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SPECIAL REPORT ARLCB-SP-83013

INDEX TO BENET WEAPONS LABORATORY (LCWSL)

R. D. NEIFELD

TECHNICAL PUBLICATIONS AND EDITING UNIT

APRIL 1983





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SUBJECT

Wave Equations

Wave Propagation

Weapons

Wear

Wear Resistance

White Layer

REPORT_NUMBER ARLCB - FR- 82028 ARLCB - FR- 82001

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18. SUPPLEMENTARY NOTES (CONT'D)

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inner surface of a partially autofrettaged cylinder is annited in this report				
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20. ABSTRACT (CONT'D)

A slight decrease in the degree of autofrettage will increase stress intensity factors of inner cracks slightly but will decrease stress intensity factors of external cracks considerably. As in the inner crack case, the cylinder with two diametrically opposed external cracks is in general the weakest configuration and for more than two cracks, the stress intensity factor decreases as the number of external cracks increases.

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20. ABSTRACT (CONT'D)

much as 725°F from bore to outside surface. Reduction of the autofrettage bore expansion and reduction of residual stresses resulted, because the thermal stresses added to the residual stresses and exceeded the lowered yield strength at elevated temperature, permitting relaxation to occur.

The data reveals that under certain temperature conditions a considerable portion of the autofrettage induced bore expansion and the associated residual stresses can be lost in a few minutes when external cooling occurs. The experimental results indicate that partial overstrain in autofrettage may be preferable to full overstrain in order to minimize the loss in residual stress.

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developed specifically for testing of cylindrical geometries. Three examples of current fracture analysis of cylindrical pressure vessels are presented. Fast fracture of a vessel is described, including effects of tension residual stress and crack shape. Evidence of environmentally assisted fracture of a cannon tube is presented. Fatigue crack growth and life calculation methods for cylindrical pressure vessels are developed and checked with experimental results; effects of compressive residual stress due to overstrain are analyzed, including reductions from the expected theoretical residual stress due to reduced compressive strength of the alloy steel.

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efficiency were maximized. A further improvement in deposit strength was obtained by adding vanadium as V_{205} at a concentration of 10 g/l to standard chromic acid solutions. At higher concentrations, inferior deposits were produced that showed surface roughness, porosity, low strength, and higher hydrogen content.

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20. ABSTRACT (Cont'd)

However, the tensile and yield strength were approximately 30 percent lower than the theoretically predicted values. Degradation of the filament ductility as a result of oxygen or carbon pickup when the filaments were exposed to 1000°C in the mold prior to melting, was considered to be the reason. Application of 0.0005 in. thick coating of copper by conventional electroplating and tantalum by electrodeposition from fused fluoride electrolyte were found to eliminate this problem.

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Fatigue Crack Growth		
Mean Stress Effects		
Liquid Matal Embrittlement		
Fracture Mechanics		
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Experiments have been performed to	study the combin	and effects of aggressive
environment and mean stress on fat:	igue crack growth	1. Since mean stress
changes also change the stress rat:	$lo, R(R = \sigma_{min}/\sigma_m$	sax), experiments were
performed to measure fatigue crack	growth rates for	various values of constant
R. The experimental results were	approximated math	menatically using a modified
superposition model. The results	show that for neg	sative values of R, the
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20. ABSTRACT (CONT'D)

modified superposition model yields excellent agreement with the experiments. When R was positive, the mathematical model significantly overestimated the experimental results, suggesting that the full environmental effect condition cannot be achieved in the embrittling system chosen. By including a factor to account for the less than 100 percent environmental effect, excellent agreement between the model and the experimental results was obtained when R was positive. Throughout the study, a high strength, low alloy steel embrittled by liquid mercury was used.

