SHEAR SLITTING OF ALUMINUM WEBS

by

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ABSTRACT

Shear slitting of aluminum webs using both disk knives and block knives were investigated using a laboratory slitter. The effects of the clearance, overlap, blade overdrive, and cant angle on burr height were studied on four different aluminum webs. It was observed that the burr height is small when the clearance was less than a critical value, and the burr height increased drastically when the clearance was larger than the critical value. The effect of overdrive was negligible for the experiments performed. The burr formation was revealed through a series of micrographs at different stages of slitting.

INTRODUCTION

A web is a thin, continuous, and usually flexible material such as an aluminum sheet or foil. Shear slitting is a process to convert a web into two narrower webs; it is an essential process in manufacturing a wide range of materials such as metal sheets, foils, paper, plastic film and fabrics. This investigation focused on shear slitting of aluminum sheets. High slit edge quality is required for all good products; in general, good slit edge quality for aluminum sheets is indicated by smooth, clean, and straight edges with no edge wave, and most importantly, none or minimal burr. It is also critical that during the slitting process there is no generation of debris, fines or slivers, which can often be carried over to down stream processes causing damage on the web surface or in rolls. The objective of this study is to investigate the burr height (see Fig. 1) during shear slitting. High edge burrs can scratch the sheet surface to cause web surface damage, and can also lead to roller damage when the burr side of the web is in contact with a roller after slitting processes; webs with high burrs can entrap air which reduces the coefficient of friction between webs and makes the web very difficult to wind.

Publications on slitting (including shear slitting) of metal, plastic, and paper webs are very limited. Ma, Lu and Li [1] recently studied the effect of slitting parameters, i.e., the clearance, cant angle and overlap, on the burr height. The relationship between the slitting parameters and the slit edge qualities has been established. It was found that the clearance is the most critical parameter affecting the burr height. There exists a critical clearance for each slitting configuration. The burr height is at its minimum if the clearance is below the critical clearance. But the burr height increases abruptly when the clearance is larger than the critical clearance. Lu, Wang and Iqbal [2] investigated the effect of shear slitting parameters on edge burr height formed on polypropylene webs up to a speed of 61 *m/s*. They revealed that an increase in web speed leads to reduction in burr height. Lu, Wang, Ma and Viswanathan [3] performed 3D finite element (FE) simulations of shear slitting of aluminum webs using the shear failure criterion. Effects of the clearance and blade sharpness on burr height have been determined. The burr profiles obtained from simulation agree very well with those from experiments.

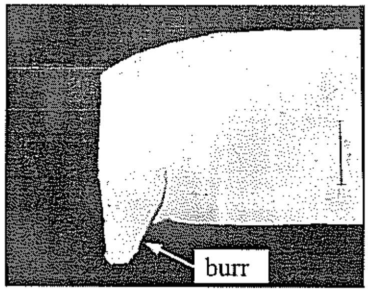


Fig. 1: An SEM micrograph of a burr at a slit edge.

While there is only limited result published on shear slitting, there have been many publications on cutting, shearing or punching of thick metal sheets. Sheet metal shearing has some common features with shear slitting. Both processes involve converting a sheet into two sheets. Some results and the research methodology from metal shearing could shed light on shear slitting. Li [4] investigated the effect of cutting angle, clearance, and tool sharpness on shearing aluminum sheets. His observation of the micrographs determined that the micromechanism in shearing of aluminum sheet is the nucleation and coalescence of voids following the formation of curved shear bands in the shearing zone. Recently, Li [5] proposed a method to trim aluminum autobody sheet using a non-zero rake angle. At optimal cutting angles, good edge quality can be achieved for a wide range of blade sharpness and clearance. This method is capable of producing almost zero burr height even when a large clearance and an extremely dull blade are used.

In this paper, a laboratory slitter capable of adjusting a variety of shear slitting parameters was utilized to investigate how the burr height on the edges of slit aluminum sheets is affected by the parameters, including the clearance, overlap, overdrive and cant angle. The definitions of these slitting parameters are given in next section. Shear slitting, in general, can be categorized as wrap shear slitting and tangential shear slitting. In wrap shear slitting, the web wraps the lower blade at a non-zero wrap angle. In tangential shear slitting, the web plane is flat and is tangent to the lower blade. This study focuses on tangential slitting which is predominantly used in converting aluminum sheets in industry.

