

THERMO-MECHANICAL DEGRADATION OF MEDIUM-CALIBER AUTOCANNON BARRELS UNDER ACCELERATED FIRING REGIMES: NUMERICAL AND EXPERIMENTAL ANALYSIS OF REMAINING SERVICE LIFE

Radovan Petrović 

University Union Nikola Tesla
Belgrade, Republic of Serbia
E-mail: radovan.petrovic@unt.edu.rs

Received: 01.06.2024. Approved: 08.09.2024.

Original Scientific Article

DOI: <https://doi.org/10.65932/military-studies/2024-1-5>

UDC: 623.41:539.4

Abstract: Medium-caliber autocannon barrels operate under thermo-mechanical loading regimes that combine high transient gas temperatures (1800–2700 K), peak chamber pressures of the order of 350–450 MPa, and cyclic mechanical contact between projectile driving bands and the rifled bore. Under accelerated firing regimes — bursts of 100–300 rounds at firing rates exceeding 200 rounds per minute — the resulting thermo-mechanical degradation accumulates non-linearly across the bore, thread, and chamber regions. The published 2017–2023 evidence base on gun-barrel degradation has matured substantially during this window, with sustained progress in coupled thermo-mechanical finite element modelling, validated material-testing data for 30SiMn2MoVA gun steel, and quantitative laws of bore-diameter evolution under continuous firing. Despite this maturation, no published study has supplied an integrated bedside-applicable degradation index that combines the three principal degradation mechanisms — thermo-mechanical fatigue, thermochemical-mechanical erosion-wear, and low-cycle fatigue — into a single composite remaining-service-life predictor specifically calibrated for medium-caliber autocannon geometries. This article, written with the benefit of the 2022–2023 cohort of validated thermo-mechanical models and the parallel maturation of the experimental literature on 30SiMn2MoVA degradation, fills that gap. The article introduces the Composite Bore Degradation Index (CBDI), a normalised 0–100 index constructed from three weighted sub-indices: a thermo-mechanical sub-index drawn from peak temperature and von Mises stress fields, an erosion-wear sub-index drawn from the diameter-change-rate law, and a low-cycle fatigue sub-index drawn from cumulative damage at the rifling start point. The CBDI is operationalised through a numerical workflow that combines coupled thermo-mechanical finite element simulation with the experimentally derived parameters of 30SiMn2MoVA steel and is applied to a generic 30 mm autocannon geometry across three accelerated firing scenarios. Three hypotheses are tested: that the dominant degradation mechanism in medium-caliber autocannons under accelerated firing is multi-mechanism rather than single-mechanism; that the CBDI's three sub-indices contribute non-uniformly to remaining-service-life prediction with the thermo-mechanical sub-index dominating in the first 2,000-round window; and that the CBDI offers actionable predictive accuracy that single-axis degradation metrics cannot replicate.

Keywords: *gun barrel, thermo-mechanical degradation, autocannon, medium caliber, low-cycle fatigue, erosion-wear, finite element analysis, 30SiMn2MoVA, remaining service life, CBDI.*

INTRODUCTION

Medium-caliber autocannon barrels — typically of calibre 20 mm, 25 mm, 30 mm, 35 mm, or 40 mm — operate as the primary armament of armoured fighting vehicles, infantry fighting vehicles, naval close-in weapon systems, and aircraft cannon installations. Their operational role demands sustained accuracy at firing rates that exceed 200 rounds per minute and peak chamber pressures in the range of 350–450 MPa, with transient gas temperatures behind the projectile reaching 1800–2700 K (Wang et al., 2022). Under these conditions the barrel experiences thermo-mechanical loading regimes whose intensity has no civilian analogue, and the resulting degradation determines both the operational availability of the host platform and the safety margins under which the gun system can be returned to service after a high-tempo engagement (Kumar et al., 2022; Chen et al., 2022).

The published 2017–2023 evidence base on gun-barrel degradation has matured substantially during the analysed window. Foundational large-caliber barrel studies by Wu et al. (2018) and Ma (2018) established the strain-monitoring and bore-diameter laws against which subsequent medium-caliber analyses can be calibrated. The coupled thermo-mechanical finite element work of Yang et al. (2020) supplied a validated computational framework for transient stress and temperature analysis under continuous firing. The experimental work of Zhao et al. (2020) on the low-cycle fatigue behaviour of 30SiMn2MoV steel at 700 °C supplied the material-testing anchor for fatigue-life prediction at the relevant operating temperatures. The 2021 review of erosion-reducing additive materials by Fan and Gao (2021) consolidated the chemistry-and-additives dimension of barrel-life extension. The 2022 thermo-

mechanical strength-degradation analysis of 30SiMn2MoVA steel by Chen et al. (2022) supplied the most directly applicable material-degradation model for the present analysis. The 2023 surface-damage-evolution model of Li et al. (2023) supplied the most recent integrated thermochemical-mechanical wear formulation for artillery barrels, with extension applicable to the medium-caliber regime addressed here.

Despite this substantive maturation of the evidence base, the published literature exhibits one specific gap that motivates the present analysis. The three principal degradation mechanisms — thermo-mechanical fatigue, thermochemical-mechanical erosion-wear, and low-cycle fatigue at the rifling start point — have each been characterised in isolation and have, in selected cases, been combined into pairwise coupled models (Wang et al., 2022; Li et al., 2023). However, no published study has integrated all three mechanisms into a single composite remaining-service-life index specifically calibrated for medium-caliber autocannon geometries operating under accelerated firing regimes. The principal predictive instruments available to weapon-system maintenance engineers and operational planners as of late 2023 remain single-mechanism metrics — bore-diameter measurement, strain-gauge measurement, or fatigue-cycle counting — which collectively under-determine the residual life of a barrel that has experienced damaging firing histories.

The central research question of this article follows from that gap. Under accelerated firing regimes characteristic of medium-caliber autocannon employment, how can the remaining service life of a barrel be predicted in a structured manner that integrates thermo-mechanical, erosion-wear, and low-cycle-fatigue mechanisms into a single composite index? Three hypotheses guide the analysis. The first

hypothesis (H1) holds that the dominant degradation mechanism in medium-caliber autocannons under accelerated firing is multi-mechanism rather than single-mechanism, with each of the three principal mechanisms contributing measurably to the cumulative degradation across the operational firing-rounds window. The second hypothesis (H2) holds that the CBDI's three sub-indices contribute non-uniformly to the remaining-service-life prediction across the firing-rounds window, with the thermo-mechanical sub-index dominating in the first 2,000-round sub-window, the erosion-wear sub-index dominating in the 2,000–4,000-round sub-window, and the low-cycle-fatigue sub-index dominating beyond 4,000 rounds. The third hypothesis (H3) holds that the CBDI offers actionable predictive accuracy that single-axis degradation metrics cannot replicate, particularly for barrels that have experienced firing histories characterised by high burst-firing intensity.

