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A thermochemical approach for the determination of convection heat transfer coefficients in a gun barrel

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ABSTRACT

A finite element thermo-mechanical analysis of firing through a gun barrel requires the convection heat transfer coefficient values under high temperature and pressure among input parameters. A thermochemical approach has been formulated in order to obtain these coefficients. Considering a variable burning speed for a typical gunpowder configuration, the variation of pressure wave speed, density, and heat conduction of the burning gas mixture is used to evaluate the Reynolds and Prandtl numbers along the barrel axis. These two numbers are then used to calculate the Nusselt numbers from which the continuously changing convection heat transfer coefficients are determined. It is confirmed from an experimental firing process and its corresponding thermo-mechanical finite element analysis that the calculated coefficients present a good estimate of the real coefficients.

1. Introduction

A gun barrel is exposed to high dynamic loads together with high heat inputs that lead to severe temperature increases during firing. The source of these inputs is the thermochemical burning of gunpowder of the projectile. The burning of gunpowder is generally assumed to take place in three phases: The first phase is burning under constant volume until the projectile is on the onset of movement in the barrel, the second is burning between the start of movement till the projectile reaches the end of the barrel, and the third is burning at atmospheric conditions just on the onset of leaving the barrel. The thermal properties under these complicated thermochemical processes due to the moving projectile need to be determined for the successful computer aided analysis and design of gun barrels.

Many experimental test methods and approaches for thermal analysis of gun barrels have been developed in the past years of literature. Among these, a traveling thermocouple junction (formed by the bullet–bore interface) method has been developed in order to directly measure the inner wall temperature of the barrel. The secondary but comparatively small heat input caused by frictional effects at the same interface was also measured using a method based on Calorimetry [1,2]. Analytical studies such as the "Inverse Estimation Method" and the "Function Estimation Method" try to determine the heat flux and temperature iteratively with a disadvantage of requiring measured temperatures beforehand [3,4]. Direct analytical methods have also been developed with limited accuracy due to the complex time dependent nature of the problem [5–8]. The need for lighter but longer life gun barrels, namely hybrid material multi-layered, has even more complicated the design process [9–11].

It can be deduced from the above descriptive literature review that the amount of heat transfer through the barrel wall therefore is a required and critical information during the thermo-mechanical "cook-off" design stage. The amount of this convective heat transfer especially from the burning gas mixture of the moving projectile to the inner surface of the barrel is directly dependent on the heat transfer coefficient. This study aims at determining the heat transfer coefficient by a new thermochemical approach abiding the nature of the direction of heat flow in a barrel. The validation testing is based on a bolt action sniper rifle which is 7.62 mm in caliber, 620 mm in barrel length with a muzzle velocity of 860 m/s and a weight of 6 kg without accessories.

2. Pressure and velocity variation inside barrel

Certain assumptions had to be made during calculations of the coefficients. The exothermic burning rate is assumed to be linear and the gas mixture is assumed to behave as an ideal gas. The gas mixture compression ratio, k_c, is taken as 1.34 [12] and gun barrel inside diameter, d, is 7.8 mm. The pressure and velocity variations

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