19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

APPLICABILITY OF THE HYDROGEN GAS EROSION THEORY TO CONVENTIONAL GUN PROPELLANTS

H. Arisawa and J. Kimura

Propellants and Explosives Laboratory, First Division
First Research Center, TRDI, JDA
2-2-1 Nakameguro, Meguro-ku, Tokyo 153-8630, Japan

Our previous study suggested that the gun barrel gas erosion is controlled predominately by thermal conductivity of hydrogen gas and partially by positive chemical effects of CO and CO_2 gases and a negative chemical effect of nitrogen gas [1]. In this report, the hydrogen gas erosion theory is applied for several conventional gun propellants i.e., single, double and triple base gun propellants. Gas erosion rates, which were evaluated with a gas erosion simulation bomb, were found to well correlate to estimated gas erosion rates at actual firing from literature [2]. In erosivity analysis of the conventional gun propellants, the gun propellants used are clustered into two groups, i.e. a single-double base group and a triple base group. In the triple base group, an inflection point in a propellant impetus vs. log of the erosion rate plot indicates that best trade-off between the impetus and the gas erosion.

INTRODUCTION

Gun wear has been known as an inevitable problem in use of current gun system, although extensive efforts have been paid to minimize it in the world. Study of gun wear is divided into three aspects known as ablation, scoring and gas erosion. Since ablation and scoring is often observed at a terminal stage of the gun barrel lifetime, minimizing the gas erosion is believed to be critical to enlarge the gun barrel lifetime. Two major research streams have been existed in the elucidation of the gas erosion mechanisms. One of the major streams is that the gas erosion is controlled by thermal events from the combustion gases onto gun barrel surface. According to this mechanism, isochronic flame temperature, which is calculated from gun propellant composition, was believed to be an only factor to determine the gas erosion rate. However since 1980 a new type of gun propellant, which contains a nitramine compound to reduce the isochronic flame temperature and increase the impetus, was developed. Although the introduction of the nitramine was expected to reduce the gas erosion, the observed results were against the prediction [3,4]. Based on this result, a new concept was proposed, in which the dominant factor is not the thermal effect but several chemical reactions between the combustion gaseous products and the gun barrel metal surface. Several mechanisms were proposed such as reduction of gun barrel by CO [4], oxidation of the gun barrel by CO_2 [4] or by H_2O [5-7], gun barrel embrittlement by hydrogen gas [8] and heterogeneous combustion of the nitramine particle in gas phase [4].

Recently our research group developed a new erosion simulation bomb which is expected to predict the gas erosion at isolated condition from the other erosion phenomena such as the scoring [1]. From results of the erosion simulation test, a new gas erosion mechanism which reconciles the thermal effect and the chemical reactions was proposed. In the proposed mechanism, most of the chemical reaction effects can be explained as the thermal effect by thermal conductivity contribution of the combustion gaseous product described as, $Tf/\sqrt{Mw}$, in which Tf is the isochronic flame temperature and Mw is a mean molecular weight of the combustion gaseous products. Although the new erosion technique was applied for research of a new LOVA gun propellant formulation which includes a new gun propellant binder CAN [9], entire gas erosion analysis in a wide isochronic flame temperature range was remained as future work. In this presentation, development of the practical estimation technique by an improved small-scale gas erosion simulation bomb was introduced in details, and effects of the gas erosion were discussed from a point of gun propellant composition.

