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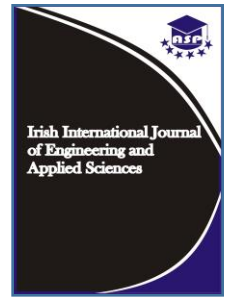

DETERIORATION OF FIREARMS: A REVIEW REPORT ON CORROSION AND WEAR OF THEIR BARRELS

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Abstract: *The barrel condition influences the performance and longevity of firearms. This paper presents a review report from various reputable research sources, highlighting barrel corrosion and wear as issues that threaten the serviceability and longevity of millions of firearms annually. The review shows that the barrel is a crucial component of all firearms, through which a rapidly expanding, high-pressure, high-temperature, and chemically aggressive propellant gas in its hollow interior part, called the bore, is used to propel a projectile out of it at high velocity. The created thermally, chemically, and mechanically aggressive barrel condition in firing rounds, together with the bore fouling and ambient detritus such as salt, water vapor, and microscopic particles that are often drawn into it and build on its metal surface, cause its corrosion and erosive wear. This degrades the bore's as-made smoothness and straightness without cavities, hanks, cracks, fouling buildup, or other defects to uniformly guide a bullet in its grooves and give it a correct axial rotation movement with the highest performance probability. Depending on the severity of the problem, corrosion and wear can cause barrel ringing or bulging to an actual blow-up and inaccurate projectile performance. The review also shows that contemporary barrels are made with high-strength metals like the SAE 4140 and 4340 special alloy steels and erosion-corrosion-resistant coatings like chromium, tantalum, and manganese phosphate coatings to improve their corrosion and wear resistance, and there has been a search for better metals, coatings, propellants, erosion-reducing additives, and lubricants for barrels. The longer a barrel is left uncleaned, the more it rusts and pits, so for longevity and effective performance of firearms, it's a common practice to store them under no or minimal exposure to moisture and air or to regularly clean and lubricate their barrels to minimize their corrosion and wear. The paper brings together information that will help many researchers and other workers find better ways to deal with barrel corrosion and wear.*

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1.0 INTRODUCTION

Corrosion is a natural phenomenon that attacks engineering products and systems depending on the corrosively level of their respective surrounding environment [1]. Corrosion basically results from repeated or constant material exposure to inimical environmental species or factors such as oxygen, moisture, fluid flow, sunlight, pollutants, stress, etc. [2]. On the other hand, wear occurs when a material deteriorates with surface damage and material loss due to physical forces like impact, abrasion, or friction when it comes into contact with another material or item [3, 4]. Erosion is a form of wear called erosive wear that is brought on by the mechanical action of fluids [5, 6]. Wear is the primary cause of about 80% of mechanical moving system failures [4]. Wear was first recognized as a major issue with firearms in 1886; it has been a major issue ever since because it hasn't been completely fixed [7, 8]. Corrosion and wear refer to the degradation of materials due to chemical and mechanical processes, respectively, with corrosive wear being a combination of both. Corrosive wear leads to accelerated material degradation and failure compared to corrosion or wear occurring independently. [3, 4]. This type of wear is common in environments with aggressive conditions, such as chemical processing, marine, oil and gas extraction, weapon firing, and aerospace applications. Under many environmental conditions, corrosion or wear of metals, weapons, machinery, equipment, and other engineering systems can only be significantly slowed down to negligible levels for reasonable periods of time but cannot be permanently and totally prevented for every exposure to environmental or service conditions (Guma et al. [2, 5]). The fight against corrosion and wear is one of the big issues in the protection and maintenance of firearms. Each year, millions of firearms lose their aesthetic appeal and functionality due to corrosion and wear, with the annual cost of their damage, upkeep, and storage, as well as research into improved firearm materials, production, and protection techniques, amounting to billions of dollars.

The barrel is a crucial component of all types of firearms: rifles, pistols, snipers, machine guns, cannons, revolvers, shotguns, etc., and it can be argued that the barrel's lifespan dictates the life of the firearm [7, 9, 10, 11 and 12]. It is the component that is used to propel bullets or projectiles at high velocity through its hollow interior part called the bore. Its condition influences the stability, accuracy, range, and overall performance of projectiles from firearms. The barrel is, however, more frequently exposed to environmentally aggressive conditions than other firearm components since its bore is often exposed to mechanically, chemically, and thermally aggressive conditions when propelling projectiles. Therefore, as the number of firing rounds grows, it is the barrel component that is most likely to deteriorate or even fail due to corrosion, wear, mechanical stresses, and thermal stresses [7, 11, 13, 14 and 15]. Gun barrel

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design has, however, addressed the issues of thermal and mechanical stresses through a number of techniques such as autofrettage, material selection, and structural optimization to enable barrels to withstand high pressures and temperatures, ultimately increasing their lifespan and performance to a significant extent [16] The corrosion and wear issue of firearm barrels is, however, to date more expensive and challenging to deal with than the issues with their thermal and mechanical stresses. A corroded barrel exhibits damage signs like pitting and rust discoloration. The damage gradually leads to permanent bore expansion or even blowout with reduced accuracy and unsafe firing conditions [11, 14 and 15]. Wear in all forms also gradually damages or enlarges the barrel bore and can be accelerated by corrosion. Severe corrosive wear can accelerate the weakening of the barrel to the point where it could fracture or even explode inadvertently during firing, posing a serious safety risk. Even minor corrosion and/or wear can lead to a decrease in firing accuracy due to barrel distortion and changes in bore diameter or caliber [7, 8, 111 and 14]. As the caliber of a gun barrel increases and the projectile mass increases with a need for greater propellant energy, the propensity for barrel wear also increases [12, 17 and 18]. This indicates that all barrels are prone to corrosion and wear, but barrels of heavier firearms like artillery are more prone to wear than those of smaller firearms. Barrel wear has received more attention as a result of the remarkable increase in artillery power over the last 30 years, and it is safe to say that it is currently one of the biggest issues facing heavy gun makers [12, 17 and 18]. This paper aims to present a review report from various credible research sources on barrel corrosion and wear as critical issues that undermine the serviceability of firearms, covering the issues' origin, effects, contemporary approaches to dealing with them, and research advances on them as pertinent facts that can help many researchers, engineers, gunnery personnel, stakeholders, and scientists in addressing the issues for greater serviceability of firearms at minimal costs.

2.0 METHODOLOGY

The review information on corrosion and wear of gun barrels was gotten from various journals, theses, and other reputable literal sources published from 2002 to 2025, combined, summarized, and fine-tuned for enhanced readability, and better understanding.