SLITTING PARAMETERS

We first define the terminologies related to shear slitting. The terms used to define the shear slitting parameters in this study are used in industry as well. As shown in Fig. 2 (a), *clearance*, also called *gap*, is the smallest horizontal separation between the upper and lower knife blades. *Overlap* is the vertical distance of the overlapped portion between the two circular blades, as shown in Fig. 2 (b). Also shown in Fig. 2 (b) is the blade *offset* between the centers of the circular blades in the horizontal direction. *Cant angle*, as shown in Fig. 2 (c), is the angle between the blade planes from the top-view of Fig. 2 (b). The cant angle as shown in Fig. 2 (c) is defined to be positive. *Cutting point* is the point where the entry web starts to engage with both blades. In this study, the cutting point was set level with the web plane so that there was no out-of-plane deformation induced by the incorrect positioning of the cutting point. This is achieved by adjusting the offset to position the cutting point on the web plane. *Blade overdrive* indicates the difference of the linear velocities of the cutting point of the top and bottom blades. Negative overdrive means the lower blade is faster than the top one in this study.

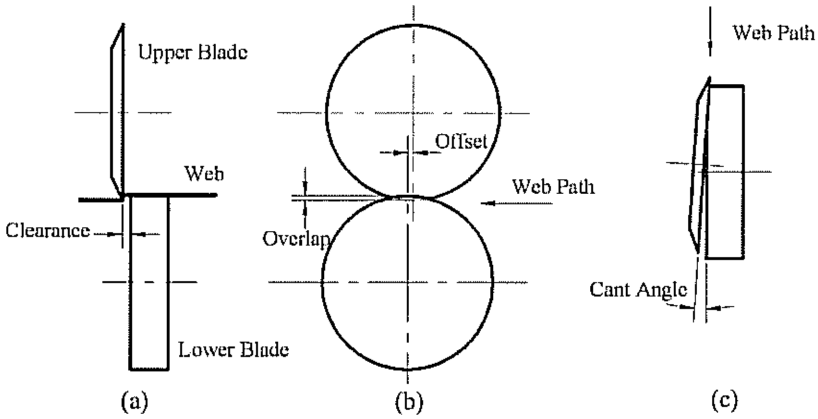


Fig. 2: Illustration of the parameters in shear slitting.
(a) A driven-roller side view of the top and bottom blades;
(b) A side view of the top and bottom blades; (c) A top view of the blades.

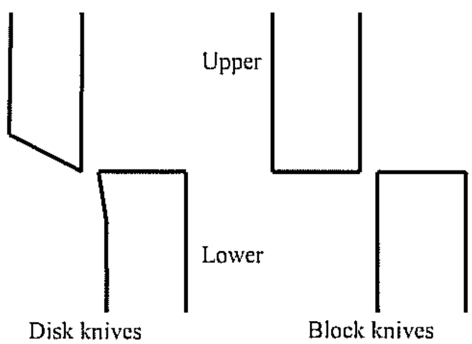


Fig. 3: Schematics of shear slitting using disk knives and block knives.

Two kinds of knives, disk and block knives, as shown in Fig. 3, were used in this investigation. These knives are identical to the knives used for shear slitting of aluminum webs in plant. Disk knives are used for thin sheets and block knives are generally used for thick sheets because their rigidity is high.

The effects of slitting parameters were studied through experiments. The slitting parameters studied in this investigation include the clearance, overlap, cant angle and blade overdrive. Four aluminum webs, with mechanical properties as shown in Table 1, were tested with the disk knives. Two aluminum webs, 1050 H18 of 0.011 in thick and 5182 H19 of 0.008 in thick are used for the experiments using the block knives. Table 2 shows the range of the slitting parameters for the experiments using the disk knives. Table 3 shows the parameters investigated using the block knives. In shear slitting with block knives the speed and tension are the same as listed in Table 2.

