimming speed, clearance, tool setup configuration, sheet orientation and thickness on the trimming behavior of AZ31 and ZEK100 magnesium sheets was systematically investigated and analyzed using a laboratory-based experiments. The following conclusions were drawn from experimental and numerical study:

- [1]. Trimmed edge quality of AZ31 and ZEK100 Mg sheets improved with increase of trimming speeds up to 5 mm/sec.
- [2]. Clearance between punch and die had the most significant influence on the trimming behavior of AZ31 and ZEK100, both the punch load peak and quality of trimmed edge decreased with increase of clearance. The larger is the clearance, the later the crack initiates. ZEK100 is more sensitive to smaller clearance compared to AZ31.
- [3]. The tool setup configuration with cushion consistently resulted in better trimmed edge quality and especially help with burr height reduction which is a key parameter for assessing the quality of the trimmed edge.
- [4]. The trimmed edge quality for ZEK100 was consistently better than that of AZ31 and could be partially attributed to its superior formability of ZEK100 compared to AZ31 sheet.
- [5]. The effect of sheet orientation was relatively small with transverse specimens showing a shift in the load displacement response towards a larger displacement for both sheet materials, likely due to delay in fracture initiation for transverse specimens.

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