2.1The Origin of Corrosion and Wear in Barrels

A firearm barrel is a metal tube that accelerates a bullet, shot swarm, or other mass to a velocity by allowing hot, quickly expanding propellant gases to transform stored chemical energy into kinetic energy [13]. More than 600 years of constant technological advancement have led to the creation of modern firearm barrels. A firearm barrel is a complicated combination of chemistry, physics, metallurgy, engineering, and ballistics, despite being little more than a tube

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with one end closed. The barrel is the single most crucial component that determines accuracy in rifles and pistols. The barrel of a shotgun regulates the pattern's quality and tightness.

The major contributors to wear and erosion of gun barrels are usually grouped under the headings: thermal factors, chemical factors, and mechanical factors [7, 8, and 15]. The relative contributions of these factors vary from system to system. Generally, however, thermal and chemical effects are considered to be the dominant factors. When a gun is fired, the barrel wall is subjected to heating by a hot gas, typically 3000K and at 400 MPa, for up to 20 ms. this barrel heating leads to softening, thermal phase transformation, and melting of the bore surface. Considerable thermal heating, due to forced convection, can be caused by gas wash between the projectile driving band and the bore surface. The main constituents of propellant gases are CO, CO_2, H_2, H_2O, and N_2. Minor components will include NH_3, CH_4, NO, free radicals, and ions [7, 8, 14, 15, 19]. These gases either react at the bore surface or form acids, chlorides, and other corrosive agents in the presence of moisture and oxygen, which act to corrode the bore. Carbon and nitrogen diffuse into the barrel, softening the bore surface. The conditions lead to a phase transformation of the gun steel; above 750°C the austenite, or gamma, phase is formed. Further carbon penetration reduces the melting point of the austenite [14, 15]. As the austenite cools, it transforms to a martensite phase. Cracks form, further degrading the quality of the bore surface. Cementite (FE_3C) is also formed at the surface, further promoting softening and cracking [7, 8, 14 and 15].

The bullet and propellant gases both contribute mechanically to wear. The high-velocity gas flow entangles unburned propellant and tiny solid particles from the primer and other sources, which abrasively affects the bore surface. The engraving of the drive band into the lands and grooves at the start of rifling causes mechanical wear on a rifled barrel. The gun barrel is subjected to significant stress throughout this process. Additional mechanical wear is brought on by the projectile's whirling as it passes through the barrel. The radial pressure between the driving band and the bore in rifled and smoothbore barrels causes friction and an abrasive action on the bore surface [7, 14 and 15]. Rusting and other corrosion forms can be exacerbated by barrel fouling, which is caused by a chemical reaction or accumulation of ammunition residues on the barrel's bore during firing rounds, as well as ambient detritus like salt, water vapor, and microscopic particles that can be drawn into the barrel and accumulate on its metal surface [8, 14, 15].

2.2 Effects of Barrel Wear on Firearms

The projectile's stability and accuracy are significantly impacted by the state of the barrels' inner surfaces. The projectile is guided uniformly in the grooves if the barrel's inner surface is smooth, straight, and free of cavities, hanks, fractures, or other flaws [7, 8 and 14]. The grooves also provide the bullet the best chance of

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performing correctly and accurately during axial rotation. There is extremely little bullet spread when firing with such barrels. Surface flaws on the interior of the barrel due to corrosion and/or wear or other sources, however, cause the projectile to experience significant friction in all of its sections, resulting in various barrel deteriorations to ringed or bulged or an actual blow-up of the barrel depending on the issue's level. The issues can also result in appreciable scattering of the projectile and

i. A decrease in its muzzle velocity [11, 14].
ii. A lower chance of its accuracy [11, 14].
iii. An increase in its dispersion, in other words it causes greater variation of projectile impact-points within a firing group [11, 14].
iv. In flight is unstable [11, 14].
v. Damages to other delicate projectile parts such as guidance system, electronics, and sensors [11, 14].
vi. Accelerated barrel fatigue failure due to increasing surface flaws in the combustion chamber and bore [11, 14].
vii. Accelerated side-body engraving and projectile driving band erosion [7, 14].

According to the research, these items could pose a serious risk to "friendly personnel located downrange or near the intended target," even if they might not be dangerous to the individual using the firearm. This reason shows the need to take extra care to prevent barrel corrosion and wear [7, 11 and 14].

2.3 Methods of Dealing with Barrel Corrosion and Wear

The control of barrel corrosion and wear has essentially been through research and development and the use of what has been available as the best. The control of barrel corrosion and wear has been achieved through the following methods:

i. The development and use of non-erosive and non-wear-causing propellants for the barrel materials through proper chemical formulations of the propellants' gaseous species since some chemical species or elements of propellants like hydrogen can embrittle the bore surface, leading to micro-cracking, and carbon can diffuse into the lattice, creating unfavorable local residual stresses [8, 9, 10, 11].
ii. The development and use of shock-resistant, superior-in-toughness, superior-in-strength, high-hardness, excellent heat-resistant, highly corrosion-resistant, and highly wear-resistant structural materials and liners for barrels. Presently, a number of high-strength metals like the SAE 4140 and 4340 special alloy steel and carbon fiber are in use for making firearm barrels [9, 10 and 11].
iii. The development and use of corrosion-resistant and wear-resistant bore coatings that have sound adhesion to the base barrel material, provide very high insulation of the bore surface from the heat transfer, distribute the heating, are benign or unreactive to the propellant gas, and have exceptional resistance to mechanical wear by the passage of the projectile. The coatings

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presently in use for barrels and liners range from ceramics to refractory metal coatings such as chromium, tantalum, manganese phosphate, tungsten, molybdenum, niobium coatings, etc. [8, 9,10, 11]

iv. The development and use of wear and erosion-reducing additives and lubricants of organic nature in firearm propellants so that the heat generated by firing of the firearms causes the compounds to decompose, thereby evolving gaseous products that buffer the barrel bore surfaces from the corrosive and wearing effects of the combustion products of the propellants. Propellant additives, like titanium dioxide (TiO_2), octaphenylsilsesquioxane (OPS), talc (magnesium silicate $H_2Mg_3 [SiO_3]_4$), wax, and polyurethane, are used to reduce barrel corrosion and wear [9, 10, 11. 13].

v. The keeping of firearms away from moist conditions to prevent the oxidation process and the rusting of the barrel or other firearm components [20].

vi. The regular and proper cleaning of barrels according to the manufacturers' specifications to remove microscopic particles, dust, salt, fouling, and water vapor that can accumulate on their metal surfaces [20].

vii. The avoidance of taking a firearm outside in inclement weather, such as when it's raining, snowing, windy, or damp, or without the appropriate dust- and water-absorbing casings, foams, or cloths to keep it entirely dry and dust-free [20, 21, 22].

viii. The development and use of vacuum seal bags for long-term storage or keeping of firearms and dehumidifiers, cosmoline, and silica gel for exuding moisture or properly controlling moisture level on firearms according to the manufacturers' specifications [20, 21, 22].