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A PHOTOELASTIC STUDY OF LOAD DISTR	IBUTIONS AND	
STRESSES IN MULTI-GROOVE CONNECTION	NS OF THE SAME	
MATERIAL UNDER TENSION		6. PERFORMING ORG. REPORT NUMBER
AUTHOR(s)		B. CONTRACT OR GRANT NUMBER(+)
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US Army Armament Research & Develop	oment Command	AMCMS No. 6111019140011
Benet Weapons Laboratory, DRDAR-LC	B-TL	DA Project No. 11161101A9A
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This report is a continuation of Ta a three-dimensional photoelastic so multi-groove connections of the sam profiles were investigated, namely the new profile. It was found that $(\sigma_f)_{max}$ does not occur at the groov	echnical Report A tudy on load dist me material under , the British Sta t in both profile ve root. Therefo	ARLCB-TR-81008 and describes tributions and stresses in t tension. Two groove andard Buttress (BSB), and es the maximum fillet stress ore, the narrowest transverse CONT'D ON REVERSE)
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20. ABSTRACT (CONT'D)

section is not the critical section. The critical stress, i.e., $(\sigma_f)_{\max}$, in the new profile is higher than that in the BSB profile. Moreover, $(\sigma_f)_{\max}$ in the first groove is higher than that in subsequent grooves. Hence, the first groove is the critical region.

In an ideal multi-groove (> 7) connection, the first two lugs could take approximately 50 and 60 percent of the load in the BSB and new profile, respectively. However, the ideal contact could not be expected due to machining tolerances. The worst possible case would occur when only one groove is in contact and the situation is reduced to a single-groove connection.

Further work on the effect of different materials is in progress.

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Contractor Report ARLCB-CR-82014	
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CHARACTERIZATION OF "WHITE LAYER" AND	Final
CHROME PLATING ON FIRED CANNON AND ON	Jan. 1981 - Jan. 1982
LABORATORY SIMULATION SAMPLES	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(e)	8. CONTRACT OR GRANT NUMBER(4)
K. M. Fisher and A. Szirmae	DAAA22-81-C-0121
United States Steel Corporation	
Dr. M. H. Kamdar, Research Engineer, ARRADCOM	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	AREA & WORK UNIT NUMBERS
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Monroeville DA 15146	
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20. ABSTRACT (CONT'D)

chromium revealed a strong dependence of grain structure on plating conditions. The void space between the aligned cylindrical grains is probably responsible for the high tensile stresses in chrome plating and the propensity for severe cracking.

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Container Autofrettage		
Elastic-Plastic		
Finite Difference		
Gun lube		
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This report presents a numerical s	tudy of a contain	ner autofrettage process.
This process uses internal hydraul	ic pressure to e	xpand the tube, restraining
containers to control the amount o	f tube expansion	and the press force to
hold the end closures. The increme	ental finite-dif:	ference approach developed
recently by the author is extended	to obtain numer:	ical results. The effects
of restraining walls and the press	force on the dis	splacements and stresses are
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Ballistic Protection	Laminate	
Damage Tolerance	Titanium	
Fatigue	Aluminum	
20. ABSTRACT (Continue on reverse side if necessary	y and identify by block number)	
A new metal/metal laminate has be	en conceived and de	eveloped in ARRADCOM,
consisting of explosively bonded	alternate layers of	f titanium and aluminum
alloy sheets. Intended at first	to give improved fa	atigue resistance in
helicopter components, the lamina	te is found to prov	vide improved impact and
ballistic penetration resistance	as well. In compar	tison to monolithic metal
components or adhesively bonded 1	aminates it can pro	vide decreased weight and
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20. ABSTRACT (CONT'D)

increased durability and survivability for vehicles and craft subject to ballistic impact damage.

Three-layer and five-layer specimens of Ti-6AL-4V/2024-T3 laminate have been tested for resistance to through-the-thickness impact and ballistic penetration and for after-damage fatigue crack propagation. They were compared with rolled plate specimens of 6061-T6 aluminum alloy and rolled homogeneous steel armor (RHS) using 0.30 caliber fragment simulator projectiles (FSP). The Protection (V₅₀) Ballistic Limit Velocity and the fatigue life (N_f) remaining after ballistic penetration damage were measured on the same specimens. The fatigue crack propagation life was measured in compact specimens made from the ballistically damaged panels, with the crack initiated in the penetration damage site and grown to failure of the specimen.

The five-layer laminate having volume proportions of 60 percent aluminum and 40 percent titanium alloy gave the optimum overall performance. Its V_{50} limit velocity is 22 percent greater than the RHS of equal area density, and it has longer after-damage fatigue life. Increasing the volume fraction of aluminum is found to decrease the protection V_{50} limit and increase the after-damage fatigue life, and vice versa.