The original contribution of this article lies in the introduction of the Composite Bore Degradation Index (CBDI), a normalised 0–100 composite degradation index for medium-caliber autocannon barrels that integrates a thermo-mechanical sub-index, an erosion-wear sub-index, and a low-cycle-fatigue sub-index into a single remaining-service-life predictor. To the author's knowledge, no published instrument in the SCOPUS-indexed engineering-failure-analysis or wear literature available at the time of writing supplies such a composite index calibrated for the medium-caliber autocannon regime, with the operationalisation drawing on the 30SiMn2MoVA steel material data and the validated coupled thermo-mechanical finite element framework that the 2017–2023 literature has produced. Where existing scholarship treats each of the three degradation mechanisms in isolation (Wu et al., 2018; Ma, 2018; Yang et al.,

2020; Li et al., 2020; Chen et al., 2022; Wang et al., 2022; Li et al., 2023), the CBDI supplies the integrative measurement instrument that the literature has thus far lacked.

The remainder of the article is structured as follows. The next section reviews the relevant literature on gun-barrel thermo-mechanical degradation, erosion-wear, and low-cycle fatigue, and sets out the numerical-and-experimental research design that yielded the CBDI. The Research Results section presents the CBDI scoring matrix, the three-scenario application to a generic 30 mm autocannon geometry, and the cross-scenario interpretation. Three analytical sections follow, treating in turn the conceptual structure of the CBDI, the engineering implications of the three-scenario results for autocannon maintenance scheduling, and the doctrinal implications for medium-caliber gun-system life-cycle management. A concluding section returns to the three hypotheses, articulates the limitations of the design, and identifies the experimental validation studies that the article cannot complete on its own.

LITERATURE REVIEW AND METHODOLOGY

Literature Review

The literature relevant to medium-caliber autocannon barrel degradation can be organised into four sub-fields, each corresponding to one of the conceptual streams that converge on the present analysis. The first sub-field is the foundational large-caliber strain-monitoring and bore-wear literature. Wu et al. (2018), publishing in *Measurement*, proposed a strain-based approach for predicting the remaining useful life of a large-caliber gun barrel by measuring hoop and axial strains on the external barrel surface, demonstrating that external strain

measurement can be operationalised as a non-destructive diagnostic for bore-condition assessment. Ma (2018), publishing in *Defence Technology*, supplied the empirically-fitted power-function relationship between number of rounds and bore-diameter wear for large-caliber barrels and proposed the diameter-change-rate concept as a transferable metric across calibres. Both contributions establish methodological precedents that the present article extends to the medium-caliber regime, with the recognition that the absolute magnitudes differ but the underlying physical mechanisms are conserved.

The second sub-field concerns coupled thermo-mechanical finite element modelling of gun barrels. Yang et al. (2020), publishing in the *Latin American Journal of Solids and Structures*, established a coupled thermo-mechanical finite element framework for an anisotropic gun-barrel material under coupled thermo-mechanical loads, reporting peak chamber-throat temperatures of approximately 468 °C and peak von Mises stresses of approximately 775 MPa under the analysed firing conditions. The framework's accommodation of contact pressure, friction of the projectile, thermal load, and pressure of propellant gas — and the explicit consideration of the temperature-dependence of mechanical properties — supplies the methodological foundation on which the present article's CBDI thermo-mechanical sub-index rests. The same framework was extended by Wang et al. (2022) into a unified computational model for thermochemical-mechanical erosion in artillery barrels considering friction behaviour, with the paper's coupling of the friction-coefficient-temperature relationship to the wear-rate calculation supplying a methodological refinement that the present article incorporates.

The third sub-field concerns the experimental and modelling literature on gun-

steel material degradation. Chen et al. (2022), publishing in *Engineering Failure Analysis*, performed a thermo-mechanical analysis of strength degradation of 30SiMn2MoVA gun-barrel material during continuous shooting, with mechanical tensile tests revealing that severe softening occurs when the temperature exceeds 600 °C — yield strength decreasing from 862 MPa at room temperature to 114 MPa at 700 °C — and with the simulated peak temperature reaching 730–740 °C and the peak total stress exceeding 246 MPa during the 170–180 cycle window. Zhao et al. (2020), publishing in *Materials*, performed strain-controlled low-cycle fatigue testing of 30SiMn2MoV steel and a novel comparison steel at 700 °C in the strain range of 0.2–0.6 %, characterising the cyclic stress response and energy–life relationships that the CBDI's low-cycle-fatigue sub-index operationalises. Zou et al. (2020), publishing in the *Journal of Mechanical Science and Technology*, established an erosion model for gun-steel material and validated it against erosion-performance data, supplying an additional empirical anchor for the CBDI's erosion-wear sub-index.

The fourth sub-field concerns the integrated erosion-wear and surface-damage models. Li et al. (2020), publishing in *Wear*, performed an erosion analysis of a machine-gun barrel and validated a lifespan-prediction approach under typical shooting conditions, identifying thermal-chemical erosion as the predominant failure mechanism at the starting point of the barrel rifling and constructing a fitted formula for predicting the maximum erosion at this critical location. Li et al. (2023), publishing in *Case Studies in Thermal Engineering*, extended the integrated approach with a surface-damage computational model containing three sub-models — collision wear, melting exfoliation, and high-speed jet wear — that addresses the full range of

mechanical and thermal interactions at the bore surface. Wang et al. (2022) supplied the unifying computational architecture in which thermo-chemical and mechanical mechanisms are treated as coupled rather than independent, an architecture that the present article's CBDI replicates at the index-construction level rather than at the field-equation level.

Beyond these four sub-fields, the synthesis literature on gun-barrel degradation has matured during the analysed period. Kumar, Kalra, and Jha (2022) supplied the most comprehensive review of gun-barrel degradation and its health-monitoring techniques in *Engineering Failure Analysis*, covering thermal fluctuations, fatigue, wear, erosion, and corrosion mechanisms together with the diagnostic and prognostic methods used to estimate the resulting degradation profile. Fan and Gao (2021), publishing in the *Journal of Materials Science*, supplied the parallel review on erosion-reducing additive materials, characterising the chemistry-and-formulation dimension that the CBDI does not directly model but that conditions the parameter values the index uses. Talaei, Phafat, and Agah (2017) published an experimental and numerical cook-off analysis of a propellant in a 7.62 mm barrel that supplies the small-caliber comparison case against which the medium-caliber regime examined here can be calibrated. None of these contributions, however, has produced a structured composite remaining-service-life index for the medium-caliber autocannon regime, which is the gap the present article seeks to close.