2.4 Some Research Advances on Barell Corrosion and Wear

Barrel corrosion and wear is a serious issue, as attested by many research reports in the literature on its origin, effects, and the ways of dealing with it. The research advances from 2002 to 2025 include the following:

Woodley et al. [7] reported that QinetiQ was conducting research into the wear and erosion of indirect fire guns under contract from the United Kingdom Ministry of Defense. The objectives of the work were to improve the United Kingdom's understanding of the causes and mechanisms of wear and erosion in gun barrels and to investigate means by which the wear and erosion may be reduced, thereby extending the life of the gun barrels. The creation of computer models that could forecast the wear and erosion of a gun system, which consists of a barrel, charge, and projectile, was essential to this study. The work also applied to mortars, cannons, and direct-fire guns. The article discussed theoretical and experimental research done to look at erosion and wear in traditional uncoated steel barrels.

Abhilash et al. [8] carried out a review on gun barrel erosion. The review report showed that the erosion of gun barrels leads to reduced gun performance and availability and increases the

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expense of barrel replacement over the lifetime of a gun system. Wear in the gun barrel usually increases the bore diameter near the commencement of refilling. The wear spreads forward toward the muzzle as the gun is fired continuously. The point of maximum wear remains near the commencement of refilling. Worn barrels are objectionable because they allow gas to escape past the shot, thus reducing muzzle velocity, range, and accuracy. As the muzzle begins to wear, the shot loses directional stability. The total wear that can be tolerated is called the condemning limit. Its value depends on the size of the gun, the required accuracy, and the factor of safety that must be maintained against catastrophic fatigue failure. On average, barrels are condemned when the bore diameter increases by about 5%. Wear depends not only on the thermal load but also on the surface metallurgy of the bore and the chemical interactions between the propellant gas and the bore surface. The erosivity of different propellants has been investigated over the years using various numerical methods, and some works have tested propellants or propellant gases in some form of simulated gun. The review discusses the various types of erosion taking place in the gun barrel. It also gives a list of various methods developed over the years to mitigate the gun barrel wear.

Perkovic [9] carried out research on the development of equipment for measuring and monitoring wear inside gun barrels. He asserted that military equipment and weapons are made of ferrous and non-ferrous metals with very high accuracy and the lowest cost guarantee. Its reliability should be at an absolute level in accordance with these specifications. Furthermore, a distinction must be made between the extremely challenging circumstances of war and the use of weapons in a peaceful setting. Special alloyed steel is utilized to make barrels for combat cannons. When it comes to quality, the steel used in the barrel of the cannon should not only corrode but also remain plastic in an emergency; it should not break into tiny pieces or develop massive flaws that would fail the crew and the system as a whole. The cannon barrel is one of the most important parts of the entire artillery system. Its performance and availability are curtailed as a result of wear during firing. Many erosion processes, most notably mechanical, thermal, and chemical erosion, are responsible for gun barrel wear. When the projectile is launched from the gun barrel, this occurs in the internal ballistic process and has an impact on the external ballistic parameters. Consequently, tools are required to track and quantify the wear inside gun barrels of various calibers. Because propellant burns at high temperatures and high gas pressures, gun barrel wear occurs under harsh firing conditions. The goal of his thesis was to create a kind of measurement apparatus that can track and measure internal gun barrel wear in the A–C mm diameter range.

Perkovic [10] worked on the mapping and characterization of surface damage and wear

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mechanisms in gun barrels. He contended that gun barrels are an important component in advanced defense systems. The gun barrels are used for direct and indirect fire, and the material of the gun barrel is exposed to great strains and high temperatures. This sets high demands on the material of the gun barrel. During firing, the gun barrel can be damaged. The first damage in gun barrels is the wear of the rifling, followed by fatigue. When fatigue occurs, cracks can propagate downwards into the bore and result in catastrophic failure. His thesis aimed to understand how and why wear and damaging mechanisms in gun barrels occur. Moreover, how other ballistic factors influence it. He therefore performed an investigation regarding the wear, the mechanisms, and the underlying factors causing the damage, with regards to how and where wear occurs in gun barrels, and also which wear mechanisms cause the wear. He found that wear in gun barrels involves extreme conditions during firing, such as high gas pressure and high temperature from the burning propellant. His work revealed that the wear in gun barrels is caused by erosion from the combustion gases and/or sliding wear caused by the high-speed projectile. The phenomena of wear are complicated, and factors like deformation state, types of wear, environment, and process are interrelated with each other. These are given to wear. In the thesis, samples from three different gun barrels were analyzed. A new unworn gun barrel, a medium-worn gun barrel, and a severely

Hasenbein [11] carried out research on wear and erosion in large caliber gun barrels. He noted that wear and erosion is one of several failure mechanisms that can cause large caliber gun barrels to be condemned and removed from service. His paper describes the phenomenon, its causes and effects, methods that are used to passively manage it, and steps that are taken to actively mitigate it.

Yuwei et al. [12] investigated the best interior ballistics design based on barrel erosion reduction, resolving the issue that the impact of barrel erosion is rarely utilized as a quantitative restriction in the previous interior ballistic design process. Their optimization design was done for a large-caliber gun to improve the barrel life of the gun and improve the performance of the interior ballistic, and the equivalent full charges (EFCs) are completed by combining different barrel erosion models with the interior ballistic model. The interior ballistic optimization design simulation represented by the minimization of barrel ablation has realized the optimization of the interior ballistic parameters with the reduction of barrel ablation as the constraint and obtained the interior ballistic scheme that not only meets the interior ballistic performance indicators but also helps to reduce the ablation of the barrel. The research method formed can guide the design of low-ablation interior ballistic schemes for large-caliber guns, which plays an important role in improving the life of barrels.

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Srinith et al. [13] carried out a study on wear intensity in gun barrels. The study posited that when a gun is fired, the metal temperature reaches a maximum temperature of 1100°C and reduces suddenly in a few seconds, and as it is repeatedly fired, the temperature gets accumulated in it. These sudden heating and cooling temperature areas of zones are called the thermal-affected zone (TAZ) or heat-affected zones (HAZ). Atmospheric contaminants in the air can change the property of the gun and lead to a chemically affected zone and cause wear on the gun barrels. The silicon carbide material has been used to overcome all the defects on the gun and to avoid a catastrophic failure on the barrel. Various tests have been taken on the specimen to provide a suggestion on the material to be used to enhance the properties from a previous material. The specimen has been cut into multiple pieces with the help of a wire-cutting machine to provide accuracy in the specimen. The wear test was taken with a rig test wear intensity machine. The graph, which shows a value of the amount of wear, has been initiated in the specimen, and there are various other graphs that show an idea about the frictional factor, coefficient of friction, and temperature with respect to the time. The load on the wear machine is 1 kg and 2 kg with a speed of 240 rpm and a duration of 6 minutes. Creep is a time-dependent process with an increase in temperature and a constant load process; in this, the graph shows a linear straight line for 1 hour. The specimen has been given a temperature of 100°C and 200°C, with a duration of 1 hour. With these graphs, we can be able to provide a suggestion that when compared with a previous material with the silicon material, it is a good thermal resistant material, high in wear-resisting rate, and high in creep-resisting rates. Most of the research focuses on the cook temperature, and little is on the analysis of the barrels, and no researchers in my analysis have given a viewpoint on recommending a material change to increase thermal efficiency to prevent material wear and fatigue. Gun barrel, silicon carbide, cook-off temperature, wear, and creep.