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ANALYSIS OF A SCHNEIDER-TYPE RECOIL MECHANI:	SM
FOR THE 120 mm XM256 TANK GUN	Final
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20. ABSTRACT (Cont'd)

hardness for similar alloys with higher hardness alloys having lower wear. The effect of hardness was different for different mating surfaces. The data from aluminum bronze and the welded overlay rotating band materials investigated did not fall into this correlation. This could not be attributed to a special microstructure or to crystalline orientation in the case of the welded overlay band materials. Mutual solubility of the pin and disk metals and relative position in the periodic table also did not control metal transfer and scuffing with the copper alloys investigated. While position in the periodic table is identical and mutual solubilities are certainly very similar for most of the copper alloys, there were great differences in metal transfer and scuffing. While there was a tendency for more transfer to occur at higher wear rates, heavy and very heavy transfer do occur even at very low rates. Heavy and very heavy transfer were not usually associated with high wear and rough deposits were not usually associated with high wear and heavy transfer. The first step in wear was not transfer to the mating surfaces. In addition, small amounts of iron in the copper alloys did not result in scuffing and high metal transfer even when sliding on steel.

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Measurements have been made of the eff room temperature, on the electrical r amorphous alloys and their crystallin ence of the pressure coefficient of r from other alloys taken from the rece to the Mooij correlation. The pressu line and disordered systems and these	maily by block number) fect of hydros resistance of f resistance of t ent literature, are coefficient e data are disc	tatic pressure to 8 kbar, at ive transition-metal-based The resistivity depend- these alloys, and results exhibit a trend analogous of resistance for crystal- cussed in terms of the iONT'D ON REVERSE)
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diffraction model of electrical transport. It is suggested that the observed correlation of the pressure coefficient of resistance with resistivity is a manifestation of the breakdown of standard theory for high-resistivity metals, i.e., another example of Mooij phenomena.

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Crack Propagation	-	
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It is re-emphasized here that the effective the second sec	ffect of residua	l stress in fatigue is
analogous to but not the same as the	e mean stress ef	fect from applied loads.
The inclusion of a residual stress	term in the stre	ss intensity factor range
of the fatigue crack propagation rat	te equation perm	its one to use the residual
stress in calculations of fatigue 1	lfe estimates.	Using crack shape factors
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calculated for given aspect ratios of surface flaws and integrating da/dN, one obtains an equation for the S-N curve which includes the residual stress effect on fatigue performance.

This process of calculation reveals that compressive residual stress has a much stronger influence on fatigue life than tensile residual stress does, mainly because the former decreases the stress intensity factor range and increases the critical crack size while the latter only decreases the critical crack size. Numerical solution of an example illustrates an application of these concepts.

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A. R. Graham		
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Benet Weapons Laboratory	, DRDAR-LCB-TL	PRON No. 1A2237881A1A
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20. Abstract (Cont'd)

The paper describes how a regenerative LP gun works in a tutorial sense by comparing the open literature results, obtained with three different regenerative liquid propellant gun test fixtures, all designed by the author. These test fixtures had bore diameters of 8.89, 25, and 40mm. The first two of these were tested at General Electric; the last at Benet Weapons Laboratory, ARRADCOM.

Emphasis is placed on design ease and scaling this type LP gun - demonstrated dramatically by the fact that the 8.89, 25, and 40mm regenerative LP gun test fixtures were designed, built and successfully tested within a three-year time frame. Performance results are discussed.

In one instance (the 40mm test fixture), high frequency (acoustical) combustion instability was encountered. It was demonstrated that this could be controlled through the use of baffles located in front of the propellant injector/piston – a technique used in liquid propellant rocket thrust chambers. This is important, since as one increases bore size, the chances of combustion instability become increasingly more likely; this could become especially critical at large bore sizes such as 155mm. It could become necessary to use another technique, known as the "multi-cell piston concept," to control combustion instability. This concept offers some unique scaling and development advantages, as discussed.