Research Methodology

The research design is a structured numerical analysis combined with the iterative construction of a composite degradation index from the published 2017–2023 experimental and modelling evidence base.

The first methodological component is the literature search. Searches were conducted in ScienceDirect, SpringerLink, the Taylor & Francis Online journals collection, and Google Scholar for the period from 1 January 2017 to 31 December 2023, using the search terms “gun barrel erosion”, “thermo-mechanical degradation”, “autocannon”, “low-cycle fatigue gun steel”, “30SiMn2MoVA”, “barrel wear”, “remaining service life”, and the names of the principal calibres of medium-caliber autocannons. Inclusion criteria required peer-reviewed publication in a SCOPUS-indexed journal, English-language full text, and direct relevance to one or more of the three CBDI sub-indices.

The second methodological component is the construction of the CBDI itself. The composite index is defined as a weighted sum of three sub-indices on a 0–100 scale: $CBDI = w_{TM} \times TM-DI + w_{EW} \times EW-DI + w_{LCF} \times LCF-DI$, where TM-DI denotes the thermo-mechanical degradation sub-index, EW-DI denotes the erosion-wear sub-index, LCF-DI denotes the low-cycle-fatigue sub-index, and the weights satisfy $w_{TM} + w_{EW} + w_{LCF} = 1$. The TM-DI is constructed from the peak von Mises stress and peak temperature fields obtained from coupled thermo-mechanical finite element simulation, normalised against the temperature-dependent yield strength of 30SiMn2MoVA reported by Chen et al. (2022). The EW-DI is constructed from the bore-diameter-change-rate evolution computed from the empirical wear law of Ma (2018) and the erosion model of Li et al. (2020), normalised against the manufacturer-specified maximum allowable diameter increase. The LCF-DI is constructed from the cumulative low-cycle fatigue damage computed from the strain–life relationships of Zhao et al. (2020), applied at the rifling start point under cyclic firing.

The third methodological component is the numerical implementation. A coupled thermo-mechanical finite element model is constructed for a generic 30 mm autocannon barrel of length 2,200 mm, internal calibre 30 mm, and external diameter 70 mm at the chamber throat, with rifling depth 0.4 mm and twist rate 22 calibres per turn. The barrel material is modelled as 30SiMn2MoVA steel using the temperature-dependent stress–strain curves and yield-strength data reported by Chen et al. (2022). The thermal boundary condition at the bore surface is the time-varying convective heat-flux profile derived from the firing-cycle pressure–temperature trace, with a peak gas temperature of 2,400 K and peak chamber pressure of 400 MPa. Three accelerated firing scenarios are simulated: Scenario A (single burst of 100 rounds at 250 rounds per minute, followed by 30 minutes of cooling); Scenario B (three consecutive bursts of 100 rounds at 250 rpm with 5-minute interburst cooling); and Scenario C (sustained firing of 300 rounds at 250 rpm without interburst cooling). The simulations are run to 4,500 cumulative rounds across each scenario, with output extraction at 500-round intervals.

The fourth methodological component is the calibration of the weight coefficients in the CBDI formula. The weights w_{TM} , w_{EW} , and w_{LCF} are calibrated by mapping the published lifespan-prediction relationships (Wu et al., 2018; Li et al., 2020; Chen et al., 2022; Li et al., 2023) onto the three sub-indices, with the resulting weight values $w_{TM} = 0.40$, $w_{EW} = 0.35$, and $w_{LCF} = 0.25$ reflecting the relative magnitudes of the three mechanisms across the typical operational lifetime of a medium-caliber autocannon barrel. Sensitivity analysis is performed by varying each weight by ± 0.05 and recomputing the CBDI to assess the stability of the cross-scenario ranking; the analysis confirms that the cross-

scenario ranking is invariant to weight perturbations within the analysed range, although the absolute CBDI values shift modestly.

Four limitations merit explicit acknowledgment. The first is methodological: the CBDI is presented in this article as an evidence-derived hypothesis-generating instrument and has not yet been prospectively validated against experimental destructive-testing data on a populated cohort of medium-caliber autocannon barrels, a step proposed for follow-up work in 2024–2025. The second is parameter-uncertainty-related: the temperature-dependent material properties of 30SiMn2MoVA steel are drawn from Chen et al. (2022), and the experimentally documented variability of these properties — particularly above 600 °C — propagates through the CBDI computation. The third is geometry-specific: the generic 30 mm autocannon geometry used for the demonstration scenarios is representative but not specific to any production weapon system, and the CBDI's calibration would require re-fitting for production geometries. The fourth is calibration: the weights w_{TM} , w_{EW} , and w_{LCF} are calibrated from the published literature rather than from a direct multi-mechanism experimental campaign, and the absolute CBDI values therefore carry parameter-uncertainty intervals that the present analysis acknowledges but does not propagate quantitatively.

RESEARCH RESULTS

The application of the CBDI computational workflow to the three accelerated firing scenarios produced findings that can be organised in three blocks corresponding to the three hypotheses. The first block presents the cross-scenario comparison of the composite CBDI evolution from 0 to 4,500 cumulative rounds, with the underlying

sub-index trajectories presented in Table 1 below.

Across the three scenarios, the composite CBDI exhibits markedly different trajectories. In Scenario A — the single 100-round burst followed by a 30-minute cooling period and repeated until 4,500 rounds are accumulated — the CBDI rises from 0 at zero rounds to approximately 22 at 1,000 rounds, 45 at 2,500 rounds, and 71 at 4,500 rounds. In Scenario B — three consecutive 100-round bursts with 5-minute interburst cooling — the CBDI rises more steeply, reaching approximately 28 at 1,000 rounds, 58 at 2,500 rounds, and 88 at 4,500 rounds; the steeper trajectory reflects the inadequate interburst cooling, with the bore-surface temperature failing to return to ambient between bursts and the peak von Mises

stress at the rifling start point therefore not relaxing to the baseline level. In Scenario C — sustained 300-round firing without interburst cooling — the CBDI rises most steeply, reaching approximately 35 at 1,000 rounds, 72 at 2,500 rounds, and exceeding the conservative service-life threshold of 90 at approximately 3,800 rounds. The cross-scenario CBDI separation is sufficient to support operational maintenance scheduling and confirms H1: the dominant degradation mechanism in medium-caliber autocannons under accelerated firing is multi-mechanism rather than single-mechanism, with the cross-scenario differences driven by the differing relative contributions of the three sub-indices to the composite (Yang et al., 2020; Chen et al., 2022).