Popescu [14] studied factors influencing the corrosion of infantry weapons' barrels. The condition of the inner surface of the barrels greatly influences the stability of the bullet and the accuracy of firing with infantry weapons. Therefore, it is of particular importance to keep the inside of the barrels in perfect condition and to protect them against corrosion. For this reason, his article aims to highlight the possible degradation of the inside of the barrels in operation and the main factors influencing their corrosion in order to counteract their effect. The whole issue is addressed both to the personnel specialized in the design and construction of infantry weapons systems and to the personnel that use them.

Kumar et al. [15], in a concise review on the degradation of gun barrels and its health monitoring techniques, noted that unpredicted failure of barrels is a common problem for cannons, artillery, and other ballistic missiles.

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The major cause of the barrels' failure is high pressure, which generates large residual stresses in the inner layers of the barrel. To reduce the stresses, autofrettage of the barrels is carried out, in which the core material is allowed to deform plastically and the upper layers produce a continuous elastic force over the inner layers. Autofrettage is a common engineering practice that is carried out while manufacturing barrels to increase the operational life significantly. The other reason for barrel failure is material degradation, which occurs due to thermal fluctuations, fatigue, wear, erosion, corrosion, etc. In order to correlate them with the life of the gun barrels, various tools such as borescopes, a variety of gauges, optical bore mapping, ultrasonic sensors, and diamond indenter-based instruments are used. The measured data is then used to formulate the empirical mathematical relation, which is further used to calculate the remaining useful life of the barrels. The other mathematical models are the prognostic models, which are generally probabilistic models or data-driven models such as machine learning or hybrid models. By using these models, we estimate the remaining life of barrels by using any of the techniques such as the heat emission method, the dimension increment method, the muzzle velocity method, and strain-based methods. The paper concisely summarizes various techniques used for the diagnosis and prognosis of barrels to estimate the degradation profile and to calculate the remaining useful life.

Yunusov [17] studied steels for tank barrels and gave information on the steels used for the development of tank barrels and combat gun barrels, as well as their quality and properties. Reparability, low price, technology, and high combat performance of steels were noted. It was found that the steels used for the development of tank barrels and combat cannon barrels are made of alloy steels. The type of steel and its category determine its strength, chemical composition, and main properties. Modern metallurgy is at a very high level. O-1200MP is able to obtain steel with higher strength.

Putti et al. [18] presented a review report on gun barrel erosion. The report showed that the erosion of gun barrels leads to its reduced performance and availability and increases the expense of its replacement over the lifetime of a gun system. Wear in a gun barrel usually increases the bore diameter near the commencement of refilling. The wear spreads forwards toward the muzzle as the gun is fired continuously. The point of maximum wear remains near the commencement of rifling. Worn barrels are objectionable because they allow gas to escape past the shot, thus reducing its muzzle velocity, range, and accuracy. As the muzzle begins to wear, the shot loses directional stability. The total wear that can be tolerated is called the condemning limit. Its value depends on the size of the gun, the required accuracy, and the factor of safety that must be maintained against catastrophic fatigue failure. Barrels are often condemned when their bore diameter

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increases by roughly 5%. In addition to the thermal load, wear is also influenced by the bore's surface metallurgy and the chemical reactions between the propellant gas and the bore surface. Several computational techniques have been used throughout the years to study the erosivity of various propellants, and some studies have tested propellants or propellant gases in a simulated gun. The several kinds of erosion that do occur in the gun barrel are covered in their evaluation report, along with a list of different techniques that have been developed over time to lessen gun barrel wear.

Jakopčić et al. [19] conducted an investigation of the material chemical composition influence on artillery weapons barrel hardness. They asserted that the powder gases and projectile have considerable thermal, mechanical, and chemical effects on the weapon barrel. The barrel bore begins to undergo a severe wear process as a result of this exposure. In their investigation, the chemical composition of the samples was analyzed, the metallographic structure of the material was imaged, the potential alteration of the barrel bore surface was tested, and the hardness across the samples' cross section was measured. They reported that one of the key elements that increases barrel wear resistance is the hardness of the barrel material. Therefore, they conducted a modelling study of HV5 hardness as a function of the chemical composition of materials. Their determined models could allow an easier selection of the wear-resistant barrel material as well as the material of other parts of the artillery weapons, with the need to establish a small number of influential parameters without carrying out extensive tests.

Ahmed et al. [20] carried out research on the formulation and testing of cleaning liquids for small firearms. The aim of their study was to assess postural risks associated with the current gun barrel cleaning methods and to develop an ergonomic gun barrel cleaning liquid that could reduce such risks posed by conventional acidic and alkaline cleaners. Four such different formulations were tried, namely, formulation-1, formulation-2, formulation-3, and formulation-4. The four formulations were prepared and successfully tested by prescribed methods. Test results showed that all four formulations were effective in cleaning the gun barrels and other parts of the gun. However, formulations 2 and 4 were found to be most effective in their intended jobs. Carbon removal tests and after-rust tests have also been carried out successfully.

Jegdić et al. [21] examined the circumstances under which corrosion processes occurred on steel military hardware and historically significant weaponry in an outdoor setting during that time. The properties of the most significant corrosion products that occur on the steel surface have received a lot of attention. Under a layer of corrosion products, active corrosion is indicated by the development of akaganite, or β-FeOOH. Analysis was done on the circumstances that lead to the production and regeneration of sulfuric and hydrochloric

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acid when exposed to the elements. Additionally mentioned were the most widely used diagnostic techniques and desalination processes, which remove active corrosion anions. The most crucial use for the desalination process is still a NaOH solution with a specific pH. It addressed how to clean the surface before applying protective coatings and how to apply chemicals that turn rust into stable molecules. Various organic coatings and occasionally specialty waxes were applied as protective coatings to steel surfaces that had been properly prepared. The corrosion product test results from the military equipment and weapon displays at the Military Museum in Belgrade are presented in this study.

