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Communication

Estimating Ultimate Shear Strength from Ultimate Tensile Strength of Aluminum and its Alloys for Blanking or Piercing

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Abstract: : In pressworking, large forces cut or deform a material, and specific shearing processes include blanking and piercing of metals, including aluminum. The force requirement is directly proportional to the ultimate shear strength, USS, of the sheared material. Nevertheless, shear strengths are not readily found in engineering references, especially for the multitude of aluminum grades and tempers. Thus, USS is often estimated from some percentage of the ultimate tensile strength. However, analyses for these estimates are lacking, and it is not clear how accurately the USS is predicted. In this review of 197 aluminum alloy data, it is shown that 60% of the ultimate tensile strength provides a satisfactory estimation for USS as the predicted shear strength is, on average, within 5.5% of the actual value. USS of weaker grades, as well as for all annealed material, tends to be underestimated while the strongest grades are overestimated. The availability of reliable aluminum shear strength data makes for more efficient pressworking.

Keywords: Aluminum; Blanking; Piercing; Ultimate Shear Strength; USS

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1. Introduction to Shearing of Metals by Blanking or Piercing

Pressworking and punching represent the application of large forces, for a short time (under one second), to cut or deform a material. The material is usually metal, 0.40 mm to 6.35 mm thick, in sheet stock or strip from a roll. Processes include shearing, blanking, piercing, notching, drawing, bending, punching, stamping, lancing, shaving. The operation is performed with a tool and die set within a single station or as part of a progressive die sequence.

In blanking, the slug is the desired part while the remaining stock/strip becomes the scrap while in piercing (also called punching), the slug is scrap, and the remainder of the stock is the manufactured part. The equation for the shear force requirement in blanking and piercing is

$$F_s = USS \times t \times L, \quad (1)$$

where USS = ultimate shear strength, or stress, of the stock material (MPa or N/mm^2), t = thickness of stock or strip (mm), and L = cutting length or cut perimeter (mm). A safety factor of 15% to 30% should be applied, increasing this force. This is now the minimum size of press needed for the application; the presses are rated in tonnes (metric).

The blanking shear stress is best represented as the ultimate shear stress since the cutting operation produces complete fracture, separating the slug or blank from the stock. In fact, without the die, the punch would tear through the stock or strip, and the fracture would be due to tension failure alone with a cutting force value equal to the ultimate tensile stress (UTS) multiplied by t×L. Once a die opening is introduced, the material being stretched by the punch encounters the inside walls of the die block. The material shears as the forces exceed plastic deformation with cutting action from both the punch side and the opening side (Figure 1). Pressure from the punch continues to drive the material into the die opening. Compressive forces are also generated as shear is a combination of tension and compression. Complete fracture happens when the two cuts meet. This entire process lowers the necessary cutting force to a level below that computed from the ultimate tensile strength. The efficiency of the shearing is determined by the proper clearance between the punch and the opening. Too much clearance and the cut edges are dull with rounded corners. With too little clearance, the shearing is not crisp but cuts, drags, cuts, etc., producing multiple cutting bands.