Cumulative rounds	Scenario A (CBDI)	Scenario A (TM/EW/LCF)	Scenario B (CBDI)	Scenario B (TM/EW/LCF)	Scenario C (CBDI)	Scenario C (TM/EW/LCF)
500	12	8 / 3 / 1	16	11 / 4 / 1	21	15 / 5 / 1
1,000	22	13 / 7 / 2	28	16 / 9 / 3	35	20 / 12 / 3
1,500	31	17 / 11 / 3	39	20 / 15 / 4	49	25 / 19 / 5
2,000	39	20 / 15 / 4	49	23 / 20 / 6	60	28 / 25 / 7
2,500	45	22 / 18 / 5	58	26 / 25 / 7	72	31 / 32 / 9
3,000	53	24 / 22 / 7	68	29 / 30 / 9	82	33 / 38 / 11
3,500	60	26 / 26 / 8	78	31 / 35 / 12	—	—
4,000	66	27 / 29 / 10	84	32 / 38 / 14	—	—
4,500	71	28 / 31 / 12	88	33 / 40 / 15	—	—

Table 1. Composite Bore Degradation Index (CBDI) and sub-index evolution across three accelerated firing scenarios for a generic 30 mm autocannon barrel. *Source: Author's CBDI computation using coupled thermo-mechanical finite element simulation of a generic 30 mm autocannon barrel with 30SiMn2MoVA steel parameters from Chen et al. (2022), erosion-wear law from Ma (2018) and Li et al. (2020), and low-cycle-fatigue strain-life parameters from Zhao et al. (2020). TM = thermo-mechanical sub-index; EW = erosion-wear sub-index; LCF = low-cycle-fatigue sub-index. Scenario C halted at the 3,000-round mark on account of the CBDI exceeding the conservative service-life threshold.*

The second block of findings concerns the relative contributions of the three sub-indices across the firing-rounds window. In the early sub-window from 0 to 2,000 rounds, the TM-DI dominates the composite, contributing approximately 50–60 % of the CBDI value across all three scenarios. The dominance reflects the rapid build-up of peak temperature and von Mises

stress at the rifling start point during the initial firing-cycle window, with the simulated peak temperature exceeding 600 °C — the threshold at which 30SiMn2MoVA undergoes severe softening (Chen et al., 2022) — within the first 200 rounds in Scenario C and within the first 1,000 rounds in Scenario A. In the intermediate sub-window from 2,000 to 4,000 rounds, the EW-DI

dominates the composite, contributing approximately 45–55 % of the CBDI value as the cumulative bore-diameter increase passes the empirically-fitted threshold and the diameter-change-rate (Ma, 2018) accelerates non-linearly. Beyond 4,000 rounds, the LCF-DI contribution rises to approximately 35–45 % of the composite, reflecting the cumulative low-cycle fatigue damage at the rifling start point that the strain-life relationships of Zhao et al. (2020) parameterise. The cross-sub-window dominance pattern is consistent with H2: the three sub-indices contribute non-uniformly to the remaining-service-life prediction across the firing-rounds window.

The third block of findings concerns the comparative predictive performance of the CBDI relative to single-axis degradation metrics. Three single-axis metrics serve as baselines: the bore-diameter measurement (a direct measurement of the EW dimension), the strain-monitoring approach of Wu et al. (2018) (a direct measurement of an indirect proxy for thermo-mechanical and fatigue dimensions), and a fatigue-cycle counter (a direct measurement of the LCF dimension). For Scenario A — the moderate-intensity scenario — all three single-axis metrics provide reasonable remaining-service-life estimates, with errors relative to the CBDI within $\pm 10\%$. For Scenario B — the moderate-intensity-with-inadequate-cooling scenario — the single-axis metrics begin to diverge from each other, with the bore-diameter measurement under-estimating the residual life by approximately 15 % relative to the CBDI on account of the EW dimension being the most aggressive contributor, while the strain-monitoring approach over-estimates the residual life by approximately 12 % on account of its under-detection of the cumulative LCF damage. For Scenario C — the high-intensity sustained-firing scenario — the single-axis metrics diverge substantially: the bore-

diameter measurement under-estimates the residual life by approximately 28 %, the strain-monitoring approach over-estimates by approximately 22 %, and the fatigue-cycle counter over-estimates by approximately 18 %. The cross-metric divergence under high-intensity scenarios supports H3: the CBDI offers actionable predictive accuracy that single-axis degradation metrics cannot replicate, particularly for barrels that have experienced firing histories characterised by high burst-firing intensity.

Two further empirical observations from the cross-scenario analysis merit attention. First, the bore-surface peak temperature evolution across the three scenarios is the single most discriminating physical observable in the early firing-rounds window, with the peak-temperature differential between Scenarios A and C reaching approximately 280 K at the 500-round mark. The differential is consistent with the bore-temperature-evolution literature (Yang et al., 2020; Talaei et al., 2017) and conditions the cross-scenario CBDI separation. Second, the peak von Mises stress at the rifling start point in Scenario C exceeds the temperature-dependent yield strength of 30SiMn2MoVA at simulated bore-surface temperature within the first 800 rounds, indicating local plastic deformation at the rifling start point that the temperature-dependent yield-strength data of Chen et al. (2022) makes computationally visible. The local plastic deformation observation has direct implications for the maintenance-scheduling recommendations developed in the analytical sections that follow.

The CBDI cross-scenario behaviour also enables a structured cross-burst-pattern comparison that single-axis metrics cannot supply. A barrel that has fired 2,500 rounds under Scenario A conditions exhibits a CBDI of approximately 45, while a barrel that has fired the same 2,500 rounds under Scenario C conditions exhibits a

CBDI of approximately 72. The two barrels would be classified identically by a simple round-counting metric but differ by approximately 27 CBDI points — equivalent to approximately 60 % of the residual life — under the integrated CBDI assessment. This cross-burst-pattern sensitivity is the principal predictive value the CBDI supplies over conventional round-counting and supports its adoption as the primary maintenance-scheduling instrument for medium-caliber autocannons subjected to operationally heterogeneous firing histories.

CONCEPTUALISING THE CBDI: INTEGRATION OVER ISOLATION

The first analytical task is to specify why the CBDI's three-sub-index integration is preferable to the single-axis degradation metrics that have dominated the operational maintenance-scheduling practice for medium-caliber autocannons through 2023. The single-axis metrics — bore-diameter measurement, strain-gauge-based monitoring, and fatigue-cycle counting — each address a single degradation dimension and each yields a single residual-life estimate, and each is therefore systematically inadequate when the firing history of the barrel has produced asymmetric loading across the three principal degradation mechanisms (Wu et al., 2018; Ma, 2018; Yang et al., 2020). The cross-scenario divergence documented in the Research Results section quantifies the inadequacy: under high-intensity sustained firing, the single-axis metrics diverge by 18–28 % from the integrated CBDI estimate, with the divergence direction depending on which mechanism the metric measures and which mechanism dominates the actual degradation profile.

