Engineering and Technology Journal e-ISSN: 2456-3358
Volume 11 Issue 01 January-2026, Page No.-8669-8679
DOI: 10.47191/etj/v11i01.32, I.F. – 8.482

Transient Heat Transfer in a Chromium-Coated 7.62 Mm Gun Barrel Under Rapid Firing Conditions

Trung Duc Vuong[1], Dinh Thi Nguyen[2], Van Dung Nguyen[1], Van Dang Hoang[1], Van Hung Nguyen[1]
[1]Faculty of Special Equipment, Le Quy Don Technical University, 236 Hoang Quoc Viet, Nghia Do, Ha Noi, 100000, Viet Nam
[2] Master's student, Faculty of Special Equipment, Le Quy Don Technical University, Ha Noi, 100000, Viet Nam

ABSTRACT: This paper presents a numerical investigation of transient heat transfer in a chromium-coated 7.62 mm gun barrel under rapid firing conditions. A two-dimensional axisymmetric finite-element model is developed using COMSOL Multiphysics to simulate the unsteady thermal response of the barrel during successive firing cycles. The barrel wall is modelled as a multilayer structure comprising a steel substrate and an inner chromium coating, with their thermal properties assumed to be temperature-dependent. Transient thermal loads are imposed on the inner surface of the barrel in the form of time-dependent heat fluxes representing the interaction between high-temperature propellant gases and the bore wall. In contrast, convective heat transfer is applied at the outer surface. The numerical results provide detailed distributions of temperature in both radial and axial directions, as well as the temporal evolution of the inner wall temperature during single-shot and multi-shot firing sequences. The influence of rapid firing on thermal accumulation within the chromium coating and the steel substrate is analysed. The study highlights the role of the chromium-coated layer in modifying heat transfer through the barrel wall and its impact on peak temperature levels under repeated firing conditions. The proposed modelling approach offers a useful tool for evaluating thermal behaviour and supporting the thermal design and durability assessment of small-calibre gun barrels.

KEYWORDS: Transient heat transfer; Gun barrel; Chromium coating; Rapid firing; Finite element method; COMSOL Multiphysics

I. INTRODUCTION

Research on heat transfer and temperature control in gun barrels has long been recognised as a critical issue, as thermal effects directly influence barrel service life, firing accuracy, and operational safety. During firing, the interaction between high-temperature propellant gases and the inner barrel surface generates intense transient thermal loads, resulting in steep temperature gradients, thermal stresses, and accelerated material degradation. Consequently, the thermal behaviour of gun barrels has attracted sustained attention from the research community over the past decades.

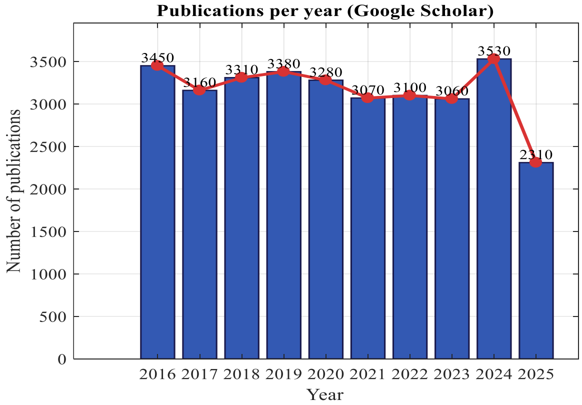


Fig. 1. Annual number of publications indexed by Google Scholar (2016–2025) about Heat transfer in gun barrels

A bibliometric overview indicates that research activity in this field has remained consistently high. According to Google Scholar statistics, approximately 3000 publications on the keyword "heat transfer in gun barrel" have been reported annually from 2016 to 2025 (Figure 1). This substantial volume of research reflects both the complexity of the problem and its practical importance in weapon system design and operation.

From a methodological perspective, a variety of numerical and analytical approaches have been employed to investigate heat transfer phenomena in gun barrels. Among them, the finite element method (FEM) has been the most widely adopted technique due to its flexibility in handling complex geometries, multilayer structures, and transient thermal loads [2], [3], [5], [7], [10], [11], [13], [14], [19]. FEM-based studies commonly focus on resolving the temporal and spatial temperature distributions within the barrel wall and assessing the influence of firing conditions on peak temperatures. In parallel, the finite difference method has been applied in several studies to solve simplified transient heat conduction problems, offering computational efficiency for parametric analyses [6], [9], [12], [17]. Mathematical modelling approaches, often based on one-dimensional or quasi-one-dimensional formulations, have also been developed to describe the thermal response of gun barrels under repetitive firing, providing valuable physical insight and analytical tractability [1], [8], [18], [21]. Other numerical techniques, such as the finite volume method [4] and inverse methods for thermal parameter identification [16], have been explored to address specific modelling or experimental challenges.

In terms of research objectives, most existing studies aim to analyse temperature distributions within the barrel under different firing conditions, including single-shot, burst, and sustained firing. These investigations are essential for understanding thermal accumulation effects and identifying critical regions prone to overheating. Accordingly, the scope of research has extended across a wide range of calibres, encompassing small-calibre barrels such as 5.56 mm [22], medium-calibre systems around 35 mm [3], [11], [14], and large-calibre artillery barrels of 120 mm [8] and 155 mm [6], [12]. Notably, a significant portion of the literature has concentrated on medium- and large-calibre barrels, where thermal loads are severe, and barrel replacement costs are high.

To support numerical investigations, various commercial simulation tools have been employed, including COMSOL Multiphysics [3], [7], [10], [13], PRODAS [7], and ANSYS [18], [19], [20]. These platforms enable the coupling of heat transfer with other physical phenomena and facilitate parametric studies under realistic firing conditions. Based on numerical and experimental findings, numerous thermal management strategies have been proposed and evaluated, including active liquid-cooling systems, innovative external fin designs, and the incorporation of cooling channels within the barrel wall [11], [14], [18], [19], [20]. These approaches aim to reduce peak temperatures and mitigate thermal damage during sustained firing.

Although chromium coatings play an important role in surface protection and heat transfer regulation, the influence of coating thickness on the temperature field of small-calibre gun barrels has not yet been clearly quantified in the published literature. In particular, systematic investigations of the transient thermal behaviour of chromium-coated small-calibre barrels under rapid-firing conditions remain limited.