Maeng et al. [23] conducted a study on the characterization of gun-barrel steel corrosion as a function of time in a concentrated hydrochloric acid solution. The corrosion behavior of gun-barrel steel in 37.8% hydrochloric acid (HCV at room temperature) was investigated as a function of exposure time by several methods, including mass loss measurement, atomic absorption spectrometer (AAS), x-ray diffraction (XRD), scanning electron microscopy (SEM)/energy dispersive x-ray analysis (EDX), x-ray fluorescence (XRF), and x-ray absorption fine structure (XAFS). The corrosion rate showed unsteady-state behavior; however, time had no significant effect on the composition of the corrosion product. XRD analyses of this surface corrosion indicated the formation of akaganeite (beta-FeOOH). Fluorescence XAFS studies revealed that the iron coordination environment in the steel was similar to that of the body-centered cubic (bcc) iron. Surface-sensitive total electron yield (TEY) XAFS showed that the structure of the corrosion product was invariant as a function of exposure time.

De Rosset and Montgomery [24] have performed fire experiments on a small-caliber experimental gun barrel composed of a cobalt-base alloy to assess the extent of wear and erosion brought on by extended firing times. The cobalt-base alloy is a great option for use as a gun liner because of the minimal barrel material loss. Near the muzzle, an odd wear pattern was seen as a result of this loss. A believable description of the wear pattern was made possible by the removal of thermal and chemical influences.

Zhu et al. [25] conducted a study on ablation wear of the gun. They noted that artillery barrels gradually ablate from wear and tear in the shooting process, which reduced its internal ballistic performance and severely limited the artillery power and service life. The research examined the ablation and wear mechanism of a gun from three perspectives: mechanical, chemical, and heat factors. An essential reference for forecasting and prolonging the tube's life was then provided by a comparison of the current ablation wear problem analysis approach.

Banerjee et al. [26] studied the effect of gun barrel wear on the muzzle velocity of a typical artillery shell. They noted that wear in gun barrels is inevitable, and it progresses with the firing of rounds. Barrel wear directly affects the

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chamber pressures and hence the muzzle velocities (MVs) of the shells being fired. Along with the loss of MV, range, accuracy, etc., are hampered, and a barrel often has to be condemned due to wear even before it has reached the end of its fatigue life. A lot of work has been reported for understanding the nature of barrel wear, its rate of progression, and ways to minimize the rate of wear. In their work, the actual effect of barrel wear on the MV of a typical artillery shell was studied. The work shows that the loss in MV does not vary linearly with the wear. A correlation between the loss of MV and the barrel wear was attempted to be determined

Zou et al. [27] carried out research on the establishment of an erosion model of gun steel material and a study on its erosion performance. The research findings show that during the firing of the artillery, the high-temperature and high-pressure gas generated by the combustion of the gunpowder directly acts on the inner surface of the barrel. The oxidizing gas contained in the combustion products is thermochemical reacted with the gun steel material, causing the loss of surface material inside the bore. Thermochemical erosion of the bore is one of the main factors affecting the life of the barrel. In order to be able to predict the amount of erosion produced by thermochemical erosion and to study the effects of thermophysical properties of gun steel materials on erosion. Based on Fourier heat conduction theory, a theoretical model of thermochemical erosion of gun steel materials was established. The semi-closed vessel test was designed to verify the theoretical model. The calculation results are in good agreement with the test results. At the same time, this paper also researched the influence of density, thermal conductivity, and specific heat capacity of a gun steel material on material erosion based on the theoretical model. The research shows that with the increase of the density and specific heat capacity of the gun steel material, the erosion amount of the material increases correspondingly; as the thermal conductivity of the gun steel material increases, the erosion amount decreases accordingly. The research of this paper provides a certain theoretical basis for predicting the life of the barrel and provides a certain guiding significance for the research of gun steel materials.

Zou et al. [28] conducted research on the construction of a small-caliber barrel wear model and a study of the barrel wear rule. They observed that the wear of small-caliber barrels is one of the key factors affecting barrel life. Based on the Archard wear model, a high-temperature pin plate wear experiment was carried out, and wear models of chrome-plated layers and gun barrel materials were established. In addition, a finite element model of the interaction between the bullet and the barrel was established. The movement of the projectile along the barrel was simulated and analyzed, and the force distribution of the spatial geometry structure of the rifling was mastered through simulation. The wear law of the gun barrel along the axial direction was obtained based on the wear model

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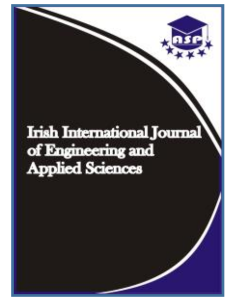

of the chrome-plated layer and gun barrel material. A position 100 mm away from the barrel breech wears very fast; this position is where the cone of the bullet is engraved in the barrel. At the position 150–350 mm away from the barrel breech, the barrel bore wears even faster. The barrel chrome layer is mainly affected by the gunpowder impact and projectile engraving, which is consistent with the actual failure of the coating. When the distance to the barrel breech is 350 m, the wear becomes stable. Through an analysis of the diameter of the barrel, it was found that, when the diameter of the barrel exceeded 12.85 mm, the barrel reached the end of its life.

Luo [29] presented a research paper on a method of plasma quenching in the gun barrel. In order to extend the service life of the barrel and improve its corrosion resistance and wear resistance, plasma quenching technology successfully processed the inner whole material. By analyzing the microstructure, hardness, and tribological characteristics, the treatment effect was determined. The findings demonstrate that when the surface hardness is raised by 725 HV and the surface abrasion resistance is improved by ten times, the plasma quenching of the barrel material can create a martensitic hardening layer on the surface. This technology offers a fresh approach to barrel longevity.

Chen et al. [30] observed that with the increasing requirements for the shooting accuracy of the sniper rifle, steel combined with excellent high-temperature strength, low-temperature toughness, and extraordinary corrosion resistance is desirable for the barrel material of the sniper rifle with high accuracy and a long lifespan. In their study, martensitic stainless steel 2Cr11Ni2Mo2WV (MPS700A) was developed by introducing Mo, W, and V into the currently used 2Cr13 steel. The 600°C tensile tests demonstrated that the ultimate tensile strength of MPS700A reached 767 MPa, which was 46.4% and 97.2% higher than those of 2Cr13 and 30SiMn2MoV, respectively. Meanwhile, the −40°C impact toughness of MPS700A reached 88 ± 4 J/cm^2, which was 20.5% higher than that of 2Cr13 and comparable to that of 30SiMn2MoV. The intralath precipitation of ellipsoidal M_2C nano carbides was observed in MPS700A after tempering, which followed a Dyson orientation relationship (OR) with the martensitic matrix. After deformation at 600°C, such a Dyson orientation relationship (OR) was maintained, and the M_2C in MPS700A exhibited higher thermal stability than the M_3C in 2Cr13, which hinders the dislocation movement and contributes to the higher strength of MPS700A at 600°C. The fine martensitic laths and homogeneously dispersed M_2C nano carbides also contributed to the higher impact toughness of MPS700A than that of 2Cr13. Additionally, the salt spray test indicated that the mass loss of MPS700A was 1.72 ± 0.24 g m^{-2} at 72 h, which was 95.6% lower than that of Cr-plated 30SiMn2MoV and comparable to that of 2Cr13. Based on these results, we demonstrate that MPS700A exhibits high strength up to 600°C,

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excellent impact toughness at low temperatures, and outstanding corrosion resistance, making it a promising gun barrel material for sniper rifles with long lifespans and high shooting accuracy.