Table 1: Material properties

Thickness (*in*)	Alloy	Yield strength σ_y (*MPa*)	Ultimate tensile stress (*MPa*)	Failure strain ϵ_f (%)
0.008	5182-H19	344.5	393.6	10.70
0.011	3004-H19	280.9	308.7	5.63
0.006	1050-H18	159.2	171.6	2.27
0.011	1050-H18	144.5	154.1	1.50

Table 2: Parameters used in experiments using disk knives

Clearance (inch)	Overlap (inch)	Cant angle	Speed (ft/min)	Tension (psi)
0-0.008	0.015-0.030	0-1.0°	30	1500

Table 3: Parameters used in experiments using block knives

Clearance (inch)	Overlap (inch)	Overdrive range	Cant angle
0-0.020	0.015- 0.030	±10%	0.25°

EXPERIMENTAL RESULTS

We first define the burrs on two slit edges as shown in Fig. 4. The lower blade is at the front side of the top blade. The burr on the front slit edge always appears on the bottom web surface. It is named the front bottom burr. The other burr appears on the top surface of the rear slit edge. It is named the rear top burr. These two burrs show different features when the slitting parameters are changed using disk knives. Detailed experimental results for disk knives have been reported [1].

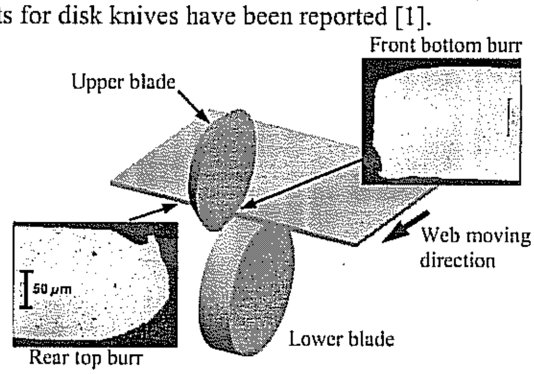


Fig. 4: Definition of two slit edge burrs.

In this paper, the results for the block knives are summarized. For the block knives, the blade edges of both top and bottom block knives are 90°. These blade edges are symmetric with respect to the web plane. We call this blade symmetry. It was found that the burr formation has no preference to either slit edge. For shear slitting with disk knives, one observation is that when the clearance is larger than the critical clearance, the front bottom burr increases drastically. For shear slitting with block knives, due to the symmetry of the knives with respect to the web plane, either front or rear slit edge may have high burrs when the clearances increases to certain value. This is a distinct feature of shear slitting with block knives. This can be seen from the plots of the front bottom burr heights and rear top burr heights.

