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Friction and wear between rotating band and gun barrel during engraving process

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ABSTRACT

It is of great importance to investigate the occurrence of engraving (also known as "scoring") of rotating bands during firing to achieve optimal design, manufacturing, use and maintenance of medium and large caliber rifled guns and their corresponding projectiles. In our present study, two short rifled gun barrel sections and projectiles with copper, Al–bronze and nylon rotating bands were prepared. Quasi-static and dynamic push tests were performed on the CSS-88500 Electronic Universal Testing Machine (EUTM) and a specially designed gas gun-based dynamic impact test rig. The quasi-static experimental results showed that the extruded materials accumulates at the end of the band and has not departed from the band base. However, the dynamic experimental results showed no clear accumulation, which is close to the recovered rotating band after firing. Large deformation and severe friction between rotating band and gun bore has occurred during engraving process. It is suggested that strain rate and temperature have great effects on the deformation behavior of rotating band during engraving process.

1. Introduction

Interior ballistics deals with the interaction of gun, projectile, and propellant (Fig. 1) before emergence of the projectile from the muzzle of the gun. It includes the ignition process of the propellant, the burning of propellant in the chamber, the first-motion event of the projectile, engraving (also known as "scoring") of any rotating band and obturation of the chamber, in-bore dynamics of the projectile, and tube dynamics during the firing cycle.

The rotating band is a band of soft metal (copper alloy) that is securely seated around the body of the projectile (Fig. 2). The primary functions of a rotating band are: (1) to act as a rear bourrelet on those projectiles that do not have a rear bourrelet to position and center the rear end of the projectile; (2) to seal the forward end of the combustion chamber against the escape of the propellant gas around the projectile; and (3) to engage the rifling in the gun bore and impart rotation to the projectile. In preparation for firing the large-caliber rifled gun, separate loading ammunition is used. The outer diameter of the projectile is usually designed to be smaller than the land diameter of the bore. Before entering the bore, the projectile enters the forcing cone, and the rotating band contacts the forcing cone, which permits proper seating of the projectile within the gun barrel. The outer diameter of the rotating band which is located on the outer surface of the projectile is larger than the groove diameter of the bore. Once the propellant ignites, gases are generated that develop enough pressure to overcome initial bore resistance, thereby moving the projectile. As a result, the radial dimension of the rotating band is gradually reduced in the forcing cone until commencement of full rifling. This process is defined as engraving of rotating band in interior ballistics.

On certain projectile, there is obturating band (Fig. 2), typically made of nylon or plastic, at the rear of the rotating band, which provides forward obturation by preventing the escape of gas pressure from around the projectile. Therefore, obturation refers to sealing off the propellant gases and preventing them from escaping alongside or ahead of the projectile (Fig. 1). Two opposing forces act on a projectile within the gun barrel. The first is a propelling force caused by the high-pressure propellant gases pushing on the base of the projectile. The second is a frictional force between the projectile and bore. It includes the high resistance during the engraving process and opposes the motion of the projectile (Fig. 3).

Projectile rotating band interaction with gun barrel is of great importance in the development of high performance gun. Montgomery [1–5] suggested that the mechanism of wear of rotating band materials at high sliding speeds is surface melting followed by subsequent removal of a portion of the melted surface layer, indicating that a rotating band material must be high melting temperature. The sliding of gilding metal banded projectiles down the gun bore could be considered hydrodynamic-lubricated sliding, and the wear of these rotating bands would be dependent on

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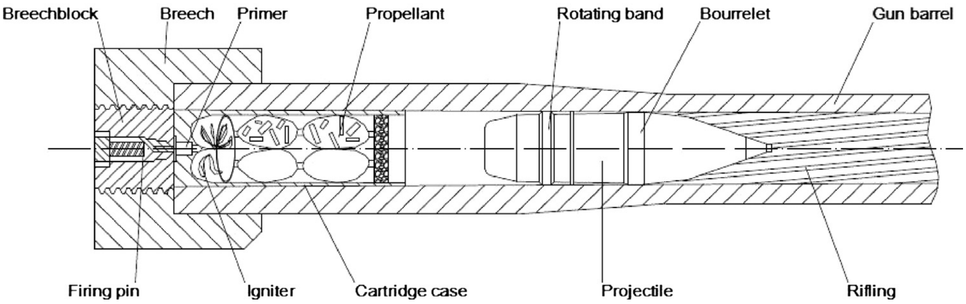

Fig. 1. A schematic of gun–projectile–propellant combination.