Therefore, the present study focuses on investigating transient heat transfer and the effect of chromium coating thickness on the thermal response of a 7.62 mm machine-gun barrel with a length of 605 mm, manufactured from 30XH2MΦA steel. A two-dimensional axisymmetric finite-element model is developed using COMSOL Multiphysics to simulate the transient heat transfer process through the multilayer barrel wall. The simulation results enable a quantitative evaluation of temperature evolution and distribution across the barrel wall thickness after single-shot and ten-shot firing sequences. These results provide a scientific basis for assessing barrel thermal performance, enhancing barrel service life, and optimising the design of chromium coatings for small-calibre gun barrels.

II. MODEL DEVELOPMENT AND SOLUTION METHODOLOGY

During firing, a 7.62 mm machine-gun barrel is subjected to high-temperature and high-pressure propellant gases acting on the bore surface for only a few milliseconds. These severe thermo-mechanical conditions induce thermal deformation, phase transformation, and the formation of crack networks on the inner surface of the barrel, leading to a significant reduction in barrel service life. For 30XH2MΦA steel, the phase transformation from ferrite to austenite occurs in the approximate temperature range of 740 -750 °C, resulting in material contraction and weakening the protective chromium layer, eventually leading to coating delamination after repeated firing cycles.

In this study, a gun barrel with a total length of 605 mm is divided into 25 axial segments, denoted as S1 to S25 (Fig. 2). The first segment, S1, starts from the location where the projectile driving band begins to engage the rifling, which is 55 mm from the breech end. Dividing the barrel into 25 segments provides a more accurate representation of thermal behaviour along its length. In each axial segment, a time-dependent convective heat transfer coefficient, hi(t), is assigned to account for the spatial variation of heat transfer between the propellant gases and the bore surface. The detailed parameters of each segment are summarised in Table 1.

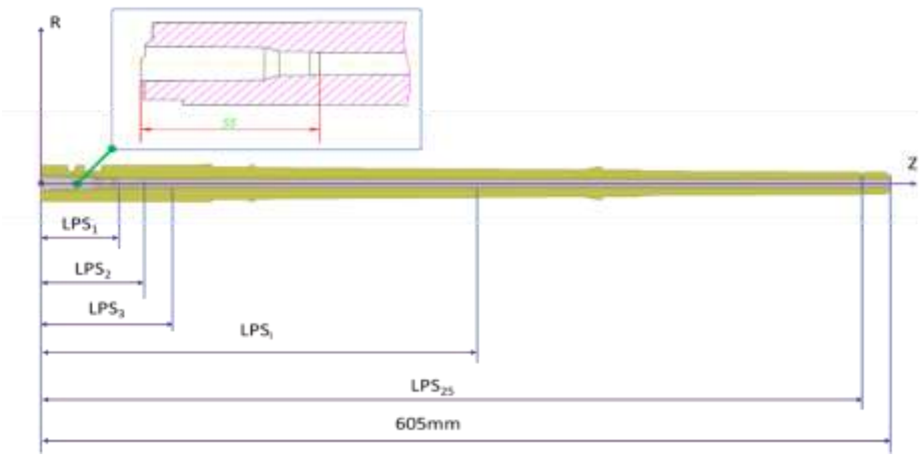


Fig. 2. Axial segmentation of the 7.62 mm gun barrel for transient heat transfer modelling

Table 1. Parameters of the axial barrel segments used in the heat transfer model

Segment index	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
LPS_i [mm]	55	77	99	121	143	165	187	209	231
$R_{out,Psi}$ [mm]	15	15	15	16.25	13.45	12.89	12.7	12.515	12.325
z_i [mm]	66	88	110	132	154	176	198	220	242
Segment index	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**
PS_i [mm]	253	275	297	319	341	363	385	407	429
$R_{out,Psi}$ [mm]	12.135	11.95	11.76	11.575	11.385	11.195	11.01	11.03	9.985
z_i [mm]	264	286	308	330	352	374	396	418	440
Segment index	**S19**	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**		
PS_i [mm]	451	473	495	517	539	561	583		
$R_{out,Psi}$ [mm]	9.96	9.73	9.605	9.48	9.355	9.28	9.28		
z_i [mm]	462	484	506	528	550	572	594		
PS_{26} [mm]	605								

In this context, LPS_i denotes the distance from the breech end of the barrel to the cross-section PS_i; Z_i represents the distance from the midpoint of segment SiS_iSi to the breech end; and $R_{out,Psi}$ is the outer radius of the barrel at the cross-section S_i.

In the radial direction, the heat transfer model is represented as a two-layer structure consisting of a base metal layer (30XH2MΦA steel) and an inner chromium coating layer (Fig. 3). The model considered in this study is two-dimensional and axisymmetric. Thermal contact resistance at the interface between the chromium coating and the steel substrate is neglected.

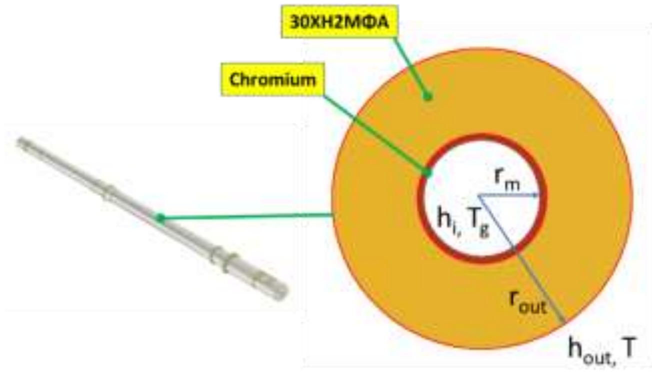


Fig. 3. Two-dimensional axisymmetric heat transfer model of the chromium-coated gun barrel

Accordingly, the equations governing transient heat conduction in the two-layer barrel model include:

Heat conduction equation for the chromium coating layer:

$$\left.\begin{aligned}&\rho_{Cr}(T).c_{Cr}(T).\frac{\partial T}{\partial t}=\frac{1}{r}.\frac{\partial}{\partial t}\left(k_{Cr}(\mathrm{T}).r.\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(k_{Cr}(\mathrm{T}).\frac{\partial T}{\partial z}\right)\\&r_{in}<r<r_m,0<z<l_m,t>0\end{aligned}\right\}\quad(1)$$