Jin et al. [31] studied numerical research on ablation and wear of the artillery barrel based on the UMESHMOTION user-defined subroutine and reported that during the firing process, the gun barrel bears the thermal and chemical erosion of high-temperature gunpowder gas and the wear of the rotation band. The forced cone tended to the most severely worn part of the barrel, which directly affects the life of the barrel. Combined with the erosion test and wear test of gun steel materials, the research inquired into the forcing cone of a medium-caliber naval gun barrel. With the commercial finite element software ABAQUS as the platform, the advanced adaptive mesh method combined with secondary development technology was used. The method was used in the study in order to better realize the numerical simulation of the radial erosion wear of the forced projectile cone in the continuous firing environment. At the same time, the numerical simulation was compared with the actual firing test data, and a new calculation method was proposed for barrel life. In conclusion, the results of the study showed that the method can better calculate the radial erosion wear of the forced cone and provide guidance for improving the life of the gun barrel in the future.

Qi et al. [32] presented a paper titled Enhancing Artillery Barrel Wear Detection via CRNN-Based Acoustic Analysis and Domain Adaptation." They noted that the wear of artillery barrels directly impacts the accuracy and firepower of weapon systems, and precise detection of barrel wear is paramount for enhancing military capabilities. This study proposes a sound-based method for detecting artillery barrel wear, aimed at addressing the challenges of invasiveness and inefficiency in traditional methods, as well as the high cost and resource demands of modern approaches. We introduce AcouDAR, an end-to-end adaptive framework designed to elevate information extraction capabilities through the integration of time convolutional networks (TCN) and bidirectional gated recurrent units (Bi-GRU). Additionally, a domain adaptation module comprising domain alignment and domain relevance elimination modules is incorporated to mitigate the model's reliance on specific historical sound data of artillery barrels and to bolster its adaptability in real-world scenarios. Extensive experimentation validates the superior performance of the AcouDAR model in detecting artillery barrel wear.

Wang et al. [33] studied the failure mechanism of the gun barrel caused by peeling of the Cr layer and softening of the bore matrix as an essential research requirement for the prolonging of the gun barrel's lifetime. To explore the gun barrel failure mechanism, the damage characteristics of a machine gun barrel were evaluated. The results show that the failure of the gun barrel is correlated with the peeling of the Cr layer on the bore surface and the softening of the bore matrix.

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The damage of the Cr layer varies along the axial direction. From the gun tail to the muzzle, the damage mode of the Cr layer changes from peeling to wearing. The damage rate in both the tail and the muzzle is higher than that in the middle of the barrel. The matrix close to the bore surface is softened due to the high temperatures caused by stress–relief–annealing and shooting. The gun tail suffers from higher temperatures, thus being softened more seriously than the other parts. The softened matrix results in an increase in the tendency of plastic deformation of the bore surface and an increment in the bore diameter, which leads to a decrease in the firing accuracy.

Fan and Gao [34] conducted a review on erosion-reducing additive materials to extend the lifespan of gun barrels. They reported that erosion and wear of gun barrels have always been engineering problems that affect the operational effectiveness of weapons. The review briefly introduces the formation of net cracks and turtle cracks that occur on the bore surface during launch. Then, influencing factors, including thermal factors, chemical factors, and mechanical wear, are analyzed, as well as their control measures. Based on these factors, erosion-reducing additive materials (ERAMs) are comprehensively discussed. First, the early development of ERAMs, such as polyurethane, TiO_2, and talc, is reviewed. Then, current ERAMs are discussed; they include improved lining TiO.sub.2-paraffin materials, polysiloxane materials, life extension repair materials, boron nitride nanomaterials, microcapsule composite particles, multifunctional carbonates, nitrogen-rich compounds, rare earth oxides, and other metal oxides. What we've talked about so far includes the chemical makeup, the way it's prepared, the microstructure, how well it stops erosion, how completely it burns, and whether it works with propellant. In addition, the erosion-reducing mechanism and principles of formula design are discussed. Finally, comprehensive analysis shows that ERAM technology is an effective way to slow erosion and wear with high efficiency.

Wang et al. [35] investigated the effects of different gun propellant flame temperatures on the erosion inhibitor's efficacy and associated mechanisms. They stated that the ineffectiveness of erosion inhibitors is one of the major obstacles to the development of high-energy gun propellants in terms of erosion. In their study, they used a vented erosion vessel tester to examine the effects of widely varying five-gun propellant flame temperatures on the erosion-reducing effectiveness of four representative inhibitor materials (talc, TiO_2, PDMS, and paraffin). From aspects of morphologies and element compositions of eroded steel samples, as well as the pressure and heat generated by propellant burning, the relevant erosion-reducing processes and mechanisms were discussed. The results indicated that erosion inhibitors should be appropriately selected according to the type of gun propellant. The erosion of gun propellants having extremely high

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flame temperatures of 3810 K was hardly reduced using talc, TiO_2, and PDMS inhibitors, which can generate numerous solid particles aggravating the melt-wipe process. While paraffin exhibits a uniquely positive erosion-reducing efficiency for the gun propellant having a flame temperature of 3810 K, that was attributed to the mitigated melt-wipe process. The inference was further supported by the high-volume cooling gas resulting from the higher burning pressure of propellants loaded with paraffin and the excellent heat absorption capacity of paraffin tested with propellants having higher propellant flame temperature. The obtained results indicated that the factors of flame temperature of gun propellants should be taken into the design and composition optimization of an effective inhibitor. Their work could provide potential reference for the development of future novel inhibitors, which serve as high-energy gun propellants.