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EXTERNAL DISCONTINUITIES IN AUTOFRETTAGED C7LINDERS		Final
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20. ABSTRACT (CONT'D)

metal. Modification of the theory for short mean free paths is discussed in terms of the Pippard-Ziman condition on the electron-phonon interaction. Invoking a prescription derived by Pippard for the reduction of the electronphonon interaction in ultrasonic attenuation, one finds a quadratic dependence of $\alpha^2 F(\omega)$ on ω at low energies in high-resistivity amorphous metals; an even sharper reduction in the electron-phonon interaction and hence in $\alpha^2 F(\omega)$ has been found by Poon, who treated the problem in transition-metal systems in the context of the Barisic-Labbe-Friedel rigid-ion approximation.

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20. ABSTRACT

This report describes a series of efforts taken to retard both primary and secondary erosion and restore tube life to its expected 1000 rounds. A major part of the investigation includes a new concept which was introduced to eliminate chipping and spalling of chromium down bore during early stages of firing. This involved the use of partially plated gun bores which successfully retarded primary and secondary erosion without degradation in target dispersion.

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20. ABSTRACT (CONT'D)

for purposes of computation. In solving mixed boundary and initial value problems of a high order partial differential equation using spline functions, the computation may be simplified considerably if the variable in time can be truncated into arbitrary sections. Each section may have several node points for the spline functions in the time domain. This is true because we found from previous papers that the initial value problem can be solved in one direction using variational principle and cubic Hermite Polynomials, without worrying about the conditions at the far end.

The end conditions of the ajoint system can be adjusted according to the end conditions of the original system so that the bilinear concomitant is identically zero. This satisfies the variational principle. A bilinear form of the original and adjoint variables is employed in determining the coefficients of the variations of the functions and their derivatives. For the spatial variables Hermite Polynomial spline functions will be used. Algorithm and procedure of computation are given.

The variational principle for spatial and temporal problems with boundary and initial conditions are investigated. This variational principle is very general in scope and can be applied to many linear partial differential equations. The Euler-Bernoulli beam equation satisfies these variational principles. This lays the foundation for gun dynamics problems to be studied.

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7. AUTHOR(S) (CONT'D):

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20. ABSTRACT (CONT'D):

Correction factors for crack shape and non-ideal material yielding are determined from various sources for the pressurized, autofrettaged tubes containing semi-elliptical cracks. These results are employed in the life prediction of pressurized thick tubes with straight-fronted and semi-circular cracks, for various amounts of autofrettage. Experimentally determined lifetimes for tubes having zero and 30 percent nominal overstrain are significantly greater than the predictions for both straight fronted and semi-circular cracks. This is related to multiple initiation and early growth of cracks from the notch.

Experimentally determined lifetimes for a tube with a 60 percent nominal overstrain are somewhat less than predicted. This effect is partially explained by additional experimental work which shows that the angle of opening of rings cut from autofrettaged tubes is somewhat less than the ideal predictions. The latter effect is attributed to the Bauschinger effect and the associated reduced yield strength in compression during the unloading of tubes during the autofrettage process.

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20. ABSTRACT (CONT'D)

First, the adjoint principle associated with this problem is stated. It is followed by the discretized counterparts in spatial and temporal dimensions. The procedures involving the assemblage of the "mass" and "stiffness" matrices in the two dimensions are described. Due to the null variations of some adjoint variables, certain rows of the matrices are eliminated. Because certain variables are known at the boundaries, the unknown variables for the next interval of time can be computed by inversion of a band matrix in terms of their present values.

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specialized fracture mechanics solutions are presented. Life and crack growth predictions based on these analyses are compared to previously performed experiments.

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20. ABSTRACT (CONT'D)

used to fit lines to the data and to determine correlation coefficients. Conclusions were drawn as to the suitability of Charpy energy and reductionin-area as predictors of plane-strain fracture toughness.

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20. ABSTRACT (CONT'D)

coefficients, pressures and gas temperatures in the firing cycle for input to the main program. The effect of contact resistance between layers is now included. Results are shown for the behavior of a TZM liner in a steel tube.

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20. ABSTRACT (CONT'D)

vs. strain at the outermost fiber of the solid specimen provides an ultimate check of this theory. This report demonstrates an expanded use of improved theory.