Boundary condition at the inner surface of the chromium coating:

$$\left.\begin{aligned}&-k_{Cr}(\mathrm{T}).\frac{\partial T}{\partial r}=\dot{q}_i(\mathrm{t},r=r_{in},z)\\&\dot{q}_i(\mathrm{t},r=r_{in},z)=h_i(t).(T(t,r_{in},z)-T_g(t,r_{in},z)\end{aligned}\right\}\quad(2)$$

Interfacial condition between the chromium coating and the steel substrate:

$$k_{Cr}(\mathrm{T}).\frac{\partial T}{\partial r}=-k_S(\mathrm{T}).\frac{\partial T}{\partial r},T_{Cr}=T_S,r=r_m \quad(3)$$

Heat conduction equation for the steel layer

$$\left.\begin{aligned}&\rho_S(T).c_S(T).\frac{\partial T}{\partial t}=\frac{1}{r}.\frac{\partial}{\partial t}\left(k_S(\mathrm{T}).r.\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(k_S(\mathrm{T}).\frac{\partial T}{\partial z}\right)\\&r_m<r<r_{out},0<z<l_m,t>0\end{aligned}\right\}\quad(4)$$

Boundary condition at the outer surface of the barrel:

$$-k_S(\mathrm{T}).\frac{\partial T}{\partial r}=\dot{q}_{out} \quad(5)$$

$$\dot{q}_{out} = h_{out}.(T(t,r_{out},z)-T_0)$$

Initial condition

$T(0,r,z) = T_0$, $r_{in} < r < r_{out}$, $0 < z < l_m$ (6)

where T_g and $h_i(t)$ denote the propellant gas temperature and the convective heat transfer coefficient, respectively, which are determined by solving the internal ballistics problem; r_{in} is the inner radius of the barrel; r_{out} is the outer radius of the barrel (i.e., the total barrel wall thickness), which varies along the axial coordinate z (Fig. 3); r_m is the outer radius of the chromium coating layer (Fig. 4); q represents the heat flux density; and i=1,…,25 where i is the index of the axial segments from S1 to S25.

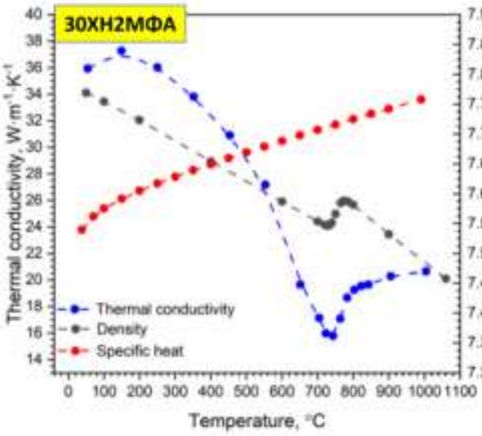


Fig. 4. Thermophysical properties of 30XH2MΦA steel [22]

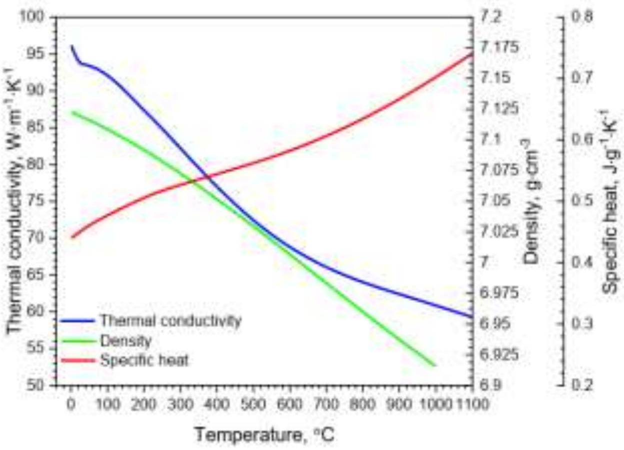


Fig. 5. Thermophysical properties of Chromium [23]

In the model and governing equations presented above, the thermophysical properties, including the thermal conductivity k(T), specific heat capacity c(T), and density ρ(T), are defined for each material and are considered temperature-dependent during firing. The temperature dependence of the thermophysical properties of 30XH2MΦA steel (ks, cs, ρs) and Chromium (kCr, cCr, ρCr) is illustrated in Figs. 4 and 5. For 30XH2MΦA steel, a ferrite-to-austenite phase transformation occurs at temperatures of approximately 740 °C, which leads to material contraction. The energy associated with this phase transformation is accounted for through the temperature dependence of the material density and thermal conductivity. At the same time, its effect on the specific heat capacity is neglected.

In this study, the initial temperature of the gun barrel is set to T_0 = 20°C. At the outer surface of the barrel, a third-type (Robin) boundary condition is applied in the form.

$\dot{q} = h_{out}.(T_{(t,rout,z)} - T_0)$

where h_{out} is the convective heat transfer coefficient at the outer surface. It is assumed that the convective heat transfer coefficient remains constant during the firing process, with a value of h_{out} = 9.2 W/(m²·K).

All calculations are performed using the finite element method (FEM) with the aid of COMSOL Multiphysics. The duration of a single firing event is taken as 0.1 s. Numerical simulations of the heat transfer process in the 7.62 mm machine-gun barrel are carried out for both a single shot and a sequence of ten successive shots. To improve simulation accuracy, mesh refinement is applied at the interfaces between axial segments and in regions near the inner surface of the barrel. Along the axial direction, the mesh is refined exponentially at the boundaries between adjacent segments (Fig. 6, illustrating the interface between segments S8 and S9). This refinement is necessary because each segment is assigned a different time-dependent convective heat transfer coefficient $h_i(t)$.