EXPERIMENTAL

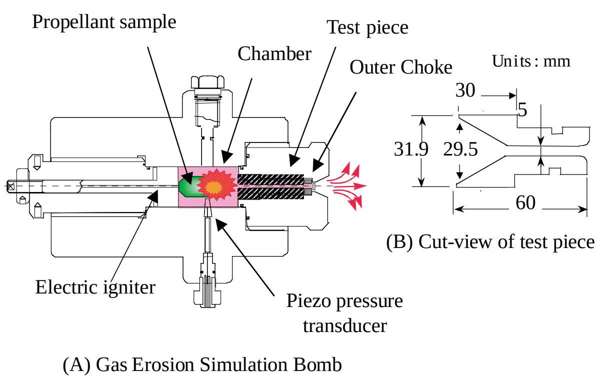


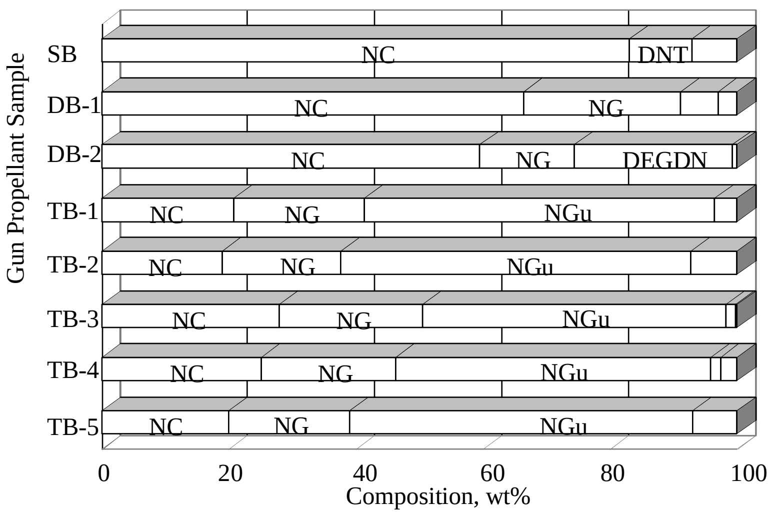
Fig. 1: A schematic set-up of gas erosion simulation bomb, (A) Overall cut-view of the simulation bomb, (B) Cut-view of the test piece.

Erosivity Measurement

Like as our previous report [1], gas erosion rate of gun propellants was measured with a double-choke type gas erosion simulation bomb. A schematic setup of the simulation bomb is illustrated in Fig 1. The gas erosion simulation bomb has a chamber volume 180 cm^3 and is equipped with a double-choke nozzle system. The double-choke nozzle consists of an inner tubular test piece and an outer choke. Orifice diameter of the outer choke (3 mm) is adjusted to be smaller than orifice diameter of the test piece (5 mm) so that speed of combustion gas flow does not exceed speed of sound. This type of double-choke erosion evaluation system was found to simulate the gas erosion at an isolated condition from the other types of gun wear [1]. The test piece was shaved in 60 degree apex cone shape to avoid unnecessary gas flow turbulence occurring at the chamber edge. The gas erosion rate of gun propellants is evaluated by the test piece weight-loss. The weight-loss measurement was carefully conducted since carbon and oily residues sticking to the test piece critically affects the error of the weight-loss measurement. Cleaning procedure of the test piece is following. First the test piece, which is detached from the simulation bomb immediately after the test, was brushed with acetone and toluene. Then the test piece was cleaned in supersonic cleaner, and finally it was dried at 60°C. This cleaning procedure can reduce the error of the gas erosion rate measurement down to 2%. In the gas erosion rate measurement, the test piece weight-loss per one shot for each gun propellant sample was used to evaluate the gun propellant composition dependence of the gas erosion.

Gun Propellant Sample

Eight types of gun propellants were used to investigate the composition dependence of the gas erosion. The composition is summarized in Fig. 2. The gun propellant samples cover popular conventional gun propellant formulations called as single base, double base, and triple base gun propellants. The single base gun propellant (Sample SB) con-



NC: Nitrocellulose, NG: Nitroglycerine, DEGDN: Diethylenclycol dinitrate,
NGu: Nitroguanidine, DNT: Dinitrotuelene

Fig. 2: Gun propellant sample compositions used in the erosion simulation test.

sists mostly from nitrocellulose at over 80 wt%. The double base propellants (Samples DB-1, DB-2) contain nitrocellulose and liquid nitrate ester compound as the major ingredients. The triple base gun propellants (Samples TB-1 to TB-5) consist from three major ingredients, nitrocellulose, nitroglycerine and nitroguanidine. The nitroguanidine is recognized to plays an important roll to reduce erosivity by a “cool burning” [10] characteristics, compared to the double base propellants. Isochronic flame temperature and impetuses of the gun propellants are in ranges of 2400 to 3450 K and 900 to 1150 J/g, respectively.