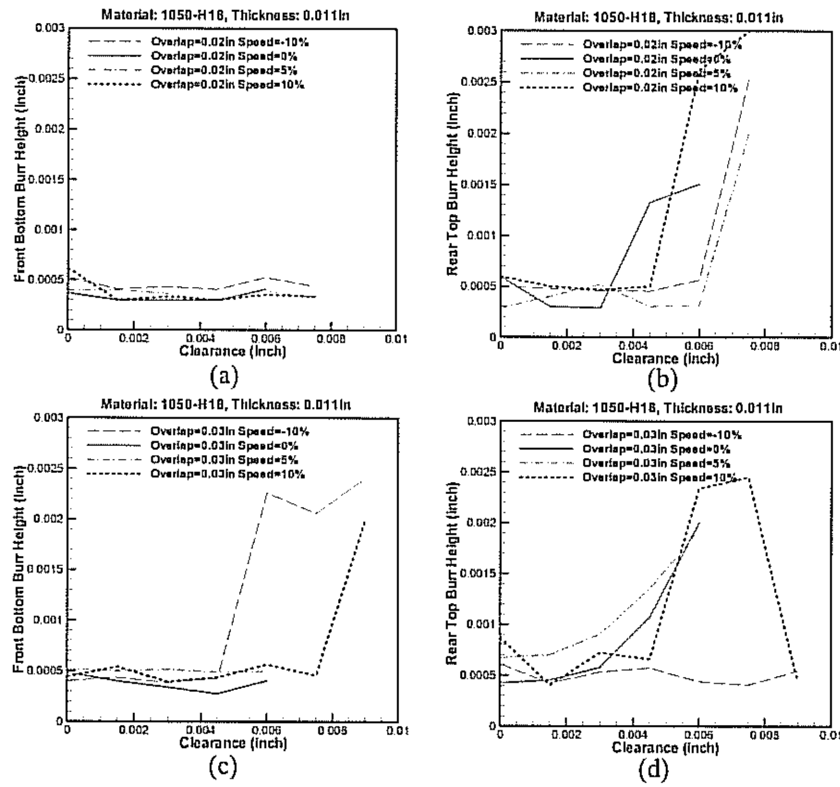
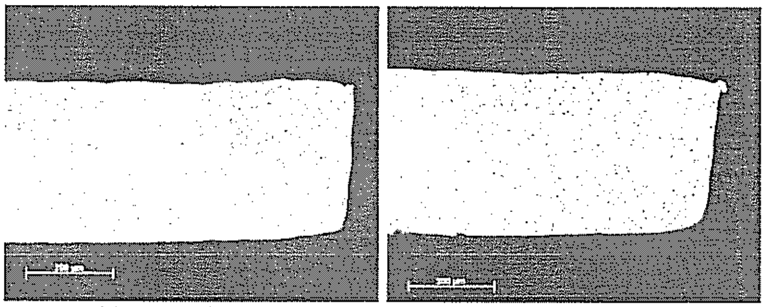


Fig. 5: Burr height for the 1050 web using block knives.

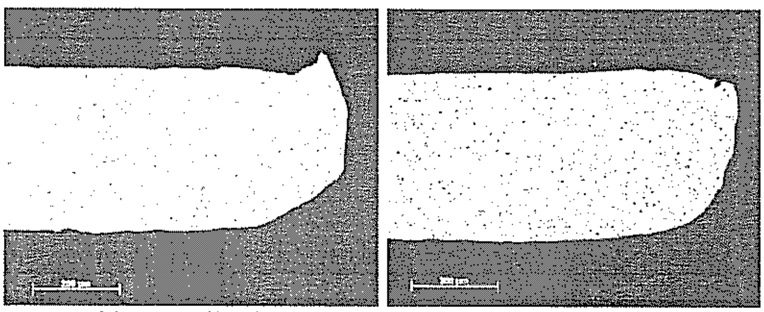
Fig. 5 plots the burr height of the 1050 web as a function of clearance using block knives. Both the front bottom burr and rear top burr can be very high at large clearances. Experiments showed that which burr increases abruptly at large clearances is not predictable. When the clearance is less than 0.003 in, both burr heights are about 0.0005 in (0.5 mils). It is noted that for slitting with disk knives, the rear top burr height is higher than the front bottom burr height when the clearance is less than the critical clearance. But due to blade symmetry, the rear top burr height and the front bottom burr height are about the same with block knives. The four curves in each plot indicate four different overdrives. The burr height and critical clearance are not consistently dependent on the overdrive. Hence, the effect of overdrive is not significant.

It is observed from the plots in Fig. 5 that the critical clearance for the 1050 web of 0.011 in thick is about 0.0025 in. The micrographs the cross sections of one sample of 1050 material obtained at zero clearance are shown in Fig. 6. Small burrs are seen in these graphs. The micrographs of a sample obtained at 0.006 in clearance are shown in Fig. 7. For this sample, the front bottom burr is about 0.002 in, which is unacceptable. As mentioned earlier, high burr can occur on either side due to blade symmetry. For this case, the front slit edge happens to have a high burr.



(a) Front slit edge (b) Rear slit edge

Fig. 6: Micrographs of the 1050 web at zero clearance
Rake angle=0°, overlap=0.02 in, cant angle =0.25°, overdrive=10%



(a) Front slit edge (b) Rear slit edge

Fig. 7: Micrographs of the 1050 web at 0.006 in clearance
Rake angle=0°, overlap=0.02 in, cant angle =0.25°, overdrive=10%.