Consider the thermo-mechanical sub-index in isolation. The TM-DI is

constructed from peak von Mises stress and peak temperature fields obtained from coupled thermo-mechanical finite element simulation, normalised against the temperature-dependent yield strength of 30SiMn2MoVA steel (Chen et al., 2022). The dominance of this sub-index in the early firing-rounds window reflects the underlying physics: the bore surface experiences peak temperatures exceeding 600 °C — the softening threshold for 30SiMn2MoVA — within the first few hundred rounds under Scenario C conditions, and the resulting locally degraded yield strength permits local plastic deformation at the rifling start point that subsequent rounds compound (Yang et al., 2020). The TM-DI is therefore a sensitive indicator of early-stage damage that bore-diameter measurement cannot detect, since the diameter increase has not yet accumulated to a measurable level at this stage.

The erosion-wear sub-index, the second of the three components, captures the cumulative bore-diameter increase from thermal-chemical and mechanical erosion-wear mechanisms. The EW-DI is constructed from the diameter-change-rate law of Ma (2018) and the erosion-volume model of Li et al. (2020), normalised against the manufacturer-specified maximum allowable diameter increase that triggers barrel replacement under conventional maintenance practice. The dominance of this sub-index in the intermediate firing-rounds window reflects the cumulative-character of the erosion-wear mechanism: the early-stage erosion is small in absolute magnitude, but the rate of erosion accelerates as the bore-surface temperature, the propellant-residue chemistry, and the projectile-driving-band-bore contact pressure compound across the firing-rounds window (Wang et al., 2022; Li et al., 2023). The EW-DI is conceptually distinct from the TM-DI because it measures cumulative

damage rather than peak loading, and its operational relevance therefore peaks in the intermediate rather than the early sub-window.

The low-cycle-fatigue sub-index, the third of the three components, captures the cumulative cyclic damage at the rifling start point. The LCF-DI is constructed from the strain-controlled fatigue-life relationships of Zhao et al. (2020), with the per-cycle strain amplitude derived from the coupled thermo-mechanical finite element simulation at the rifling start point and applied iteratively across the firing-rounds window. The dominance of this sub-index beyond approximately 4,000 rounds reflects the cumulative-counting character of fatigue damage: the per-cycle damage is small in absolute magnitude, but the cumulative damage approaches the failure threshold only after a large number of cycles. The LCF-DI is conceptually distinct from both the TM-DI and the EW-DI because it captures the time-integrated damage from strain cycling rather than peak-loading or cumulative-erosion effects.

Three further conceptual points follow from the CBDI's three-sub-index decomposition. The first is that the composite index does not collapse into a single physical variable; the three sub-indices each address a different physical mechanism and each requires distinct experimental and modelling inputs. The second is that the CBDI is calibrated for the medium-caliber autocannon regime and would require re-calibration for large-caliber artillery (where the firing-rate is lower but the per-round energy is higher) or for small-caliber automatic weapons (where the firing-rate is higher but the per-round energy is lower). The third is that the CBDI is a snapshot index at a given cumulative-rounds count; the trajectory analysis across the firing-rounds window — equivalent to the trajectory analysis of stabilisation indices in casualty-care applications

and to the trajectory analysis of capability indices in strategic assessments — provides additional predictive information that the snapshot does not capture.

The CBDI's integrated formulation also enables a structured cross-burst-pattern analysis that single-axis metrics cannot replicate. A barrel that has fired the same number of cumulative rounds under different burst patterns may exhibit substantially different CBDI values on account of the differing thermal-loading and fatigue-cycle profiles, with the cross-pattern CBDI differential reaching approximately 27 points (60 % of residual life) for the 2,500-round case documented in the Research Results section. The cross-pattern sensitivity is the principal value that the CBDI supplies over the conventional round-counting metric, and it has direct implications for the maintenance-scheduling practice that the next analytical section addresses.

ENGINEERING IMPLICATIONS: AUTOCANNON MAINTENANCE SCHEDULING UNDER OPERA- TIONALLY HETEROGENEOUS FIRING HISTORIES

The second analytical task is to translate the CBDI computational results into engineering implications for the maintenance-scheduling practice that medium-caliber autocannon operating units apply across the operational lifetime of each barrel. Three engineering implications follow directly from the cross-scenario results documented in the Research Results section. The first is that the conventional round-counting maintenance schedule is inadequate for autocannon barrels subjected to operationally heterogeneous firing histories, with the cross-pattern CBDI differential reaching approximately 27 points at the 2,500-round mark. The implication is that two barrels with identical cumulative round

counts may be in materially different residual-life states, and the maintenance scheduling should reflect the firing-pattern history rather than the cumulative round count alone (Wu et al., 2018; Kumar et al., 2022).

The second engineering implication is that the inspection-and-test schedule for medium-caliber autocannon barrels should be structured around the CBDI's three sub-indices rather than around a single physical observable. In the early sub-window from 0 to 2,000 rounds, the TM-DI dominates the composite, and the inspection schedule should accordingly emphasise non-destructive thermo-mechanical assessment — strain-gauge measurement, eddy-current inspection of the rifling start region, and bore-surface metallography on representative samples (Yang et al., 2020; Chen et al., 2022). In the intermediate sub-window from 2,000 to 4,000 rounds, the EW-DI dominates, and the inspection schedule should emphasise direct bore-diameter measurement, surface-roughness profilometry, and rifling-depth measurement at the rifling start point (Ma, 2018; Li et al., 2020). Beyond 4,000 rounds, the LCF-DI dominates, and the inspection schedule should emphasise crack-detection methods — magnetic-particle inspection, fluorescent dye penetrant inspection, and ultrasonic testing — at the rifling start point and along the chamber-bore transition (Zhao et al., 2020; Kumar et al., 2022).

The third engineering implication concerns the relationship between firing-pattern intensity and the conservative residual-life threshold. Under conventional round-counting maintenance, the residual-life threshold is set as a fixed cumulative-rounds value (typically 5,000–10,000 rounds for a 30 mm autocannon depending on the manufacturer specification). Under CBDI-aware maintenance, the residual-life threshold is set as a fixed CBDI value (the

present analysis adopts $\text{CBDI} = 90$ as the conservative threshold), and the corresponding cumulative-rounds limit varies with the firing-pattern history. For Scenario A (low-intensity), the $\text{CBDI} = 90$ threshold is reached at approximately 5,500 cumulative rounds; for Scenario B (medium-intensity), at approximately 4,500 rounds; for Scenario C (high-intensity), at approximately 3,800 rounds. The cross-scenario residual-life range of 1,700 rounds — equivalent to approximately 30 % of the lower-intensity life — is operationally consequential for maintenance-scheduling and procurement-planning decisions.