Sample amount used in the erosion simulation test was 50 g per shot. Since grain shape of the gun propellant was found not to affect the gas erosion [1], several types of gun propellant grains such as seven perforated and nineteen perforated shape were used in this study.

RESULTS AND DISCUSSION

Validation of Erosion Simulation Test Results

In the gas erosion analysis, it is practically important to find a correlation between gas erosion rate obtained with the simulation bomb and that in actual firing test. However the validation is, in turn, a relatively tough problem because it is difficult to separate effects of gas erosion from the other erosion effects in the actual firing test, and moreover there is less data available for the validation. In this study, the validation was conducted with reliable erosivity data presented in the past Ballistic Symposium [2]. Fig. 3 shows a relation between the gas erosion rate obtained with the gas erosion simulation bomb and gas erosion rate estimated at a condition of 30 mm test gun firing. In Fig 3. the gas erosion in firing test was estimated by eq (1) [2] in which an propellant wear coefficient *lnA* was taken from literature [2],

$$\ln W = \ln A + \frac{1.5T_{\max}}{69} \quad (1),$$

where *lnW* is a log of gas erosion rate, T_{max} is a maximum bore surface temperature. In eq (1), the maximum bore temperature was estimated from eq (2) [2] by assuming full charge firing,

$$\frac{T_{\max} - T_i}{T_f - T_i} = \left[\sqrt{\frac{900}{Cm}} \left(1.7 + 670 \frac{d^{2.22}}{m^{0.86}} \right) \right]^{-1} \quad (2),$$

where T_f is the isochronic flame temperature, T_i is a initial gun barrel surface temperature, *Cm* is a projectile initial velocity, *d* is a gun barrel bore diameter and *m* is a mass of gun propellant charge. For easy understanding the gas erosion rate obtained with the simulation bomb was expressed as a test piece diameter change by simple conversion from the test piece weight-loss. As shown in Fig. 3, gas erosion rate was found to well correlate to estimated gas erosion rate in an actual firing test.

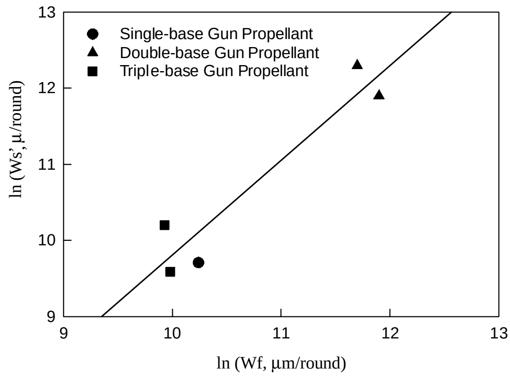


Fig. 3: A correlation between natural log of gas erosion rate measured by the gas erosion simulation test ln(Ws') and natural log of gas erosion rate estimated simulation test for firing test ln(Wf).

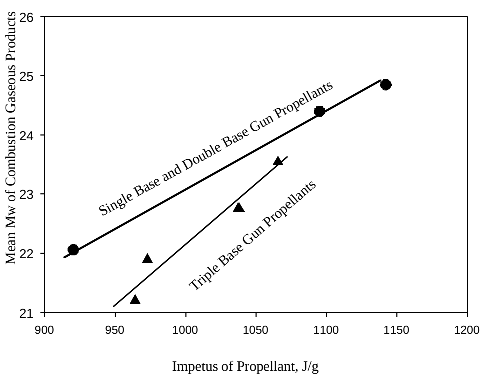


Fig. 4: A relation between mean molecular weight of combustion gaseous products and impetus of propellant.