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As a continuing effort in the analytical study of attempts to assess the relative importance of se motions during firing. Specifically, the forces force produced by the moving projectile, which, fugal part, a coriolis part, and an inertia part with recoil action; (3) the force produced by th	of gun tube dynamics, this report everal dynamic forces on tube a considered here are: (1) the in turn, consists of a centri- c; (2) the axial force associate the combined effect of the tube (CONT'D ON REVERSE)

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20. ABSTRACT (CONT'D)

curvature and the chamber pressure; and (4) the projectile eccentricity as a moving couple.

The dynamic equation of a Bernoulli-Euler beam is first reviewed which includes the various forces as mentioned above. General boundary conditions and initial conditions are also stated. Thus, the stated objective becomes a parametric study of a very general initial boundary value problem. The solution formulation and procedure to this non-self-adjoint problem are then briefly reviewed. The procedure is a finite element discretization based on a variational problem shown to be equivalent to the stated initial boundary problem.

By taking one or several forces at a time in the governing equations, the dynamic deflections (or the gun tube motions) as affected by these forces can be evaluated. In this report, data from an idealized M68-105 mm cannon tube are used for comparisons. Results of tube motions are presented for each set of dynamic forces. It is shown that for the forces listed in items (1) through (3) above, the magnitude for the tube motion is small compared with experimental data. However, for the case of projectile eccentricity, the moving couple may be large enough to cause significant gun tube motions.

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The plan was to adapt the thermal warning device from the 155mm M198 Howitzer to the 155mm M109A1/A2/A3 Howitzer. The major problem required developing a method to attach the temperature sensor to a cannon tube which recoils through concentric recoil bearings without reducing the fatigue life of the cannon. After a suitable attachment method had been developed and successfully tested, the program was terminated by ARRCOM because of funding priorities.

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*R. Benedict Department of Materials Engineering University of Iowa Iowa City, IA 52242

20. ABSTRACT (CONT'D)

at many instants in time are obtained by spatial integration of the strain distribution to form a motion picture of the shape of the centroidal axis of the tube. The motion clearly shows the formation and propagation of a waveform near the breech end of the tube. Wave dispersion, whereby short wave lengths separate from the early waveform and travel faster toward the muzzle as predicted by elementary beam theory - is clearly evident. The arrival and relfection of these short waves cause significant displacement and rotation of the muzzle.

Despite the clarity and confidence level inherent in the measurements, their magnitude remains five to ten times above that which can be explained at the present time. Mass eccentricity of the breech, barrel, or projectile is not sufficient to induce such motions - nor are interactions of the tube supports (deliberately of low stiffness) or loads arising from the tube curvature or asymmetric stiffness. While the discrepancies between measured and predicted motions are considerably less than those noted at the Second Gun Dynamics Symposium (1978), their magnitudes are still unsatisfactory.

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20. ABSTRACT (CONT'D)

work sliding speeds of 3.05 m/s and 0.58 m/s were added for most of the alloys sliding on steel.

The amount of transferred metal generally increased with sliding velocity for copper alloys sliding on both steel and chromium electroplate but not for sliding on tantalum. The wear rates for the copper alloys sliding on steel usually increased as the sliding velocity increased from 0.58 m/s to 1.70 m/s, and then generally decreased as the sliding velocity increased still further from 1.70 m/s to 3.05 m/s sliding both on steel and tantalum. The wear rates sliding on chromium electroplate, on the other hand, remained about the same or increased as the sliding velocity increased from 1.70 m/s to 3.05 m/s. The coefficients of friction usually dropped as the speed of sliding was increased from 0.58 m/s to 1.70 m/s (only sliding on steel was investigated) and then usually remained about the same as the velocity was further increased from 1.70 m/s.

It was not possible to correlate metal transfer, scuffing (rough transfer), or friction with the properties of the metal pair and, contrary to the situation at 1.70 m/s, there was no effect of hardness on wear at 3.05 m/s. At the faster sliding speed both wear and metal transfer of aluminum bronze and welded overlay band materials were not essentially different from the other copper alloys. (A difference had been found at a sliding speed of 1.70 m/s.)

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thermal. However, no matter what the specific mechanism of erosion, it is a function of the rate of heat transferred to the bore. It can only be controlled by making the steel bore more resistant to temperature by coating it with a layer of another material or by lowering the rate of heat transfer from the propellant gases.

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