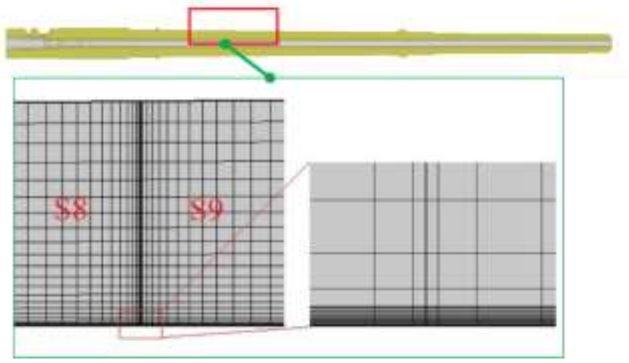


Fig. 6. Mesh refinement at the interface between axial segments S8 and S9 of the gun barrel

In addition, in the radial direction, the finite element mesh is strongly refined near the inner surface of the barrel in order to accurately capture the steep temperature gradients that develop in this region. The initial condition for each subsequent firing event is taken from the final temperature field of the previous shot, i.e.,

T(tj, r, z)=T(0, r, z),

where j denotes the firing index. The boundary conditions remain unchanged throughout the simulation. The overall simulation workflow implemented in COMSOL Multiphysics is illustrated in Fig. 7.

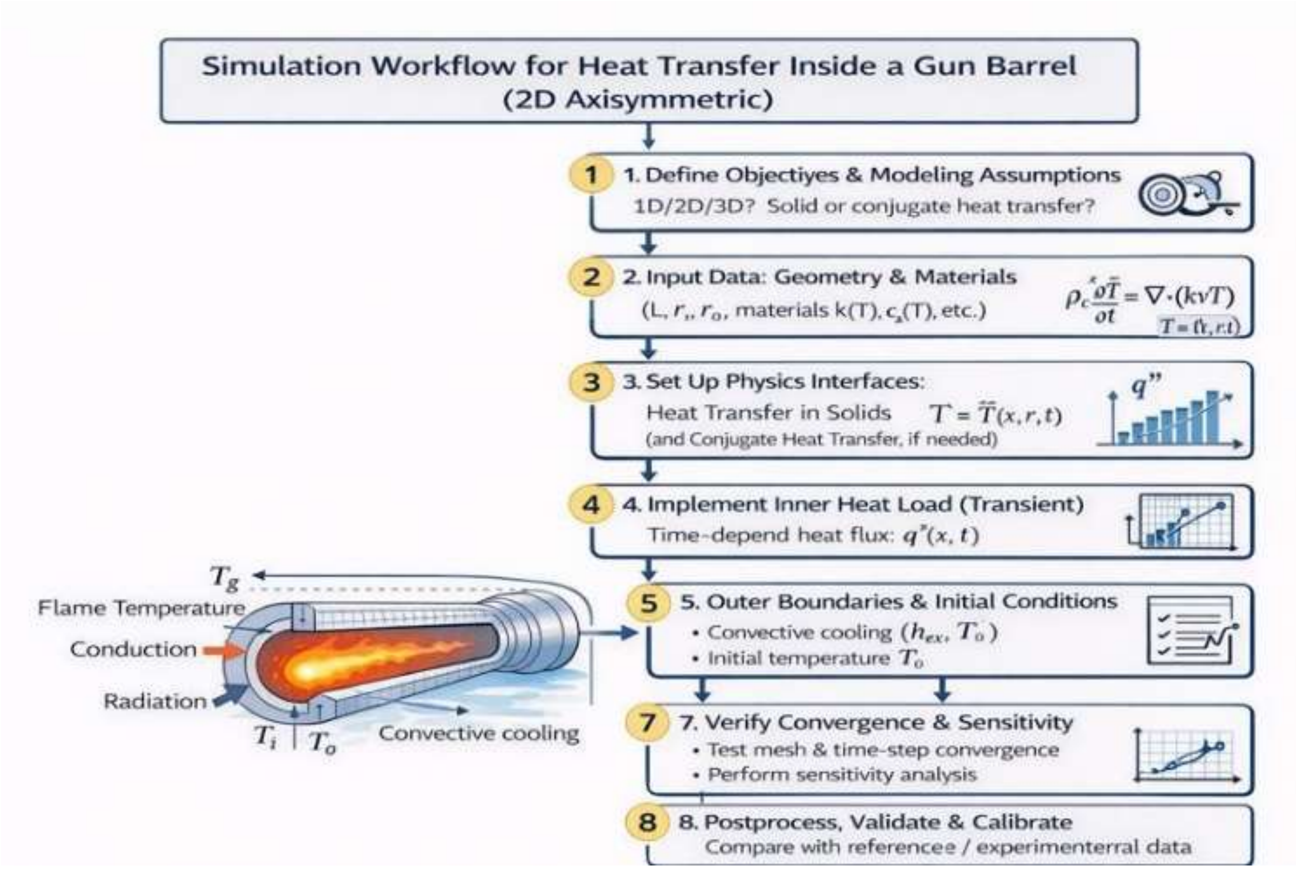


Fig. 7. Workflow of the numerical simulation for transient heat transfer analysis

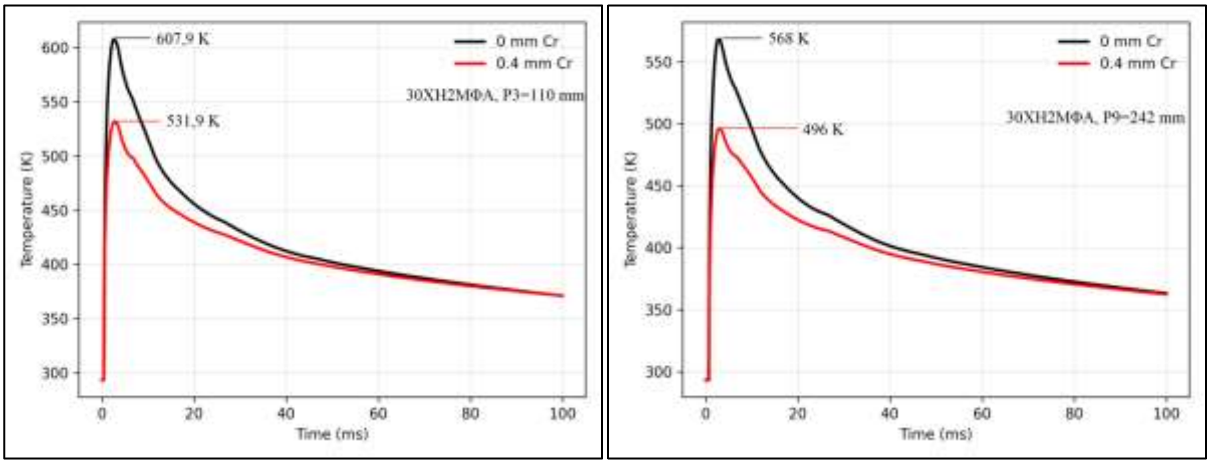
The calculations are performed for 25 axial barrel segments, denoted as S1 to S25, and the results are presented at the axial coordinate z corresponding to the midpoint of each segment.