For the 5182 web, the rear top burr height appears to be unpredictable, and does not show a clear trend. At the zero clearance, the burr height can be up to 0.75 to 1 mil. This is generally unacceptable. The effect of overdrive is not significant in these experiments for the 5182 web. The critical clearance for this web is about 0.002 in. The micrographs of two samples obtained at zero clearance and 0.006 in clearance are shown in Fig. 9 and Fig. 10, respectively. The quality of the rear slit edge appears to be very good for these two samples. It is noted that the overall edge quality is not as good since the burr is not always continuous. These sections were taken at the locations where there were no burrs. The front bottom burr is not high at 0.006 in clearance in the micrograph in Fig. 10. The burr height is about 0.5 mils.

BURR FORMATION

Burr height is one of the major indicators of edge quality. Understanding the mechanism of the burr formation could help select appropriate slitting conditions and lead to development of other slitting methods to produce high quality slit edge. Fig. 11 shows six snap shots of a web in shear slitting at zero clearance using the disk knives. The web longitudinal (or MD) distance between neighboring micrographs is approximately 10 μm. In the initial stage, when the web starts to engage with both blades, localized deformation/indent can be observed. The left part (rear slit edge) is pushed to move downward relative to the right part (front slit edge), causing localized shear deformation in the web. Figs. 15 (a)-(c) show the progression of the shearing process. Fig. 11 (d) shows the formation of a through crack separating the two edges. Edge deformation, as shown in Figs. 15 (e) and (f), accumulates due to the further blade engagement, and a V shaped dip in the rear slit edge is formed. Fig. 11 (f) shows the complete separation of the two slit edges and a small overlap in the two connected webs in the horizontal direction after slitting. No further deformation of either slit edge was observed after this stage. As indicated in [2], shear slitting can be identified as three stages: the initial indentation by the top blade into the web, the shearing by blade shearing motion, and the final tearing fracture. The first two stages can be identified in Figs. 15 (a)-(c). The tearing fracture is as seen in Figs. 15 (d)-(e). It is noted that the rear slit edge deforms as a result of tearing of the two converted webs immediately following the formation of a through crack in the web. This deformation is most likely the major factor contributing to the formation of rear edge burr.