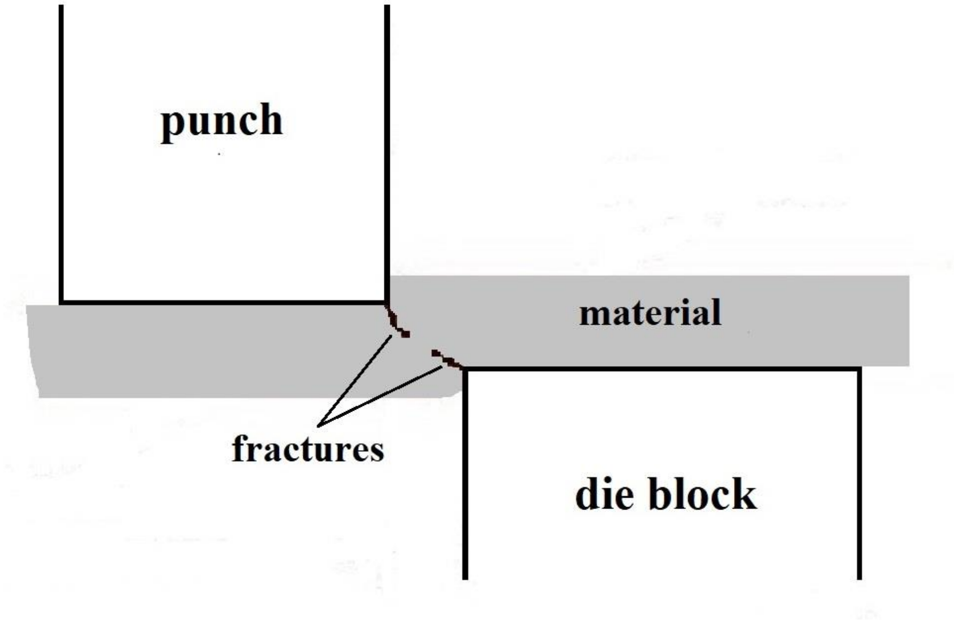

Figure 1. Simplified illustration of the shearing mechanism in a punch and die combination.

2. Analysis of Estimating Ultimate Shear Strength from Tensile Strengths

While ultimate tensile strength and yield stress are generally reported, shear stresses are not commonly available in engineering, manufacturing, and materials sources, especially for the various aluminum alloys, grades, and tempers and heat treatments. Additionally, there is no known exact, calculation-based methodology for obtaining shear strength from first principles. Further complicating the situation is the fact that the aluminum may start in its annealed condition and then undergoes some forming or bending process before any cutting. Now this same material has been workhardened and the USS has increased substantially. In any case, estimates for USS are often employed, commonly as some percentage, from 50% to 80%, of UTS or yield stress. One such formula for the estimated ultimate shear stress is

$$USS_{est} = A \times UTS, \tag{2}$$

where A is an adjustable fractional coefficient (or percent) of the ultimate tensile strength. For aluminum, and other metals, Table 1 presents some values for A. Using the ultimate tensile strength to forecast ultimate shear is reasonable; compared to the yield point, UTS is more likely to be closer to, or at, the fracture point and thus a better predictor of complete shearing. Furthermore, aluminum and some other metals exhibit a less precise yield, even when employing the 0.2% offset. In any case, there are no analyses provided with these estimates, and it is not known how accurately the USS_{est} is calculated. Therefore, there will be an uncertainty in the force calculation, equation (1), that may exceed any safety factor in choosing the press. The end result may be an undersized press. If USS_{est} is too high, a larger press, although sufficient, is not being used at its full strip utilization capacity, and the part production rate is not maximized. Thus, it becomes clear that there is a need for a better understanding of the implications of using an estimated ultimate shear stress when blanking or piercing.

Table 1. Coefficient, A from equation (2), to estimate ultimate shear stress from ultimate tensile strength for selected metals.

Reference	Material	A
[1] (p. 25)	low carbon steel	0.70–0.80
[1] (p. 573)	stainless steel	0.80
[1] (pp. 24–25)	aluminum & alloys	0.50–0.70
[2]	wrought steel & alloy steel	0.75
	wrought iron	0.83
	ductile iron	0.90
	aluminum & alloys	0.65
[3] (p. 390)	metal	0.70
[4] (p. 224)	metal	0.60–0.80

Aluminum features corrosion resistance, lightweight, and ease of manufacture for a variety of products, including those made by pressworking. It is also available in a great many forms, thicknesses, and tempers. Thus, it becomes useful to evaluate USS_{est} based upon its known UTS. Figure 2 presents 197 ultimate shear predictions versus actual shear data for aluminum and many of its alloys. For each data point, the UTS and actual shear strength were obtained for the 1000 series, commercially "pure" aluminum (>99%), as well as alloys through the 7000 series [1 (pp. 566–569),5]. Then, equation (2) was employed to compute USS_{est} from its UTS. The best agreement is noted with A=0.60, and this is displayed in Figure 2. Comparing with Table 1 entries, this 60% coefficient is significantly lower than the 65% value from Beardmore [2] as well as more accurate than any suggested ranges [1,4] and the 70% nonspecific value [3].