III.RESULTS AND DISCUSSION

The simulation, calculation, and investigation of the effect of the chromium coating are conducted based on the actual production conditions of a 7.62 mm machine-gun barrel. In this study, the analysis is performed for two cases: an uncoated barrel and a barrel with a chromium coating thickness of 0.4 mm, under single-shot and ten-shot firing sequences. The heat transfer calculations provide the temperature distributions T(t, rin, z) on the inner bore surface along the barrel axis, as well as the temperature distribution T(t, r, z) across the barrel wall thickness measured from the inner bore surface.

A. Transient thermal response under a Single-shot firing

The temperature distribution T(t, rin, z) on the inner bore surface at selected axial segments (S3, S9, S15, and S25) for the uncoated barrel and the barrel with a 0.4 mm chromium coating under single-shot firing conditions is shown in Fig. 8.



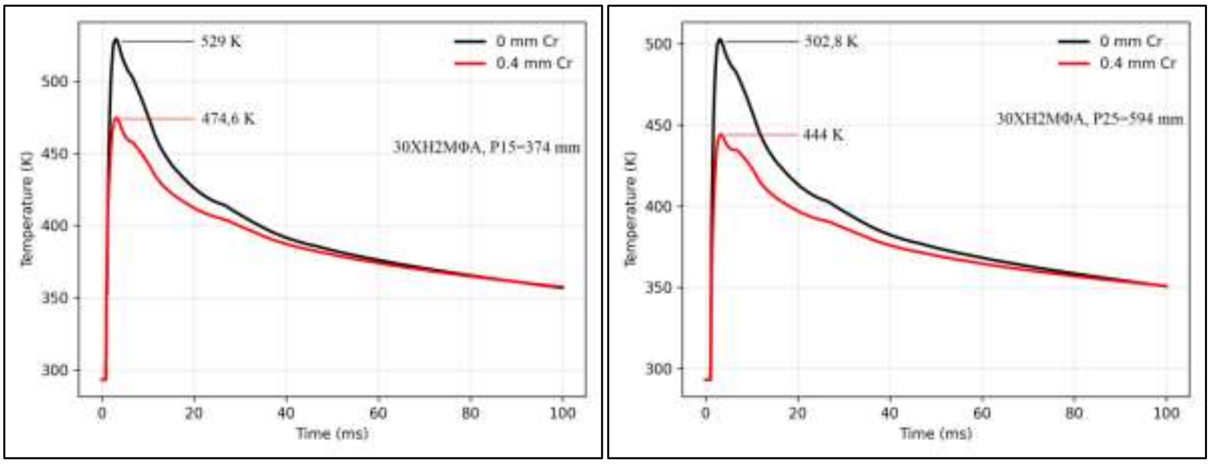


Fig. 8. Temporal evolution of the inner bore surface temperature T(t, rin, z) at selected axial segments (S3, S9, S15, and S25) for uncoated and 0.4 mm chromium-coated barrels under single-shot firing conditions

Figure 8 shows the temporal evolution of the inner bore surface temperature T(t,rin,z) at four representative axial segments (S3, S9, S15, and S25) during a single firing event. For all considered positions, the temperature rises rapidly immediately after ignition, reaching a peak within the first few milliseconds, then decays gradually due to heat conduction through the barrel wall and convective heat transfer to the surroundings.

For the uncoated barrel, the peak temperatures are highest near the chamber region and decrease progressively along the barrel axis. Specifically, the maximum temperature reaches approximately 607.9 K at segment S3, and decreases to about 568 K, 529 K, and 502.8 K at segments S9, S15, and S25, respectively. This trend reflects the reduction of thermal loading along the axial direction as the propellant gas temperature and pressure decrease during projectile travel.

The presence of a 0.4 mm chromium coating leads to a noticeable reduction in the peak inner surface temperature at all axial segments. Compared with the uncoated case, the peak temperature is reduced by approximately 76 K at S3, 72 K at S9, 54 K at S15, and 59 K at S25. In addition to lowering the peak temperature, the chromium coating slightly modifies the cooling rate after the peak, resulting in a smoother temperature decay during the post-firing period.

Overall, the results indicate that the chromium coating acts as an effective thermal barrier during single-shot firing, limiting the maximum temperature on the inner bore surface along the entire barrel length. This effect is particularly pronounced in the regions closer to the chamber, where the thermal load is most severe.