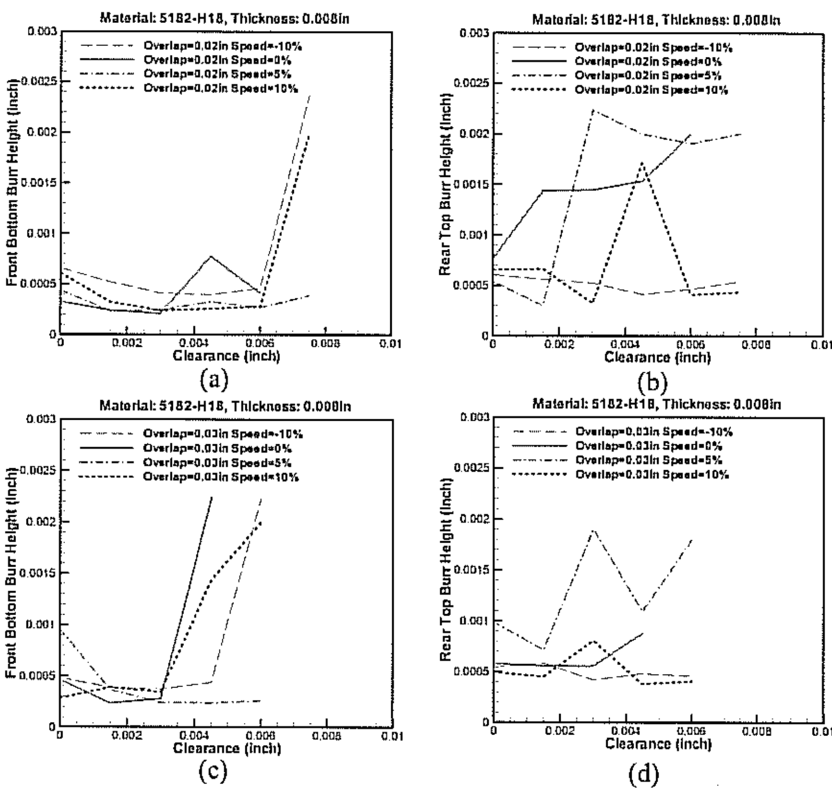
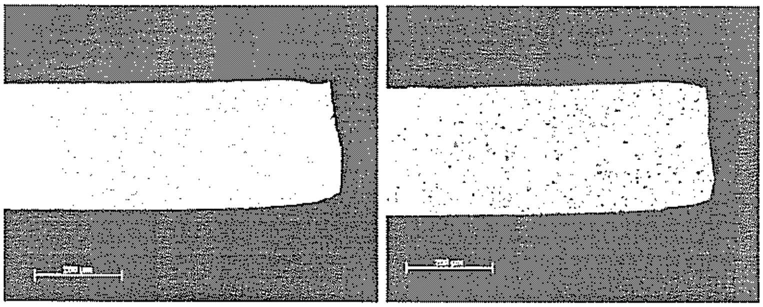
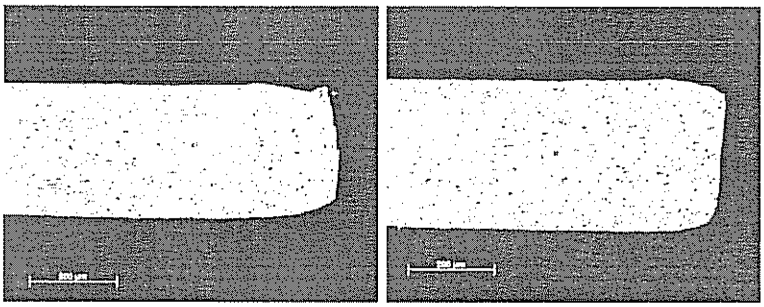


Fig. 8: Burr height for 5182 web at zero rake angles



(a) Front slit edge (b) Rear slit edge

Fig. 9: Burr height for 5182 web at zero clearance
Rake angle=0°, overlap=0.02 in, cant angle =0.25°, overdrive=10%



(a) Front slit edge (b) Rear slit edge

Fig. 10: Burr height for 5182 web at 0.006 in clearance
Rake angle=0°, overlap=0.02 in, cant angle =0.25°, overdrive=10%

SUMMARY

Shear slitting with block knives was conducted on two aluminum webs, 1050 H18 of 0.011 in thick and 5182 H18 of 0.008 in thick. Three parameters, namely the clearance, overlap, and overdrive, were investigated. Using the block knives, it was found that the critical clearance for the 1050 web of 0.011 in thick is about 0.0025 in. For the 5182 web of 0.008 in thick, the critical clearance is 0.002 in. The speed at the cutting point on the lower blade is 35 ft/min. At this speed, the effect of the overdrive up to ±10% on the burr height was negligible.

Due to blade symmetry in block knives, there is no preference for the burr to form on either slit edge. Either the front bottom or the rear top burr height can increase drastically when the clearance is larger than the critical clearance. The burr formation process was investigated through a series of micrographs taken at consecutive stages. Shear slitting can be identified as three stages: the initial indentation by the top blade into the web, the shearing by blade shearing motion, and the final tearing fracture.

ACKNOWLEDGEMENTS

The authors acknowledge the technical assistance from Professor Bruce Feiertag and Mr. Song Lu for setting up the laboratory slitter for this study.