Wang et al. [36] conducted a study on thermodynamic coupling simulation of CrN/Cr composite coating barrel bore. They asserted that the inner coating of the artillery's barrel, which is its main component, is essential for protecting it and extending its service life. The CrN/Cr composite is a viable substitute for the already utilized Cr coating because of its advantageous qualities. They analyzed the temperature field and coupled stress field of the Cr coating barrel and the CrN/Cr composite coating barrel, respectively, during firing in their work, utilizing finite element simulation and the program Ansys Workbench. Their findings demonstrated that the CrN/Cr coating can lower the temperature and considerably lessen the stress in the coating/steel matrix contact when compared to a barrel coated with Cr. As a result, it is anticipated that the CrN/Cr coating will provide superior artillery barrel protection.

Yucel et al. [37] conducted research on the tribo-corrosion behavior of electroplating, nitro carburizing, and quench polish quench (QPQ) processes on barrel finishing. In the study, the effects of nitro carburizing, QPQ, and Cr coating on the surface properties of 32CrMoV12-10-gun barrels are discussed. Hardness measurements, pin-on-disc tests, and anodic polarization tests were performed to examine the hardness values, wear resistance, friction coefficient, and corrosion resistance. The hardness of the specimen treated with QPQ was found to be the highest. Comparing the hardness profiles, it was observed that the casing depth of the nitro carburized sample was shallower than that of the QPQ-treated sample. The pin-on-disc test revealed that the nitro carburized sample exhibited a high coefficient of friction, while the Cr-coated sample showed the lowest coefficient of friction. Analyzing the Tafel polarization curve, it was determined that the nitro carburized and QPQ-treated specimens demonstrated similar levels of corrosion resistance. However, it can be noted that the QPQ-treated specimen had a slightly lower corrosion rate.

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Zhang et al. [38] carried out a review of life prediction methods of gun barrels. They reported that in a large-caliber gun system, the high-speed, high-temperature, and high-pressure gas produced by propellant combustion can cause serious erosion damage to the inner wall of the barrel, which will lead to a continuous decline of gun performance and termination of the maximum life of the barrel. The theories and methods of gun barrel life prediction mainly involve thermodynamics, chemistry, and material and machinery science. Their paper essentially introduces the main mechanism of gun erosion and the calculation model of gun erosion, which involves the numerical solution in the internal ballistic combustion process, the heat transfer, and the erosion calculation of the gun barrel. In view of the accurate calculation of parameters such as the temperature of gunpowder gas, which can more accurately reflect the erosion of the inner wall of the gun barrel, their paper summarizes the calculation methods of the temperature, thermal physical property parameters, and convective heat transfer coefficient of high-temperature and high-pressure gas in the gun barrel. In order to determine the erosion wear quantity and study the effect of heat input on the erosion process of the inner wall of the gun, erosion experiments are usually required. At present, the common erosion experiments mainly include the measurement of erosion quantity with a semi-closed explosive device and the change of surface characteristics of a gun steel target with laser pulse heating. By analyzing the criterion of barrel life, the establishment method of the barrel life prediction model is studied deeply, and the main barrel life prediction model is introduced, which is convenient to guide engineering application.

Ningal and Orios [39] conducted the characterization of wear patterns in the gun barrel's throat region using a forensic microscope with the aim of exploring the damage sustained by the gun barrel's throat region over a long period of use, shedding light on the wear characteristics, and providing valuable insights into the long-term effects of high-pressure gas exposure during firing. To achieve the objective, the appearance of the gun barrel's throat region was characterized using forensic microscopy techniques. Visual and microscopic examinations were conducted on five different gun barrels with ten years or less of service usage and five different gun barrels with over ten years of service usage from the Philippine National Police to assess the degree of wear in the barrel's throat region. The findings revealed varying degrees of wear in the barrel throat regions. Firearms with 10 years or less of service usage exhibited moderate corrosion, narrow cracks, and minimal soot particle presence, while firearms with over 10 years of service usage showed severe corrosion, deep cracks, scattered potholes, superficial scraped surfaces, and heavy soot particle presence. The research contributes to the understanding of barrel performance, maintenance, and potential hazards associated with aging firearms, thus providing novel insights into the long-term effects of high-pressure gas exposure during firing. By examining the changes in material properties and surface roughness of the gun barrel's throat region, this study seeks to improve the understanding of how repeated firing impacts gun barrel performance and longevity. This, in turn, may aid in developing future maintenance practices to enhance firearm durability and safety.

Shuo et al. [40] carried out research progress on the life extension of barrels based on the basis of coating modification. The study showed that three relevant performance indicators of various artillery equipment have been significantly improved in recent years; however, the development of artillery is still limited by the service life of the gun barrel. Improving the firepower and extending the service life of artillery have become a hot spot for researchers. Therefore, stricter requirements are put forward on the ablation and wear resistance of the gun barrel, which has been the focus of the study on the longevity of the gun barrel. It is an effective method to improve the performance and to prolong the service life of the gun barrel by changing the material and the structure of the gun barrel. The development and recent advances in coating modification of the barrel bore are summarized in this paper, and the performance requirements and modification-related problems of the gun barrel bore are pointed out. The research progress and properties of Cr coating, Ta coating, and new ceramic coatings are introduced emphatically. Then, the advantages and disadvantages of various coatings are comparatively analyzed to also provide a reference for further research on life extension technology for gun barrels. Sides, the significant improvement in the resistance to ablation, oxidation, and wear of coatings prepared by electroplating and magnetron sputtering is introduced emphatically. The comprehensive analysis shows that the Cr coating and Ta coating prepared by electroplating and magnetron sputtering, respectively, have good resistance to ablation, oxidation, and wear, which are the current and future research hotspots. Meanwhile, the new ceramic materials also show their advantages, namely, they present properties similar to the previous two coatings. It is also the development direction of surface modification of gun barrel bore in the future.

Wu et al. [41] studied the erosion behavior of gun barrel material under azido nitramine gun propellant loading conditions. A high-energy component-based azido nitramine gun propellant was prepared by using nitrocellulose (NC), nitroglycerin (NG), and hexogen (RDX). The erosion characteristics of the propellants were determined using a vented vessel method. The erosion behavior of the gun barrel material was investigated through morphological and element analysis. And the erosion characteristics of the gun barrel material under different propellant flame temperatures and loading densities were analyzed. The results indicated

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that the erosion degree of the gun barrel material samples intensified with increasing flame temperature and loading density. Scanning electron microscope (SEM) observations showed that the surface flatness of the erosion samples decreased with higher propellant flame temperature and decreased, followed by an increase with varying propellant loading densities. The surfaces of samples under different loading conditions exhibited various typical features, including solid particles, clusters, erosion pits, erosion marks, and rod-like solids. Energy Dispersive Spectrometer (EDS) testing revealed that, compared to the pre-erosion samples, the content of C and Fe on the surface of the erosive samples decreased, while the content of elements such as Mn, Ni, and Mo increased. The content of C, O, and Cr elements increased in the erosion pits, along with the detection of V. Finally, based on the experimental results, the morphological and elemental distribution characteristics of the gun barrel material after erosion were summarized.