A relatively rough prediction of real gun barrel lifetime was conducted through the least square fitting from Fig. 3. For a triple base gun propellant TB-3 (M30A1 composition), the gun barrel lifetime 2660 rounds was predicted. Since the predicted value is well agreed to the reported gun barrel lifetime for 155 mm Howitzer, 2700~3500 rounds [4], the prediction result also supports the verification of the erosion simulation test method.

Propellant Composition Dependence of the Gas Erosion

Our previous report suggests that gas erosion of gun propellant should be discussed by both the isochronic flame temperature and combustion gas composition which contributes both the thermal and the chemical effects. In fact, as shown in Fig. 4, a plot of isochronic flame temperature vs. mean molecular weight of the combustion gaseous products suggests that a relation for the triple base gun propellant is in a different trend from that for the single base and double base gun propellants. This difference in the relations suggests that gas erosion of the gun propellants should be discussed separately as a single-double base group and a triple base group. Figs. 5 and 6 show plots of the gas erosion rate vs. the isochronic flame temperature of the propellant and the gas erosion rate vs. the impetus of the propellants, respectively. The both plots indicate that the gas erosion rate was found to better correlate in the individual group rather than in the overall. Unfortunately no RDX containing gun propellants were examined with the simulation bomb. However it is possible to estimate the gas erosion with our past data [1]. Fig. 5 also contains an estimate trend for the RDX-Polyurethane base gun propellant. From the trends in Figs. 5, it is easily understood that nitramine containing gun propellants are more erosive than the conventional gun propellant. This result is a concrete support for our past finding that the gas erosion is dominated not only by the thermal effect, which

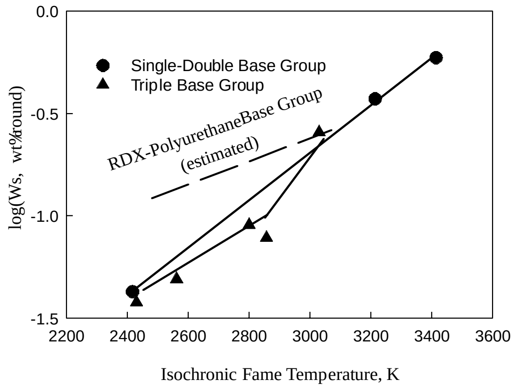


Fig. 5: Relations between log of gas erosion rate by the erosion simulation test log(Ws) and isochronic flame temperature for the single-double base group and the triple base group. Dashed line shows an estimated trend of RDX-polyurethane base group.

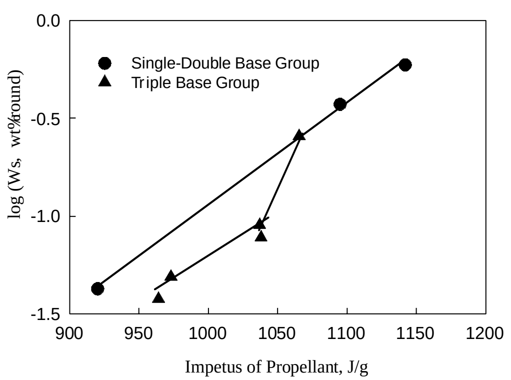


Fig. 6: Relations between log of gas erosion rate by erosion simulation test log(Ws) and impetus of propellant for the single-double base group and the triple base group.

understood as a increase of thermal conductivity mostly by hydrogen gas in the combustion gaseous products. If all of the erosivity data are discussed without clustering against discussed in Fig. 4, the data looks scattered or a minimal erosive point should be observed.