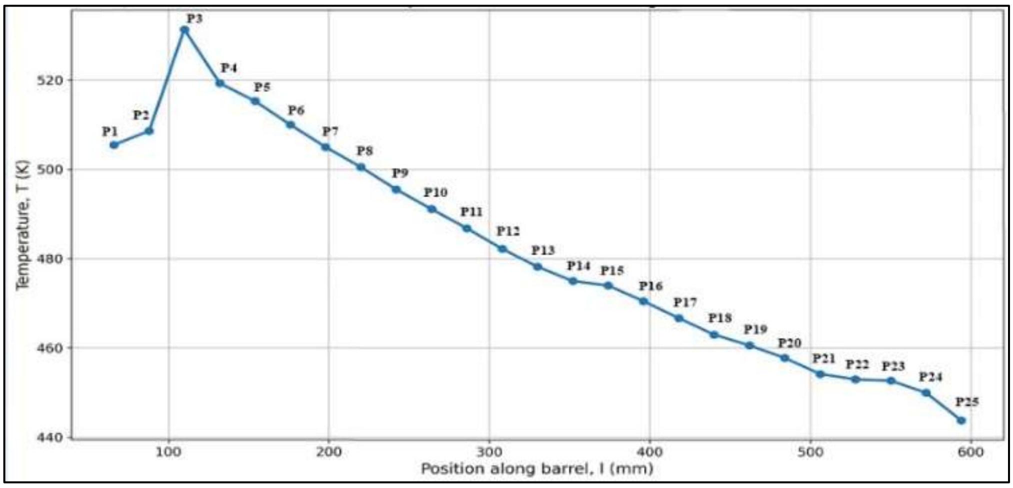


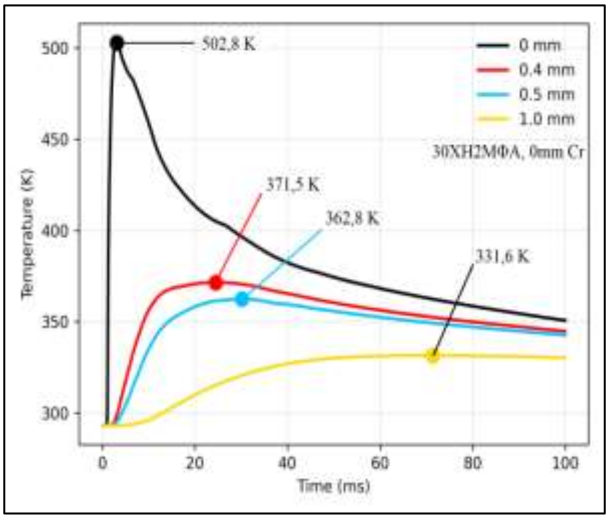
Fig. 9. Axial distribution of the maximum inner bore surface temperature along the 7.62 mm gun barrel with a 0.4 mm chromium coating under single-shot firing conditions

Figure 9 presents the axial distribution of the maximum inner bore surface temperature along the length of the 7.62 mm gun barrel with a 0.4 mm chromium coating during a single-shot firing event. The temperature profile exhibits a non-uniform distribution, with the highest temperature occurring in the region close to the chamber and gradually decreasing toward the muzzle.

The maximum temperature reaches its peak at segment S3, corresponding to an axial position of approximately 110 mm from the breech, and then decreases monotonically along the barrel axis toward segment S25 near the muzzle. This behavior reflects the combined effects of decreasing propellant gas temperature and pressure as the projectile travels along the barrel, as well as the progressive reduction of convective heat transfer intensity along the axial direction.

A slight local variation can be observed in the region between segments S1 and S5, where the temperature initially increases before reaching its maximum value. This local rise is associated with the transition of the projectile from the chamber into the rifled bore, where the interaction between the propellant gases and the barrel wall becomes more intense. Beyond this region, the axial temperature distribution follows a smooth decreasing trend, indicating a gradual attenuation of thermal loading along the barrel length.

Overall, the results demonstrate that even with a chromium coating thickness of 0.4 mm, the thermal load is highly concentrated in the vicinity of the chamber and the early bore region, while the downstream sections experience significantly lower peak temperatures under single-shot firing conditions.



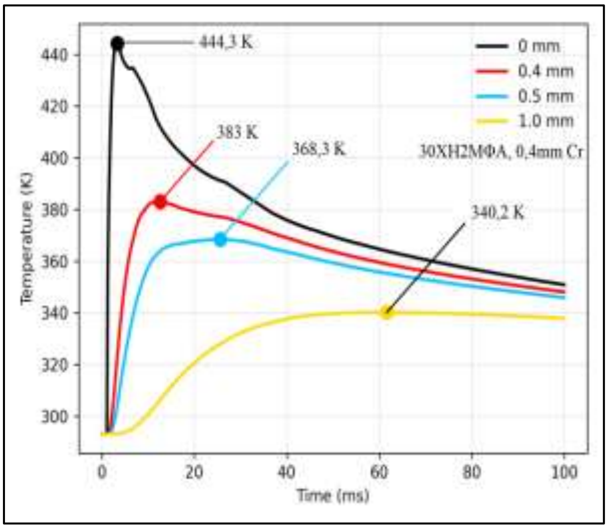


Fig. 10. Transient temperature distribution T(t,r,z) along the radial direction (from the inner bore surface into the barrel wall) at segment S25 under single-shot firing conditions for uncoated and 0.4 mm chromium-coated barrels

Figure 10 presents the transient temperature distribution along the radial direction, measured from the inner bore surface into the barrel wall, at segment S25 under single-shot firing conditions. The results are shown for two cases: an uncoated barrel and a barrel with a 0.4 mm chromium coating.

For both cases, the temperature reaches its maximum value at the inner bore surface shortly after ignition and decreases with increasing radial distance due to heat conduction into the barrel wall. In the uncoated barrel, the peak temperature at the inner surface reaches approximately 502.8 K, followed by a steep temperature gradient near the bore surface, indicating strong thermal loading concentrated in the inner region of the barrel wall.

When a 0.4 mm chromium coating is applied, the maximum temperature at the inner bore surface is significantly reduced to approximately 444.3 K. In addition, the radial temperature gradient near the bore surface becomes less steep compared with the uncoated case. This behaviour indicates that the chromium coating acts as a thermal barrier, limiting heat transfer from the propellant gases into the steel substrate during the short firing duration.

At larger radial depths, the temperature difference between the two cases gradually decreases, suggesting that the influence of the chromium coating is most pronounced in the near-surface region of the barrel wall. These results demonstrate that a chromium coating alters radial heat transfer and effectively reduces extreme thermal loads at the bore surface.

Table 2 summarises the maximum and minimum temperatures along the barrel wall depth at segment S25 for the uncoated barrel and the barrel with a 0.4 mm chromium coating under single-shot firing conditions. The results show that applying a chromium coating leads to a pronounced reduction in the maximum temperature. Specifically, the peak temperature decreases from 502.8 K in the uncoated case to 444.3 K in the chromium-coated case.

In contrast, the minimum temperature within the barrel wall increases slightly, from 362.8 K for the uncoated barrel to 368.3 K for the chromium-coated barrel. This indicates a redistribution of thermal energy within the barrel wall, where the chromium coating suppresses extreme surface temperatures while promoting a more uniform temperature field across the wall thickness.

The quantitative results in Table 2 are consistent with the radial temperature profiles shown in Fig. 10 and further confirm the chromium coating's role in moderating thermal gradients and reducing peak thermal loads at the inner bore surface.

Table 2. Maximum and minimum temperatures along the barrel wall depth at segment S25 under single-shot firing conditions for uncoated and 0.4 mm chromium-coated barrels

Chromium-coated	0 mm	0,4mm
Maximum temperatures (K)	502,8	444,3
Minimum temperatures (K)	362,8	368,3

B. Transient thermal response under a ten-shot firing sequence

Figure 11 illustrates the temporal evolution of the inner bore surface temperature T(t, rin, z) at four representative axial segments (S3, S9, S15, and S25) during a sequence of ten successive shots. For all axial positions, the temperature exhibits a cyclic behaviour characterised by a rapid rise during each firing event, followed by partial cooling in the interval between consecutive shots.