Dobrynin et al. [42] investigated if it was possible to determine the degree of artillery barrel wear using auditory fields of bullets. Existing techniques for assessing wear are insufficiently quick, notwithstanding the significance of understanding the current barrel status. These techniques need costly equipment or provide fairly imprecise wear predictions. In contrast to the established techniques, the article's suggested approach is quick, inexpensive, easily automated, and compatible with training firings. Studying the characteristics of the shock and muzzle waves produced by a gunshot, it was demonstrated how the parameters of these waves differed for barrels with a critical wear level and those without. One key indication of wear is initial shell velocity. It was demonstrated that a shot from a barrel with any amount of wear is equivalent to a shot from a gun of a lower caliber based on the acoustic characteristics. Real acoustic data captured during a 155 mm howitzer's firing were used in a computational experiment. Acoustic signals from gunfire were chosen for their informative qualities. They enable the automatic classification of barrels into two groups: those with wear above the critical level and those that are fit for use. Based on the temporal and spectral characteristics of the shock and muzzle waves, it was demonstrated that the support vector method (SVM) may be used to reliably categorize barrels according to the degree of wear. The auditory signals from gunfire were analyzed using a cumulative study of spectrum properties. There is a far higher chance of accurate barrel categorization with this. The findings can be applied practically in field settings to artillery units. The findings of the study make it possible to create an automated system that can quickly determine the state of the barrel. This guarantees adequate precision in determining the degree of barrel wear during battle drills.

Jain et al. [43] averred that the phenomenon of steel wearing at high temperatures is complicated. A crucial part of determining a

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component's lifespan is quantifying its wear per event. We need to examine the system under standard conditions and extend the findings due to the need for lightweight components and economics. It is impossible to measure the temperatures or pressures within a gun directly. Its correctness can only be predicted through mathematical modeling and comparison of outcomes with end-effect quantifiable factors. Wear rate cannot be accurately predicted by a single quantitative demonstration. Gun wear is specific to gun systems and cannot be predicted by a single theory. Regarding any specific gun system, gun wear is a distinct phenomenon that requires independent study. The wear of steel below 600°C has been the subject of numerous investigations. To accurately explain wear phenomena, wear tests conducted at higher temperatures, that is, above 600°C, are insufficient.

Fan and Gao [44] conducted a review on erosion-reducing additive materials to extend the lifespan of gun barrels. They said that gun barrel wear and erosion have long been engineering issues that compromise a firearm's ability to function effectively. They began their study by providing a brief overview of how net cracks and turtle cracks do originate on the bore surface during launch. After that, affecting elements, such as mechanical wear, chemical factors, and heat factors, as well as their mitigating strategies, were examined. Additive compounds that reduce erosion were thoroughly examined in light of these considerations. The early development of ERAMs, including talc, polyurethane, and TiO_2, was examined first. This was followed by a discussion of the current ERAMs, which include nitrogen-rich compounds, microcapsule composite particles, rare earth oxides, boron nitride nanomaterials, life extension repair materials, polysiloxane materials, improved lining TiO_2-paraffin materials, and other metal oxides. Chemical composition, preparation technique, micromorphology, erosion-reducing effectiveness, combustion completeness, and propellant compatibility are all covered in the discussion above. The fundamentals of formula design and the mechanism that reduces erosion are also covered. Ultimately, thorough research demonstrates that ERAM technology is a highly efficient means of reducing wear and erosion.

Liang et al. [45] conducted a study titled "Reduced Erosion and Its Erosion-Reducing Mechanism of Gun Propellants by Ctaphenylsilsesquioxane." They observed that low-erosion, high-energy propellant is one of the research directions to extend the weapon’s life and improve the weapon’s capability. In this study, energetic propellants containing different corrosion inhibitors were designed and prepared. Close bomb tests and semi-confined bomb experiments were used to investigate the burning and erosion properties of the propellants. The mechanism of erosion-reducing of titanium dioxide (titania, TiO_2), talc, and octaphenylsilsesquioxane (OPS) on the propellant was comparatively analyzed. The results show that OPS has the lowest burning

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Advance Scholars Publication
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rate and the longest burning time and a minimized loss of fire force, with the best effect of explosion heat reduction. The erosion reduction efficiency of OPS is twice that of TiO_2 and talc. The mechanism analysis shows that the decomposition and heat absorption of OPS can effectively reduce the thermal erosion effect and carbon erosion, and the gas produced can reduce the loss of chamber pressure and form a uniformly distributed nano-SiO_2 protective layer. This solid-state, high-efficiency organosilicon erosion inhibitor is an important guide for designing high-energy, low-erosion gun propellants.

3.0 CONCLUSIONS

A review report on barrel corrosion and wear issues, compiled from a number of credible research sources on their causes, consequences, current solutions, and research advancement, has been presented as integrated, pertinent material. The report shows that barrel corrosion and wear:

i. Affect all firearm types, and the propensity increases as the barrel caliber increases or as the size of the firearm increases, making artillery barrels most prone to the issues.

ii. Originate from the high-temperature and high-pressure harsh condition of the barrel due to generated chemical species that either react to form corrosive agents or interplay with the barrel surface and the projectile motion that mechanically interplays with propellant gas on the barrel surface during firing, as well as from fouling and ambient detritus such as salt, water vapor, and microscopic particles that are drawn into the barrel and build on its metal surface.

iii. Cause the projectile to experience significant friction in all of its sections, resulting in its scattering, decrease in muzzle velocity, lower chance of accuracy, increase in dispersion, unstable flight, damages to more delicate parts, driving band erosion, and barrel fatigue due to accelerated surface flaws in the combustion chamber and bore by side-body engraving of the projectile.

iv. Are critical issues that undermine the aesthetic value and serviceability of millions of firearms every year, with costs to the tune of billions of dollars every year, which arise from damages, regular cleaning and maintenance, performance defaults, storage, and research for material and production improvements against the issues?

v. Have been controlled by methods that include the use of non-erosive and non-wear-causing propellants, superior structural materials, coatings, and liners for barrels; wear-resistant and erosion-reducing additives and lubricants of organic nature in firearm propellants; keeping firearms away from moist or other inclement weather conditions; and regular and proper cleaning of barrels.

vi. Has been a critical engineering problem in attaining the required performance and durability of firearms, as attested by so many research advances from 2002 to date, many of which are not included in the review report on better ways of addressing it.

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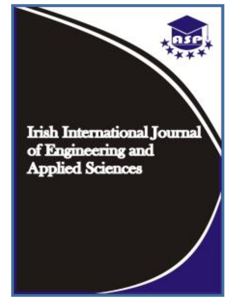

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