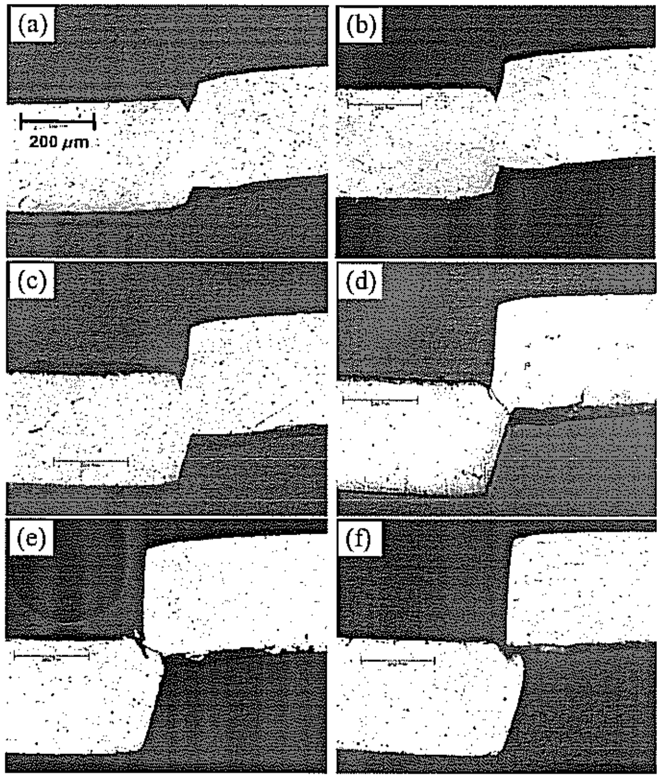


Fig. 11: Six stages of the shear slitting process of 3004 web.
Clearance=0 *mm*, overlap=0.63 *mm*, cant angle=1°, tension=10.3 MPa

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Name & Affiliation	Question
David Landskron Quad Graphics Printing	When you had zero clearance, did you know what the side lay pressure was on your slitters?
Name & Affiliation	**Answer**
Jin Ma Oklahoma State University	It is very small. We have the ability to apply a rather large side lay pressure in the lab. In this experiment, I show the pressure was close to zero.
Name & Affiliation	**Question**
Tim Walker TJWalker & Associates	Does your finite element model predict the z direction force that is trying to push the knives as you force the web into this nip point?
Name & Affiliation	**Answer**
Jin Ma Oklahoma State University	Yes, it does, but I did not plot it out.
Name & Affiliation	**Question**
Tim Walker TJWalker & Associates	When you make a series of cuts across the width of the machine this becomes more difficult. The force keeps building up and adds to deflection issues that affect how much overlap you can run, the rigidity of your machine becomes an issue. Knowing the z-direction force would be useful output with this type of analysis. Did you measure deflection of the blades at all? Did you see side deflection of the blades you measured? Do you know what the clearance was during your tests?
Name & Affiliation	**Answer**
Jin Ma Oklahoma State University	We monitor the deflection in the cross machine direction. We found that there is a small force that affects our clearance and we kept monitoring that deflection. The clearance I am reporting here, the clearance during slitting is not what we presented. To measure the cutting force we must install a load cell above the knife. The load cell results in some deflection. We remove the load cell to reduce that deflection.
Name & Affiliation	**Question**
Tim Walker TJWalker & Associates	The clearance is measured at the cut point where the overlap is?
Name & Affiliation	**Answer**
Jin Ma Oklahoma State University	Yes it was measured at the cutting point.
Name & Affiliation	**Question**
Tim Walker TJWalker & Associates	So when you have a cam angle, it's not the distance from the centerline of the knives but at the cutting point?
Name & Affiliation	**Answer**

Jin Ma Oklahoma State University	Yes.
Name & Affiliation	**Question**
Claude Faulkner Dupont	Do you expect that your empirical formula would apply to other materials besides aluminum? Would it apply for plastics?
Name & Affiliation	**Answer**
Jin Ma Oklahoma State University	If your material is metallic and the properties are similar to aluminum, the formula should apply.
Name & Affiliation	**Question**
Herong Lei Eastman Kodak	You are using a constant speed of 30 meters per minute. What effects would you see if the minimum speed increased to 300 meters per minute?
Name & Affiliation	**Answer**
Jin Ma Oklahoma State University	In general, the speed actually helps reduce the burr height. At high speed, the strain rate and deformation rate is a little higher, so the bur height is smaller. We performed some experiments at a higher speed, about 200 feet per minute. That is the maximum speed our lab's meter can attain. That burr height is a little smaller than what we reported here. In other references, we found that increased speed helps reduce the burr height.