Even with the simplicity of equation (2), the estimated shear strength is, on average, within 5.5% of the actual value as computed by the mean deviation, $\frac{100\%}{N}\sum_1^N\left|\frac{USS_{est}-USS_{act}}{USS_{act}}\right|$, where N is the total number of data (197 in this study). Generally, low stress values tend to be slightly underestimated while largest stresses (7000 series) are somewhat overpredicted. Estimated shear strengths for annealed grades, regardless of series, are slightly underpredicted. Overall, all data lie close to the 45^o line shown; points on this line signify that the estimated value equals the actual. Likewise, a relatively equal number of data are above and below the line, with a -1.2% mean bias as computed from $\frac{100\%}{N}\sum_1^N\left(\frac{USS_{est}-USS_{act}}{USS_{act}}\right)$. The bias ranges from -22% for the annealed grades 6063-O and 6463-O, and up to +17%. Values for A of 0.59, 0.61, and 0.62 yield a mean deviation and bias of 5.7% and -2.8%, 5.6% and 0.50%, and 6.0% and 2.1%, respectively. Having nearly the same mean deviation but with a mean bias of plus 0.50%, 0.61 could also be an acceptable value. But the negative bias associated with A=0.60 is also quite low and provides a slight conservatism while underpredicting shear strength.