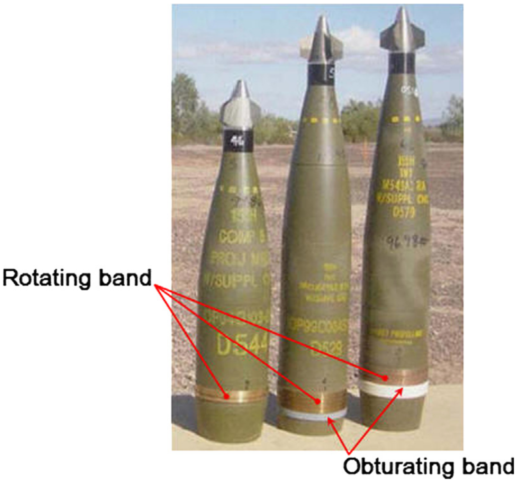

Fig. 2. Projectiles with rotating band and/or obturating band.

the amount of heat transferred to them. Severe wear of the rotating bands occurring near the origin-of-rifling in some cases can lead to excessive bore wear near the muzzle [6,7]. Matsuyama [8] proposed a slider melting wear theory based on the non-steady heat conduction equation to estimate the melting wear quantitatively from thermal properties of sliders. Based on the theory, he established a practical selection of slider materials, such as red brass, Al–bronze and brass. Lisov [9] presented theoretical and experimental research of wear mechanism on 105- and 155-mm artillery projectile rotating band using variable parameters of internal ballistics process. The effect of the projectile rotating band on the stress applied to a 155 mm gun barrel during firing was investigated by Andrews [10]. Strain gage instrumentation applied to the exterior of gun barrels during firing trials was measured, which is subsequently used to examine parameters affecting the forces applied to the barrel by the projectile. It was found that high charges generally degrade the rotating band and reduce the load applying to the barrel. Highest band strains have been observed in new barrels, and the band strain decreases with even moderate wear from all charges. Influences of rotating band construction on gun tube loading were studied experimentally and numerically by Toivola et al. [11] and Keinänen et al. [12]. Rotating band pressure effect on band and tube wear was investigated. Effect of high band pressure on gun tube strength and fatigue was also discovered. Schupfer et al. [13] investigated three alternative materials, nickel, titanium, and carbon fiber-reinforced composites (CFC), as possible substitutions for copper rotating bands. Glass-fiber (GF) reinforced polyamide was proposed as alternative material for rotating band by Eleiche et al. [14]. Experimental results indicate that 2% GF content as reinforcement to PA66 resin appears to be the ideal compromise and the rotating band withstands the associated plastic deformation without failure at all sliding speeds. Vigilante et al. [15] performed gleeble testing to assess the solid/liquid metal embrittlement of gun steels by copper. A Gleeble 1500 thermo-mechanical tester was used to evaluate the embrittlement of three different gun steels by pure copper. The Gleeble tester was originally developed over 50 years ago for weldability studies, which enables rapid resistance heating rates up to 10,000 °C/s in vacuum and mechanical testing using servo-hydraulic control and an 80 kN capacity load cell. Temperatures ranged from 868 to 1100 °C under testing conditions. It was found that embrittlement occurred in all copper plated steels tested at 1100 °C and there was only slight evidence of embrittlement below 1100 °C.

The engraving process of the rotating band is one of the basic research aspects of the interior ballistics and has not been thoroughly understood until now, in which gun barrel, projectile and propellant are involved. Investigation of the mechanism of the engraving process is beneficial to the optimal design, manufacturing, use and maintenance of gun and projectile. A large deformation analysis of the engraving process and wear in a projectile rotating band is considered by Chen [16,17]. The band pressure is large with severe plastic deformation occurring in the band. Balla et al. [18] studied interaction between projectile driving band and forcing cone of weapon barrel in course of ramming. Two types of weapons were chosen for performing calculations and simulations. One is a self-propelled howitzer 152 mm mod 77 with high explosive projectile, the other is a 125 mm T72 tank cannon with shaped charge penetration projectile. It was found that ramming and extraction forces depend on wearing degree of forcing cone diameter remarkably.

In this present research, engraving of rotating bands was investigated experimentally. Short rifled gun barrel sections and projectiles with copper, Al–bronze and nylon rotating bands were prepared. Quasi-static push tests were performed on the CSS-88500 Electronic Universal Testing Machine (EUTM). A specially designed gas gun-based dynamic impact test rig was proposed for dynamic push tests. The deformation and worn surface of rotating band after engraving were observed.

2. Experimental

2.1. Materials

2.1.1. Gun barrel

Two simulated short gun barrel sections made of CrNiMo steel were manufactured (Fig. 4). Geometry parameters of these two gun barrels are listed in Table 1 (L—barrel full length/mm; L_F—forcing cone length/mm; L_f—rifling length/mm; W_L—land width/mm; W_G—groove width/mm; D_L—land diameter/mm; D_G—groove diameter/mm; n—number of rifles). To simplify the manufacturing process and subsequent analysis, linear rifling, namely, the rifling profile without a twist, was cut in the gun bore and