For the triple base propellant group, an inflection points of impetus 1030 J/g in Fig. 6 were observed. Below the inflection point, decrease of the impetus does not so much contribute to the decrease of the gas erosion. Above the inflection point, increase of a slope in gas erosion-impetus relation indicates that much erosivity reduction can be achieved with sacrificing less impetus. This finding implies that the best trade-off between the thermodynamic parameters and the erosivity is lying above the inflection point. However above an impetus 1070 J/g, the gas erosion of the triple base gun propellants seems to be close to that of the single-double base gun propellant group. The result indicates that for the triple base group the thermal effect predominately controls the gas erosion and less chemical effect can be expected to reduce the gas erosion above the impetus.

CONCLUSION

By using a gas erosion simulation bomb with double choke system, effects of gas erosion was quantitatively evaluated for several gun propellants, which cover single, double and triple base gun propellants. From the correlation between obtained gas erosion rate and gas erosion rate estimated from literature, validation of the gas erosion simulation technique was established. Estimated gun barrel lifetime for M30A1 propellant is agreeable to a literature value.

Based on the hydrogen gas erosion theory that we proposed in previous report, gun propellant samples were clustered into two groups for the gas erosion analysis i.e. a single-double base group and a triple base group. Correlation in the individual group was found to be better than the overall correlation. In the triple base group, an inflection in a relation between propellant impetus vs. log of the gas erosion rate was observed. This new finding suggests that the base trade-off between the impetus and the erosivity in the triple base group.

We believe that the development of the new gas erosion simulation bomb and the propellant ingredient depending trend in the gas erosion are an important direction in future gun propellant formulation research.

ACKNOWLEDGEMENT

Authors would like to express our gratitude to Dr. T. Sasajima for his support to this study.

REFERENCES

1. J. Kimura, “Hydrogen Gas Erosion of High-Energy LOVA Gun Propellants”, Proceedings of 16th International Symposium on Ballistics, Vol 1, 307, 1996.
2. B. Lawton, “Thermal and Chemical Effect on the Gun Barrel Wear”, Proceedings of 8th International Symposium on Ballistics, Vol. 2, 27, 1984.
3. D.C.A Izod and R.G. Baker, “Gun Wear: an Account of Recent UK Research and New Wear Mechanisms”, RARDE, 115(1982).
4. L. Ahmad, “The Problem of Gun Barrel Erosion: Overview”, in “Gun Propulsion Technology”, L. Stiefeld, Ed., Progress in Astronautics and Aeronautics Vol.1, 109, M. Summerfield, Chief in Eds, Institute of Aeronautics and Astronautics, Washington, 1988.
5. A.C. Alkidas, S.O. Morris and M. Summerfield, “Erosive Effect of High Pressure Combustion Gases on Steel Alloy”, J. Spacecraft and Rocket, 13, 461, 1976.
6. A.C. Alkidas, Christoe, C.W., L..H. Caveny and M. Summerfield, “Erosive Effects of High Pressure Gases on Steel”, Trans. ASME, J. Enginnering Materials and Technology, 239, 1977.
7. A.C. Alkidas, L.H. Caveny and M. Summerfield, “High Pressure and High Temperature Gas-Metal Interactions”, Proceedings of 13th JANNAF Combustion Conference, CPIA Pub., Vol.1, 475, 1976.
8. M. Kobayashi, “Effects of Gas Compositions of Gun Propellant on Gun Erosion”, TRDI Report 5761, 1990.
9. J. Kimura, “Minimal Erosive and High-Energy LOVA Gun Propellant Using A Desensitized Nitrocellulose (CAN) as the Binder”, Proceedings of 17th International Symposium on Ballistics, 23, 1998.
10. H. Krier and M.J. Adams, “An Introduction to Gun Interior Ballistics and a Simplified Ballistic Code”, in Interior Ballistics of Guns”, H. Krier Ed., Progress in Astronautics and Aeronautics Vol.1, 1, M. Summerfield, Chief in Eds, Institute of Aeronautics and Astronautics, Washington, 1988.