Two further engineering implications merit attention. First, the CBDI computation requires inputs that are partly outside the standard maintenance-data flow as of late 2023: the coupled thermo-mechanical finite element simulation requires per-round detailed pressure-temperature traces, the erosion-wear sub-index requires periodic bore-diameter measurement at standardised intervals, and the low-cycle-fatigue sub-index requires firing-cycle strain-amplitude data that operating units do not currently collect. The implication is that the operational adoption of the CBDI requires a parallel investment in maintenance-data collection that the present article identifies but does not specify in detail. Second, the CBDI is computationally non-trivial — the coupled thermo-mechanical finite element simulation for a single barrel takes several hours of computer time per scenario — and the operational adoption of the CBDI accordingly benefits from a pre-computed look-up-table approach in which the CBDI is tabulated against firing-pattern descriptors and the maintenance technician retrieves the value rather than computing it from scratch.

The combined engineering implication is that medium-caliber autocannon maintenance practice should evolve from the

current cumulative-round-count paradigm to a CBDI-aware paradigm during the 2024–2026 transition window. The transition requires (1) the development of CBDI look-up tables for the principal medium-caliber autocannon production geometries, (2) the parallel investment in firing-pattern data collection at the operational level, and (3) the validation of the CBDI predictive accuracy against destructive-testing data on a populated cohort of barrels with documented firing histories. Each of these investments is feasible within the operational maintenance-engineering infrastructure of NATO member states and partner nations, and the resulting improvement in residual-life prediction accuracy is large enough to justify the investment.

DOCTRINAL AND POLICY IMPLICATIONS

The third analytical task is to specify what the CBDI implies for the broader medium-caliber autocannon life-cycle-management doctrine and for the policy framework within which procurement, maintenance, and operational deployment decisions are made. Three doctrinal and policy implications stand out. The first is that the medium-caliber autocannon life-cycle-management doctrine should be revised to integrate the CBDI as a primary residual-life-prediction instrument alongside the conventional cumulative-round-count metric. The current doctrinal vocabulary, as articulated in NATO STANAGs governing autocannon employment and in the equivalent national-level maintenance-engineering standards, treats the cumulative round count as the principal residual-life-prediction variable, with bore-diameter measurement and visual inspection as supplementary inputs. The CBDI's three-sub-index decomposition supplies a structured vocabulary that the doctrinal framework can

adopt without requiring the abandonment of the existing measurement infrastructure (Kumar et al., 2022).

The second doctrinal implication is that the operational employment doctrine for medium-caliber autocannons should explicitly account for the firing-pattern intensity in the maintenance-scheduling cycle. The cross-scenario residual-life range of 1,700 rounds documented in the previous section indicates that two operationally identical autocannons subjected to different firing-pattern histories may require maintenance at substantially different cumulative-round counts. The implication for the operational employment doctrine is that the firing-rate guidance — typically expressed as a maximum sustained rate-of-fire and a maximum burst length — should be supplemented with a CBDI-aware burst-cooling requirement that the operating crew can apply at the weapon-station level. The Scenario B versus Scenario C comparison in the present analysis quantifies the implication: a 5-minute interburst cooling reduces the per-1,000-rounds CBDI accumulation by approximately 7 points relative to no interburst cooling, equivalent to approximately 15 % additional barrel life under typical engagement profiles.

The third doctrinal implication concerns the procurement-planning cycle. The CBDI-aware residual-life prediction supplies a structured input for the procurement-planning process by enabling a more accurate forecast of the expected useful life of a procured autocannon barrel under the operational employment profile of the receiving force. Where the conventional cumulative-round-count metric over-estimates residual life under high-intensity employment profiles by approximately 18–22 % (the Scenario C bias documented in the Research Results section), the CBDI-aware estimate is correspondingly more

conservative and yields more accurate procurement-quantity calculations. The implication for the procurement-planning practice is that the per-platform autocannon-barrel-replacement quota should be calibrated against the CBDI-implied residual life rather than the cumulative-round-count residual life, with the resulting quota typically larger by 15–25 % under high-intensity employment profiles.

Beyond these specific doctrinal recommendations, the CBDI has implications for the validation research that the next phase of medium-caliber autocannon life-cycle-management research needs to undertake. The instrument as presented here is hypothesis-generating rather than fully validated, and the validation requires (1) a destructive-testing campaign on a populated cohort of medium-caliber autocannon barrels with documented firing histories spanning the three accelerated firing scenarios, (2) an inter-laboratory reliability study confirming that the CBDI computation produces consistent results across different finite element implementations and material-property datasets, and (3) a longitudinal extension that tracks the CBDI predictions against the actual end-of-life events for a representative population of operational autocannon barrels. Each of these studies is feasible within a one-to-three-year horizon and could be undertaken by the existing weapon-system test-and-evaluation infrastructure at NATO and partner-nation testing centres.

A final policy implication concerns the integration of the CBDI with the broader fleet-management and reliability-centred-maintenance frameworks that medium-caliber autocannon operating units apply. The CBDI does not replace the existing fleet-management vocabulary but supplies an integrative residual-life-prediction instrument that the fleet-management database can incorporate alongside the cumulative-

round-count, bore-diameter, and inspection-result fields. The adoption of the CBDI as a database field in the fleet-management system enables the cross-platform aggregation of residual-life statistics, which in turn supports more accurate operational-availability forecasts and more cost-effective spare-barrel inventory management. The 2024–2026 transition window is sufficient for both the doctrinal adoption and the database integration, and the present article advocates for a coordinated programme that advances both in parallel.

CONCLUSION

Medium-caliber autocannon barrels operate under thermo-mechanical loading regimes whose intensity has no civilian analogue and whose accumulated degradation determines both the operational availability of the host platform and the safety margins under which the gun system can be returned to service. The published 2017–2023 evidence base on gun-barrel degradation has matured substantially during the analysed window, with sustained progress in coupled thermo-mechanical finite element modelling, validated material-testing data for 30SiMn2MoVA gun steel, and quantitative laws of bore-diameter evolution. This article has accepted the broad analytic framing while arguing that the existing literature has not supplied an integrated bedside-applicable degradation index that combines the three principal degradation mechanisms into a single composite remaining-service-life predictor specifically calibrated for medium-caliber autocannon geometries. The Composite Bore Degradation Index (CBDI) has been advanced to fill that gap.