For the uncoated barrel, the peak temperature increases progressively with the number of shots, suggesting a thermal accumulation effect. This accumulation is most pronounced in the regions closer to the chamber (segments S3 and S9), where the thermal loading is highest. At segment S3, the peak temperature increases markedly from shot to shot, reaching the highest values among all considered locations.

In comparison, the barrel with a 0.4 mm chromium coating exhibits consistently lower peak temperatures throughout the firing sequence at all axial segments. Although thermal accumulation is still observed, the rate of temperature increase from shot to shot is lower than in the uncoated case. This indicates that the chromium coating effectively mitigates heat transfer from the propellant gases to the barrel wall during rapid firing.

Along the barrel axis, the peak temperature decreases from segment S3 toward S25 for both cases, reflecting the axial decay of thermal loading. However, the temperature difference between the uncoated and chromium-coated barrels remains evident at all positions, demonstrating that the influence of the chromium coating persists along the entire barrel length under multi-shot firing conditions.

Overall, the results in Fig. 11 highlight the combined effects of rapid firing and axial position on the thermal response of the gun barrel and confirm the role of the chromium coating in reducing peak temperatures and moderating thermal accumulation during a ten-shot firing sequence.

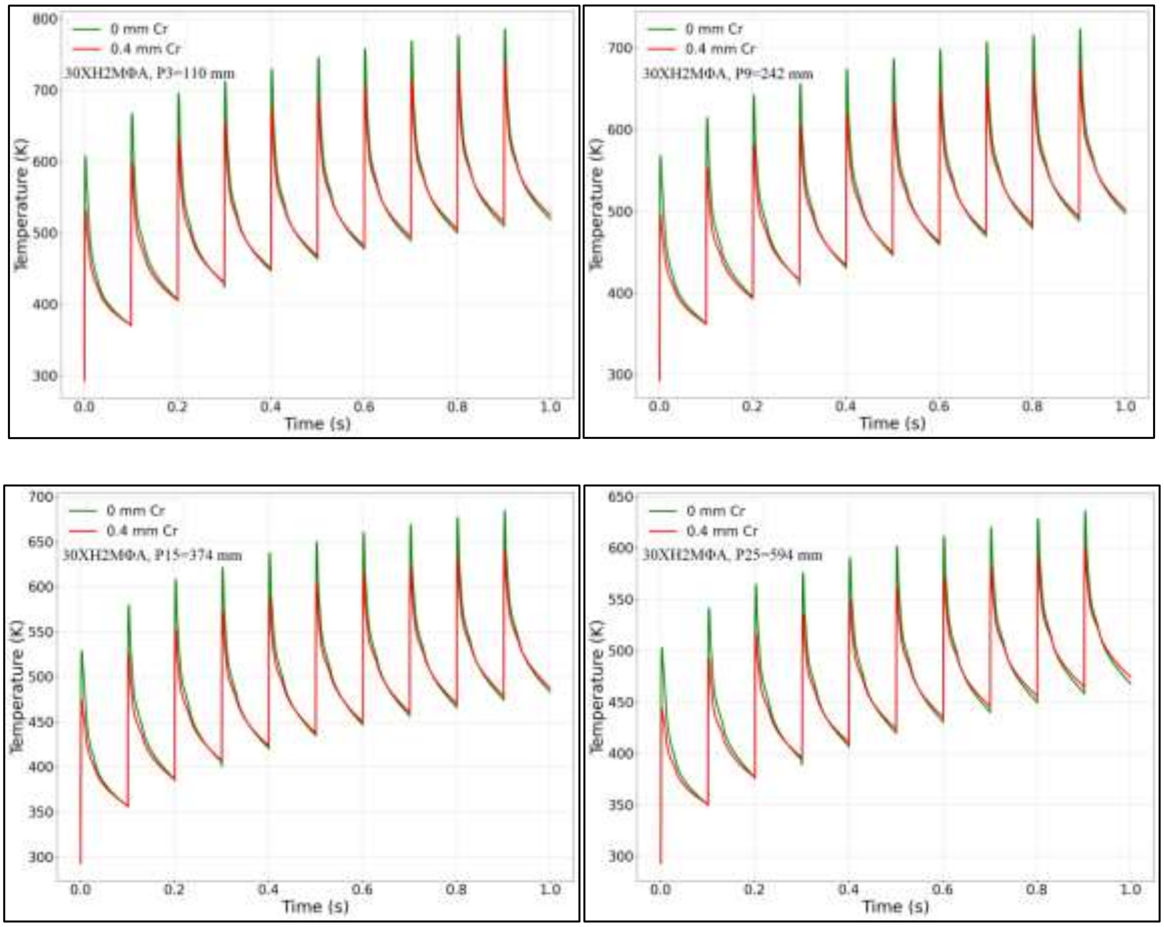


Fig. 11. Temporal evolution of the inner bore surface temperature T(t, rin, z) at selected axial segments (S3, S9, S15, and S25) for uncoated and 0.4 mm chromium-coated barrels under a ten-shot firing sequence

Figure 12 presents the transient temperature response at segment S25 during a ten-shot firing sequence at several radial depths measured from the inner bore surface. Two cases are compared: the uncoated barrel (left panel) and the barrel with a 0.4 mm chromium coating (right panel). In both cases, the temperature exhibits a pronounced cyclic pattern: a sharp increase during each shot, followed by partial cooling between shots, leading to a gradual rise in the baseline temperature as the number of shots increases.

