Fracture under Constrained Deformation

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Abstract

A number of important variables in the process of wire-drawing, including die geometry, reduction, pulling stress and material inhomogeneities, were examined with a view toward understanding the mechanisms of fracture of metallic alloys during constrained deformation. Two modes of failure, centerline defect and "cuppy" fracture, and the conditions surrounding their development, have been described.

Introduction

Material deformation in wire drawing is limited under certain conditions by a type of fracture known as cuppy coring that occurs at stresses below the yield strength. The failure is associated with inhomogeneous deformation that results from drawing through dies of large angles coupled with slight reductions[1,2], and is characterized by regularly spaced chevrons located along the wire axis or by complete cup and cone fracture of the material. The nucleation of fracture has been associated with the formation of holes and with inclusions[3,4,5]. Additional factors of importance include microstructural damage caused by previous working of the material, the level of drawing stress, and work-hardening behavior.

Sequentially, microstructural damage is introduced by a first pass through a die[4]. The rationale is that this damage results from the opening up of voids (frequently found at grain boundary triple points[6]) by the radial component of the hydrostatic tension prevailing along the axis of the material. During a second drawing pass, if the stresses are large enough or are aided by back tension, the voids enlarge. Hill[7] has shown that, in sheet drawing, the absolute value of hydrostatic pressure, $|P|$, is proportional to the die semi-angle, (α), divided by the reduction, (r):

$$|P| \propto \frac{\alpha}{r} \qquad (3\text{-}1)$$

Considering the indentation of a rectangular block of metal with a flat die, a dimensionless parameter is useful in equating the applied pressure to the deformation. This is proportional to the size of the indentor edge divided by the thickness of the block. This approach has been applied to wire drawing[8] and yields the following expression:

$$\Delta = \frac{\text{diameter of the wire halfway through the die}}{\text{slant length of the core of the die}} \qquad (3\text{-}2)$$

It follows that: $$\Delta = \frac{\alpha}{r}\left(1 + \sqrt{1-r}\right)^2 \qquad (3\text{-}3)$$

Experimental Procedures

Materials tested were 1100 and 2011 aluminum, OFHC and tough pitch copper, phosphor bronze "A", commercial bronze (leaded), and yellow brass (leaded). Prior to testing, specimens were annealed in a helium atmosphere to a dead soft condition and a grain size of A.S.T.M. number 6. They were cold-swaged to reductions in area of

35%, 60% and 90% without intermediate annealing. Samples were then drawn through conical dies of either 20° or 30° total included angle on an Instron testing machine at slow speeds. Lubricants used included Teflon spray, cup grease, or liquefied soap.

Two types of test were performed:

(1) Single Pass Wire Drawing: Specimens were first swaged to the various levels and then drawn part way through the die with the most severe reduction first. The draw was stopped, the wire removed, and a second, less severe draw was taken on the next section of material. This was repeated for all reductions with 20° and 30° dies.

(2) Multiple Pass Drawing: In this series, the entire length of the wire was drawn through each reduction. After the completion of a pass, an end section was removed for metallographic inspection and the remaining wire given another, more severe, reduction.

Results and Discussion

In this study, fracture developed in multiple-pass drawing of 2011 aluminum, tough pitch copper, yellow brass, and leaded bronze. Detailed data are shown for the latter alloy in Table I. With the lubricants employed, no cuppy fractures were found in any of the single-pass drawing tests up to prior strains of 90% and over a wide range of Δ. In both single-pass and multiple-pass drawing, friction was highest with grease and lowest with Teflon. The single-pass tests with inferior (grease) lubricant showed that the higher pulling stress required could initiate centerline defects with $\Delta \sim 5$-6.

Fracture can occur in two ways. The first involves nucleation of centerline voids, which was found to be a prerequisite for cuppy coring. The conditions for initiation were large die angles, Δ of ~5-6, material inhomogeneities, and high drawing stresses. The effect of producing a high hydrostatic tension along the axis of the wire is indicated in Fig. 1a by the opening of voids at inhomogeneities such as grain boundary triple points and inclusions (microprobe analyses of the commercial bronze and yellow brass showed the existence of elemental lead at triple points). Upon subsequent drawing at slightly larger values of Δ, the voids then coalesce into cracks which often run along grain boundaries (Fig. 1b). The second mode of failure involved the enlargement of the centerline defect itself as Δ was slightly reduced in subsequent draws. Such enlargement continued with the formation of a cylindrical central hole, and finally, splintering of the material at the exit of the die, similar to the kind of failure that occasionally occurs in swaging. Since all the materials were processed in a similar fashion, it is evident that geometry, reduction and drawing stress were only important when certain kinds and levels of impurities were present.

References

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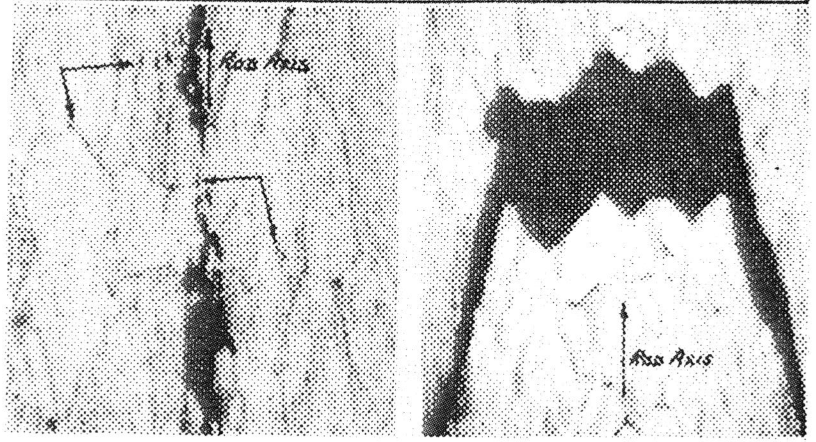
Table I. Leaded bronze rods drawn through 30° angle dies

% Prior Reduction	% Reduction in drawing Per Pass	Cumulative	Δ (Per Pass)	Drawing Stress (KSI)	Yield Stress (KSI)	Type of Fracture
* 0	0				45	None
	18	18	5.2	23.5		None
(annealed)	12	29	8.0	19.8		None
	18	36	5.4	26.9		Centerline
	11	43	9.3	21.8		Cuppy Core
* 35	0				79	None
	18	18	5.2	24.5		Centerline
	12	29	8.0	21.5		Cuppy Core
	18	36	5.4	26.3		Cuppy Core
	11	43	9.3	21.6		Cuppy Core
*	0				86	None
60	18	18	5.4	28.9		Centerline +Cuppy Core
	13	28	7.9	26.4		Centerline +Cuppy Core
* 90	Failed during swaging (splintering along longitudinal axis)					
* 35	18	18	5.2	24.8		Centerline
	28	40	3.0	33.8		Centerline
	22	52	4.1	31.1		Centerline
35	8	8	12.3	20.2		None
**	18	18	5.2	29.1		Centerline
	29	29	3.4	37.9		Centerline
	36	36	2.4	51.9		None
	42	42	1.9	64.7		None

*with Teflon lubricant, multiple-pass reduction
**with grease lubricant, single-pass reduction



a. b.

Fig.1 a) Centerline defect in longitudinal section of drawn bronze bar; voids at triple points and opening cracks are indicated. Δ=5.2, magnification: 100 x b) Section showing development of cuppy core from condition in a) upon subsequent draw. Δ=8.0, magnification: 20 x.