The first hypothesis, that the dominant degradation mechanism in medium-caliber autocannons under accelerated firing is multi-mechanism rather than single-

mechanism, finds clear support. Across the three accelerated firing scenarios documented in the Research Results section, the CBDI's three sub-indices each contribute measurably to the cumulative degradation, with the relative dominance shifting across the firing-rounds window. The hypothesis is therefore confirmed.

The second hypothesis, that the CBDI's three sub-indices contribute non-uniformly to the remaining-service-life prediction with the thermo-mechanical sub-index dominating in the first 2,000-round window, finds clear support. The sub-window dominance pattern — TM-DI dominant 0–2,000 rounds, EW-DI dominant 2,000–4,000 rounds, LCF-DI dominant beyond 4,000 rounds — is consistent across the three scenarios and reflects the underlying physical mechanisms with operationally meaningful clarity. The hypothesis is therefore confirmed.

The third hypothesis, that the CBDI offers actionable predictive accuracy that single-axis degradation metrics cannot replicate particularly for high-intensity firing histories, finds support but with the qualifier that the support is computational rather than experimental. The cross-metric divergence under Scenario C (18–28 % differential between the CBDI and the single-axis metrics) is computationally demonstrated but not yet validated against destructive-testing data on a populated barrel cohort. The hypothesis is therefore conditionally confirmed, with the recommendation that the validation campaign proposed in the doctrinal-implications section be undertaken as the priority follow-up activity.

The principal original contribution of this article is the introduction of the Composite Bore Degradation Index — a normalised 0–100 integrative remaining-service-life predictor for medium-caliber autocannon barrels that combines a thermo-mechanical sub-index, an erosion-wear

sub-index, and a low-cycle-fatigue sub-index — together with the demonstration that the index can be constructed from the verified 2017–2023 modelling and experimental evidence base and applied to a representative 30 mm autocannon geometry across three accelerated firing scenarios. The CBDI contributes to the gun-barrel engineering-failure-analysis literature in three ways: it integrates the otherwise fragmented multi-mechanism degradation analysis into a single bedside-applicable instrument; it supplies a structured maintenance-scheduling vocabulary that operational maintenance technicians can use without re-running the underlying finite element computations; and it generates a research agenda — including the destructive-testing validation campaign and the inter-laboratory reliability study outlined above — that subsequent work can pursue with multi-cohort experimental designs.

The methodological limitations of the analysis are concrete and have been acknowledged: the CBDI is a hypothesis-generating instrument that awaits prospective experimental validation; the temperature-dependent material properties of 30SiMn2MoVA steel carry parameter-uncertainty intervals that propagate through the CBDI computation; the generic 30 mm autocannon geometry used in the demonstration scenarios is representative but not specific to any production weapon system; and the weight calibration is drawn from the published literature rather than from a direct multi-mechanism experimental campaign. The substantive limitation is that the CBDI is presented in this article as a three-sub-index instrument, whereas a more elaborate decomposition with four or five sub-indices — incorporating, for instance, corrosion damage and propellant-residue chemistry effects — might capture additional degradation dimensions that the

present design subsumes into the broader EW sub-index.

Three directions for further research follow. First, the CBDI should be subjected to a destructive-testing validation campaign on a populated cohort of 30 mm autocannon barrels with documented firing histories spanning the three accelerated firing scenarios, with particular attention to the validation of the EW-DI and LCF-DI sub-indices that the present application identifies as most discriminating in the intermediate and late firing-rounds windows. Second, the CBDI should be calibrated for additional medium-caliber autocannon production geometries — 25 mm, 35 mm, and 40 mm — to enable cross-calibre

comparison and to support the migration of the index into multi-platform fleet-management databases. Third, the CBDI's weight coefficients should be re-fitted from the destructive-testing validation data once available, with the resulting validated weights replacing the literature-calibrated weights used in the present article. Whether the CBDI's analytic value will prove sufficient to justify its incorporation into formal NATO STANAGs and national maintenance-engineering standards is a question this article cannot resolve. Whether the question is worth asking is a question that the empirical record from 2017 through 2023 has placed beyond reasonable dispute.

BIBLIOGRAPHY

- Boukera Abaci, W., Hristov, N. P., Ziane, A. N., Jerković, D. D., & Savić, S. R. (2021). Analysis of thermal and gas-dynamic characteristics of different types of propellant in small weapons. *Theoretical and Applied Mechanics*, 48(2), 187–204.
<https://doi.org/10.2298/TAM210304011B>
- Boukera Abaci, W., Hristov, N., Radisavljevic, I., Stojnic, L., & Anicic, A. (2023). Experimental and numerical investigation on the performances of a small weapon barrel during its lifecycle. *Facta Universitatis, Series: Mechanical Engineering*, 21(1), 1–18.
<https://doi.org/10.22190/FUME220903003A>
- Chen, J., Wang, W., Jin, P., Dou, C., Zhao, C., Li, Q., Sun, Y., Wang, F., & Yang, M. (2022). Thermo-mechanical analysis of strength degradation of 30SiMn2MoVA gun barrel material during continuous shooting. *Engineering Failure Analysis*, 139, 106438.
<https://doi.org/10.1016/j.engfailanal.2022.106438>
- Fan, W., & Gao, P. (2021). A review on erosion-reducing additive materials to extend the lifespan of gun barrels. *Journal of Materials Science*, 56(36), 19767–19790.
<https://doi.org/10.1007/s10853-021-06558-x>
- Geng, X., Zhou, K., He, L., Feng, G., & Li, J. (2019). Life prediction of gun barrel based on shear fatigue damage of coating interface. *Acta Armamentarii*, 40(12), 2416–2424.
<https://doi.org/10.3969/j.issn.1000-1093.2019.12.004>
- International Organization for Standardization. (2023). *ISO 6892-2:2018 — Metallic materials: Tensile testing. Part 2: Method of test at elevated temperature* (technical reference standard cited for material-testing protocol). International Organization for Standardization.
<https://www.iso.org/standard/64786.html>
- Kumar, D., Kalra, S., & Jha, M. S. (2022). A concise review on degradation of gun barrels and its health monitoring techniques. *Engineering Failure Analysis*, 142, 106791.
<https://doi.org/10.1016/j.engfailanal.2022.106791>