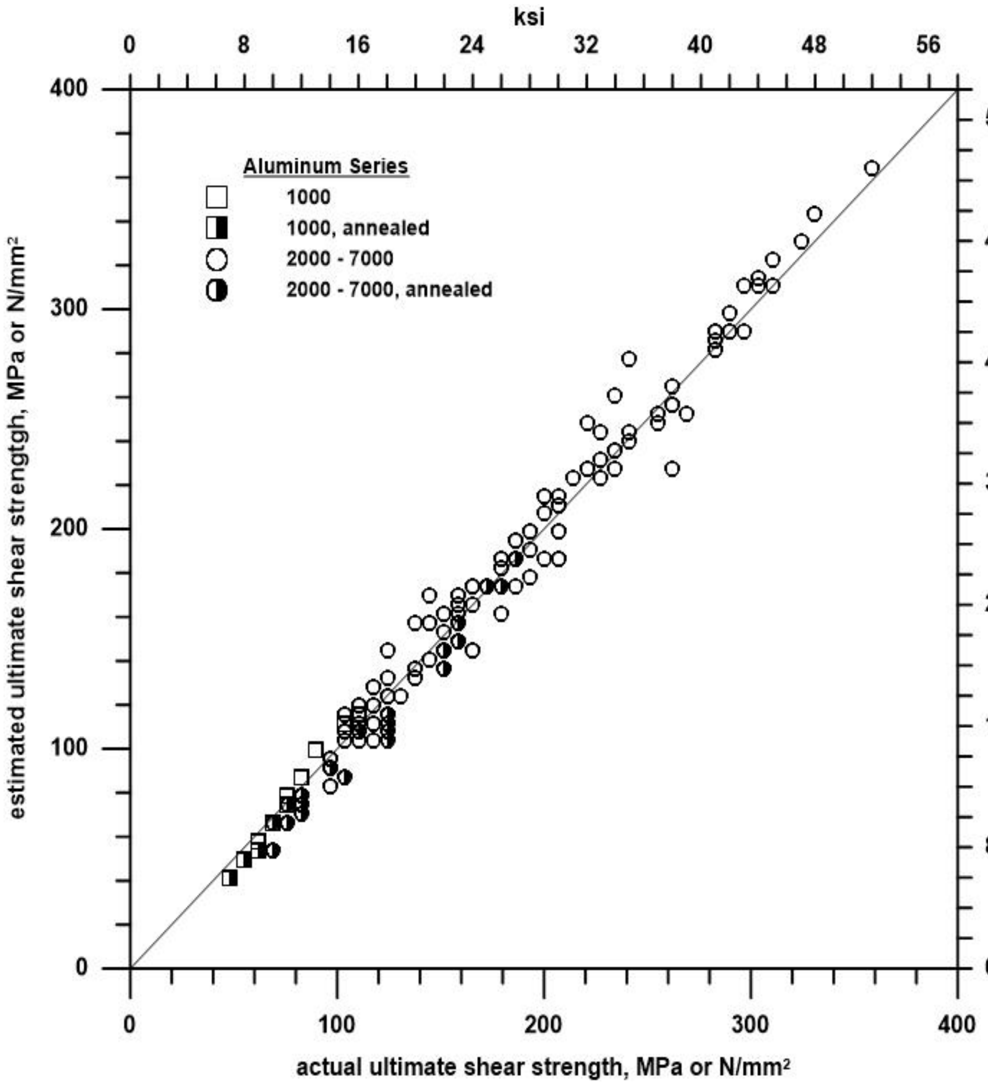

Figure 2. Estimated ultimate shear strength versus actual shear strength for aluminum and alloys: 1060-H12, 1060-H14, 1060-H16, 1060-H18, 1100-H12, 1100-H14, 1100-H16, 1100-H18, 1345-H12, 1345-H14, 1345-H16, 1345-H18, 1345-H19, 1350-H12, 1350-H14, 1350-H16, 1350-H19, 1060-O, 1100-O, 1345-O, 1350-O, 2011-T3, 2011-T6, 2011-T8, 2014-T4, 2014-T451, 2014-T6, 2014-T651, 2017-T4, 2017-T451, 2018-T61, 2024-T3, 2024-T351, 2024-T361, 2024-T4, 2024-T6, 2024-T81, 2024-T86, 2025-T6, 2117-T4, 2218-T72, 2219-T31, 2219-T37, 2219-T62, 2219-T81, 2219-T87, 2618-T61, 3003-H12, 3003-H14, 3003-H16, 3003-H18, 3004-H32, 3004-H34, 3004-H36, 3004-H38, 3105-H12, 3105-H14, 3105-H16, 3105-H18, 3105-H25, 4032-T6, 5005-H12, 5005-H14, 5005-H16, 5005-H18, 5005-H32, 5005-H34, 5005-H36, 5005-H38, 5050-H32, 5050-H34, 5050-H36, 5050-H38, 5052-H32, 5052-H34, 5052-H36, 5052-H38, 5056-H18, 5056-H38, 5083-H112, 5083-H113, 5083-H323, 5083-H343, 5086-H32, 5086-H34, 5086-H36, 5086-H112, 5154-H32, 5154-H34, 5154-H36, 5154-H38, 5154-H112, 5252-H25, 5252-H28, 5252-H38, 5254-H32, 5254-H34, 5254-H36, 5254-H38, 5254-H112, 5357-H25, 5357-H26, 5357-H38, 5454-H32, 5454-H34, 5454-H111, 5454-H112, 5454-H311, 5456-H24, 5456-H112, 5456-H116, 5456-H311, 5456-H321, 5456-H323, 5456-H343, 5457-H25, 5457-H26, 5457-H28, 5457-H38, 5557-H25, 5557-H26, 5557-H38, 5652-H32, 5652-H34, 5652-H36, 5652-H38, 5657-H25, 5657-H28, 5657-H38, 6061-T4, 6061-T451, 6061-T6, 6061-T651, 6061-T81, 6061-T91, 6061-T913, 6062-T4, 6062-T6, 6063-T1, 6063-T4, 6063-T42, 6063-T5, 6063-T6, 6063-T83, 6063-T831, 6063-T832, 6063-T835, 6066-T4, 6066-T451, 6066-T6, 6066-T651, 6070-T6, 6101-T6, 6351-T6, 6463-T1, 6463-T4, 6463-T42, 6463-T5, 6463-T6, 6951-T6, 7049-T73, 7049-T7352, 7050-T7451, 7050-T7651, 7075-T6, 7075-T651, 7079-T6, 7178-T6, 2014-O, 2017-O, 2024-O, 2219-O, 3003-O, 3004-O, 3105-O, 5005-O, 5050-O, 5052-O, 5056-O, 5083-O, 5086-O, 5154-O, 5254-O, 5357-O, 5454-O, 5456-O, 5457-O, 5557-O, 5652-O, 6061-O, 6062-O, 6063-O, 6463-O, 6066-O, 6951-O, 7075-O, 7178-O.

3. Concluding Remarks

It has been shown that the ultimate shear strength of aluminum sheet, used in blanking or piercing operations, can be estimated from equation (3) within 5.5%, on average, using 60% of its ultimate tensile strength:

$$USS_{est} = 0.60 \times UTS. \tag{3}$$

While shear strengths for annealed grades tend to be underpredicted, the estimate holds for all grades and tempers of pure aluminum (1000 series) and its alloys up through the 7000 series.

The present review suggests that other metals, especially steel and copper alloys, ought to be assessed in the same manner. This would provide direction as to how reliable estimates are for other materials. In the end, the ultimate shear strength is directly proportional to the press capacity needed for blanking and piercing. Thus, any efforts to improve the accuracy of the parameters used in calculating the pressworking force result in more efficient and cost-effective processes.

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Conflicts of Interest: The author declares no conflict of interest.

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