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Expression for Calculating Plastic Radius, c , from Slit Opening of a Disk from an Autofrettaged Tube

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ABSTRACT

Prior research [1] gives good estimates of the autofrettage plastic radius for a range of gun tube conditions and material strengths. A linear fit of a portion of these results gives an expression here for the plastic radius of a partially autofrettaged tube, with accurate results for tube outer radius to tube inner radius, b/a near 2.0 and degree of autofrettage near 50%, configurations of common use with autofrettaged gun tubes. These results are presented here and compared with finite element calculations from autofrettaged gun tubes.

INTRODUCTION

In prior research [1] Parker gives results for the opening angle in radians of a slit disk from a partially autofrettaged tube, dependent on yield strength, Y , and elastic modulus, E , of the tube material, the ratio of outer radius to inner radius, b/a , and degree of autofrettage of the tube, $(c-a)/(b-a)$. A linear fit of a portion of these results gives an expression described here for the plastic radius, c , of a partially autofrettaged tube that gives good results for b/a near 2.0 and degree of autofrettage near 50%, configurations of common use with autofrettaged tubes. See Figure 1.

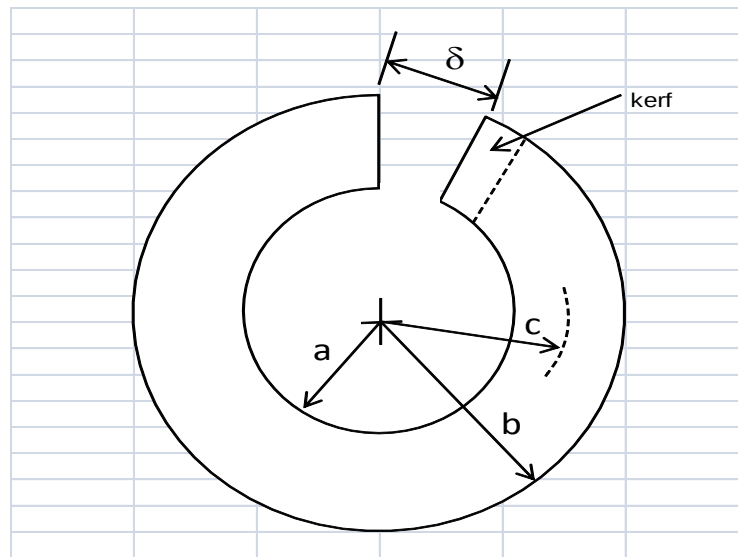


Figure 1 – Sketch of Disk Slitting Configuration.

EXPRESSION FOR PLASTIC RADIUS

The resulting expression for plastic radius, c , in terms of slit opening, δ , the as-slit inner radius, a_s and outer radius, b_s , and material yield strength and elastic modulus, Y and E , is:

$$c = a_s + [b_s - a_s] [0.0505 \delta E / b_s Y + 0.111] \quad [1]$$

Equation [1] gives a close approximation of plastic radius from disk slit opening for $1.75 < b/a < 2.25$ and for $0.2 < (c-a)/(b-a) < 0.8$. Note also that the slit opening on the OD, δ , does not include the saw kerf that occurs during the slitting, see Figure 1.

COMPARISON WITH MEASUREMENTS AND FEA

Results from recent tests and analysis to determine the plastic radius in autofrettaged tubes are discussed next. Finite element analysis, FEA, and neutron diffraction and X-ray diffraction measurements have been performed recently from chamber and bore sections of M256 and XM360 tubes. And slit tests have been performed from which plastic radius can be calculated as described in Equation [1]. These various results are summarized in Table 1. The neutron, X-ray and slitting results are each compared with the FEA calculations, as shown in the far-right column of Table 1. All results are in reasonable agreement for chamber and bore sections of M256 and XM360 tubes. This is encouraging, particularly considering that the results are obtained from four different and independent test and analysis methods. This indicates that Equation [1] can be used with some confidence for determining the plastic radius based on a slit test from a given axial location of an autofrettaged tube. Then plastic radius can be used to calculate the percent autofrettage at that location, once the tube ID and OD are machined to their final dimensions, considered next.

Table 1 - Comparison of Plastic Radius, c, Determination.

tube	Y; Yield	a	b	δ	c	c/c _{FEA}
	Strength	[ID/2]	[OD/2]	[slit disk]	[calc]	
	MPa	mm	mm	mm	mm	(--)
FEA Results						
M256	1170	60	135	n/a	95	n/a
M256	1170	79	155	n/a	114	n/a
XM360	1360	60	135	n/a	94	n/a
Neutron Results						
M256	1170	60	135	n/a	96	1.01
M256	1170	79	155	n/a	114	1.00
X-ray Results						
XM360	1360	60	135	n/a	94	0.99
M256	1170	79	155	n/a	114	1.00
Slitting Results						
M256	1170	60	143	5.22	95	1.00
XM360	1360	60	124	6.25	91	0.97
XM360	1360	79	141	7.42	110	0.97

CALCULATION OF PERCENT AUTOFRETTAGE

Using the Table 1 FEA results for an M256 tube with plastic radius of 114 mm [shown in bold in Table 1] as an example, calculation of percent autofrettage for dimensions of interest, such as the $a = 79$ mm, $b = 148$ mm finish machined chamber dimensions of the M256 tube, gives:

$$\% \text{autofrettage} = 100 [(c-a)/(b-a)] = 51\% \quad [2]$$

Note that this % autofrettage is different from the value that would be obtained from the $b = 155$ mm outer radius dimension of the M256 tube, for which the FEA analysis was performed. In general Equation [2] can be used to calculate degree of autofrettage [in %], where c is calculated from Equation [1] for the axial location and a_s and b_s of the slit disk, and a and b are the final tube dimensions at a nearby location whose degree of autofrettage is of interest.

REFERENCES

[1] "Stress Intensity and Fatigue Crack Growth in a Pressurized, Autofrettaged Thick Cylinder," A. P. Parker, J. H. Underwood, J. F. Throop, and C. P. Andrasic, *Fracture Mechanics: Fourteenth Symposium – Volume I: Theory and Analysis*, ASTM STP 791, 1983.