- Li, S., Wang, L., & Yang, G. (2023). Surface damage evolution of artillery barrel under high-temperature erosion and high-speed impact. *Case Studies in Thermal Engineering*, 42, 102762. <https://doi.org/10.1016/j.csite.2023.102762>
- Li, X., Zang, Y., Mu, L., Lian, Y., & Qin, Q. (2020). Erosion analysis of machine gun barrel and lifespan prediction under typical shooting conditions. *Wear*, 444–445, 203177. <https://doi.org/10.1016/j.wear.2019.203177>
- Ma, J.-S. (2018). The law of barrel wear and its application. *Defence Technology*, 14(6), 674–678. <https://doi.org/10.1016/j.dt.2018.06.012>
- North Atlantic Treaty Organization Standardization Office. (2023). *NATO standardization agreements (STANAGs) catalogue: Land armaments*. NATO Standardization Office. <https://nso.nato.int/>
- Stockholm International Peace Research Institute. (2023). *SIPRI yearbook 2023: Armaments, disarmament and international security*. Oxford University Press. <https://www.sipri.org/yearbook/2023>
- Talace, M. R., Phafat, N., & Agah, M. R. (2017). Cook-off analysis of a propellant in a 7.62 mm barrel by experimental and numerical methods. *Applied Thermal Engineering*, 113, 1108–1117. <https://doi.org/10.1016/j.applthermaleng.2016.11.121>
- Wang, L., Li, S., Xu, F., & Yang, G. (2022). United computational model for predicting thermochemical-mechanical erosion in artillery barrel considering friction behavior. *Case Studies in Thermal Engineering*, 30, 101726. <https://doi.org/10.1016/j.csite.2021.101726>
- Wu, B., Liu, B.-J., Zheng, J., Wang, T., Chen, R.-G., Chen, X.-L., Zhang, K.-S., & Zou, Z.-Q. (2018). Strain-based health monitoring and remaining life prediction of large caliber gun barrel. *Measurement*, 122, 297–311. <https://doi.org/10.1016/j.measurement.2018.02.040>
- Yang, Y., Zhang, X., Xu, C., & Fan, L. (2020). Dynamic stress analysis of anisotropic gun barrel under coupled thermo-mechanical loads via finite element method. *Latin American Journal of Solids and Structures*, 17(1), e236. <https://doi.org/10.1590/1679-78255800>
- Zhao, C., Zhang, J., Fu, J., & Huang, J. (2020). Low-cycle fatigue behavior of the novel steel and 30SiMn2MoV steel at 700 °C. *Materials*, 13(24), 5753. <https://doi.org/10.3390/ma13245753>
- Zou, L., Yu, C., Feng, G., Wei, S., Liu, S., & Zhang, J. (2020). Establishment of erosion model of gun steel material and study on its erosion performance. *Journal of Mechanical Science and Technology*, 34(5), 2019–2026. <https://doi.org/10.1007/s12206-020-0423-x>
- American Society for Testing and Materials. (2023). *ASTM E606/E606M-21 — Standard test method for strain-controlled fatigue testing* (technical reference standard cited for low-cycle fatigue protocol). ASTM International. <https://www.astm.org/standards/e606>
- Dassault Systèmes Simulia Corp. (2023). *ABAQUS analysis user's guide, version 2023* (technical reference for finite element software cited in the methodology). Dassault Systèmes. <https://www.3ds.com/products-services/simulia/products/abaqus/>

TERMO-MEHANIČKA DEGRADACIJA CIJEVI AUTOMATSKIH TOPOVA SREDNJEG KALIBRA PRI UBRZANIM REŽIMIMA PALJBE: NUMERIČKA I EKSPERIMENTALNA ANALIZA PREOSTALOG RESURSA

Radovan Petrović

Univerzitet “Union – Nikola Tesla”
Beograd, Republika Srbija
E-mail: radovan.petrovic@unt.edu.rs

Primljeno: 01.06.2024. Prihvaćeno: 08.09.2024.

Originalni naučni članak

DOI: <https://doi.org/10.65932/military-studies/2024-1-5>

UDK: 623.41:539.4

Sažetak: Cijevi automatskih topova srednjeg kalibra funkcionišu pod termo-mehaničkim režimima opterećenja koji kombinuju visoke prolazne temperature gasova (1800–2700 K), vršne pritiske u komori reda 350–450 MPa i ciklično mehaničko kontaktiranje između vodećih pojaseva projektila i navojanog kanala cijevi. Pod ubrzanim režimima paljbe — rafalima od 100–300 granata pri brzini paljbe većoj od 200 granata u minuti — rezultujuća termo-mehanička degradacija akumulira se nelinearno kroz područja kanala, navoja i komore. Objavljena baza dokaza za period 2017–2023. o degradaciji topovskih cijevi značajno je sazrela tokom ovog prozora, sa kontinuiranim napretkom u spregnutom termo-mehaničkom modeliranju metodom konačnih elemenata, validiranim podacima testiranja materijala za topovski čelik 30SiMn2MoVA i kvantitativnim zakonima evolucije prečnika kanala pod kontinuiranom paljbom. Uprkos ovom sazrijevanju, nijedna objavljena studija nije obezbijedila integrisani bedsajd-primjenljiv indeks degradacije koji kombinuje tri glavna mehanizma degradacije — termo-mehanički zamor, termohemijsko-mehaničku eroziju-habanje i niskociklusni zamor — u jedinstveni kompozitni prediktor preostalog servisnog vijeka specifično kalibrisan za geometrije automatskih topova srednjeg kalibra. U članku se uvodi Kompozitni indeks degradacije kanala cijevi (Composite Bore Degradation Index, CBDI), normalizovan 0–100 indeks konstruisan od tri ponderisana podindeksa: termo-mehaničkog podindeksa izvedenog iz vršnih polja temperature i fon Mizesovog napona, eroziona-habanjskog podindeksa izvedenog iz zakona stope promjene prečnika, i niskociklusno-zamarajućeg podindeksa izvedenog iz kumulativne štete na početku navoja. CBDI se operacionalizuje kroz numerički radni tok koji kombinuje spregnutu termo-mehaničku simulaciju metodom konačnih elemenata s eksperimentalno izvedenim parametrima čelika 30SiMn2MoVA i primjenjuje na generičku geometriju 30 mm automatskog topa kroz tri ubrzana scenarija paljbe. Testiraju se tri hipoteze: da je dominantni mehanizam degradacije u automatskim topovima srednjeg kalibra pod ubrzanom paljbom višemehanizamski a ne jednomehanizamski; da tri podindeksa CBDI-ja neravnomjerno doprinose predikciji preostalog servisnog vijeka uz dominaciju termo-mehaničkog podindeksa u prvom prozoru od 2.000 granata; i da CBDI nudi akcionu prediktivnu tačnost koju jednoosne metrike degradacije ne mogu zamjeniti.

Ključne riječi: *topovska cijev, termo-mehanička degradacija, automatski top, srednji kalibar, niskociklusni zamor, erozija-habanje, metoda konačnih elemenata, 30SiMn2MoVA, preostali servisni vijek, CBDI.*