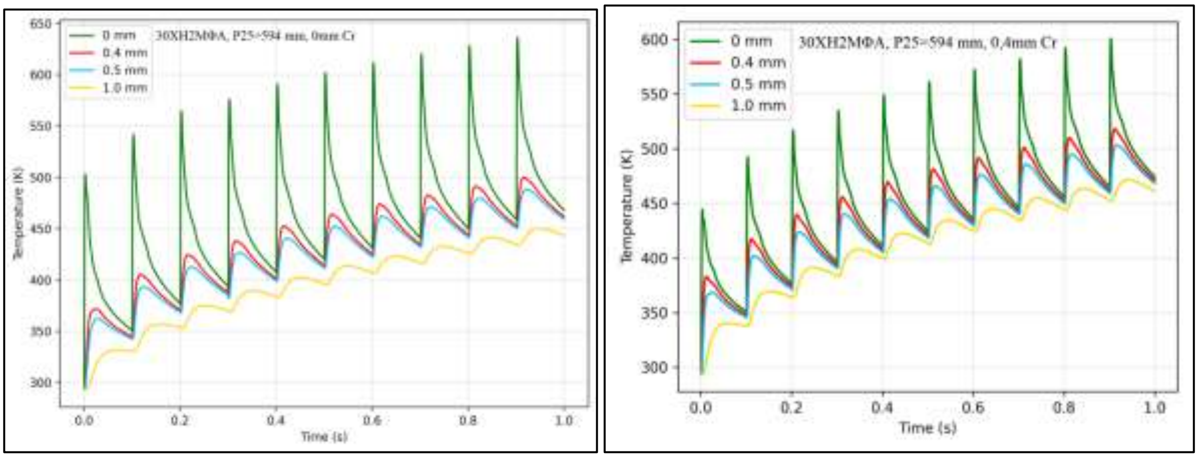


Fig. 12. Transient temperature histories T(t, r, z) at segment S25 during a ten-shot firing sequence, evaluated at different radial depths from the inner bore surface for uncoated and 0.4 mm chromium-coated barrels

At all firing cycles, the temperature amplitude is most significant at the inner surface (0 mm depth) and decreases with increasing radial depth (0.4 mm, 0.5 mm, and 1.0 mm). This behaviour indicates strong thermal gradients concentrated near the bore surface, while heat penetration into deeper regions of the barrel wall is more moderate during the short firing intervals. As rapid firing continues, temperatures at deeper locations also increase, demonstrating cumulative heat conduction through the wall thickness.

Comparing the two cases, the chromium-coated barrel shows consistently lower temperatures at corresponding depths throughout the firing sequence, particularly near the inner surface where the thermal load is most severe. In addition, the coated case exhibits a slightly reduced peak-to-valley temperature variation at the same radial depth, indicating that the coating moderates extreme thermal excursions near the bore surface under rapid firing. Overall, the results confirm that the temperature field during multi-shot firing is strongly depth-dependent and that the chromium coating reduces near-surface thermal loading and thermal gradients at segment S25

While the results of the single-shot firing analysis clarify the instantaneous thermal behaviour of the barrel, practical firing scenarios often involve successive shots, leading to thermal accumulation. Consequently, the ten-shot firing sequence is analysed to assess both the temporal evolution of the inner bore surface temperature and the depth-dependent temperature distribution within the barrel wall.

IV. CONCLUSIONS

This study presents a numerical investigation of transient heat transfer in a chromium-coated 7.62 mm gun barrel under rapid-firing conditions using a two-dimensional axisymmetric finite-element model. The barrel was modelled as a multilayer structure comprising a 30XH2MΦA steel substrate and an inner chromium coating, with temperature-dependent thermophysical properties for both materials. The thermal response of the barrel was analysed for single-shot and ten-shot firing sequences under realistic firing conditions.

The results of the single-shot analysis show that the inner bore surface temperature rises rapidly after ignition, reaching a peak within a few milliseconds, then gradually cools due to heat conduction through the barrel wall and convective heat transfer at the outer surface. The peak temperature is highest near the chamber region and decreases progressively along the barrel axis. The presence of a 0.4 mm chromium coating significantly reduces the maximum temperature at the inner bore surface across all axial segments, with the most significant effect observed near the chamber.

For the ten-shot firing sequence, the simulations reveal an apparent thermal accumulation effect, characterised by a progressive increase in both peak and baseline temperatures with successive shots. Compared with the uncoated barrel, the chromium-coated barrel exhibits consistently lower peak temperatures and a reduced rate of temperature increase from shot to shot, indicating that the chromium coating effectively mitigates heat transfer from the propellant gases to the barrel wall during rapid firing.

The radial temperature analysis further demonstrates that the thermal load is intensely concentrated near the inner bore surface, where steep temperature gradients develop. The chromium coating modifies radial heat transfer behaviour by reducing peak surface temperatures and moderating near-surface thermal gradients, while the temperature difference between coated and uncoated barrels diminishes with increasing wall depth.

Overall, the numerical results confirm that applying a chromium coating plays an essential role in reducing extreme thermal loads at the inner bore surface and moderating thermal accumulation during rapid firing. The proposed modelling approach provides a useful framework for evaluating transient thermal behaviour in small-calibre gun barrels. It can support the optimisation of chromium coating design to improve barrel thermal performance and durability.

ACKNOWLEDGMENT

The authors would like to thank the technical assistance of the Faculty of Special Equipment of Le Qui Don Technical University.

REFERENCES

1. Zhang, Y., Xue, T., & Zhang, X. (2024). Investigation of heat transfer in cracked gun barrels. International Journal of Thermal Sciences, 201, 109024. https://doi.org/10.1016/j.ijthermalsci.2024.109024
2. Değirmenci, E., & Dirikolu, M. H. (2012). A thermochemical approach for the determination of convection heat transfer coefficients in a gun barrel. Applied Thermal Engineering, 37, 275-279. https://doi.org/10.1016/j.applthermaleng.2011.11.029
3. Zieliński, M., Koniorczyk, P., Surma, Z., Zmywaczyk, J., & Preiskorn, M. (2022). Numerical study of heat transfer in a gun barrel made of selected steels. Energies, 15(5), 1868. https://doi.org/10.3390/en15051868
4. Suyadnya, K. A., Tarwidi, D., Setiawan, E. B., & Umbara, R. F. (2019). Numerical modeling of heat transfer in gun barrel with experimental validation. International Journal of Engineering & Technology, 8(1.9), 62-66.
5. Wu, B., Chen, G., & Xia, W. (2008). Heat transfer in a 155 mm compound gun barrel with full length integral midwall cooling channels. Applied Thermal Engineering, 28(8-9), 881-888. https://doi.org/10.1016/j.applthermaleng.2007.07.010
6. Hill, R. D., & Conner, J. M. (2012). Transient heat transfer model of machine gun barrels. Materials and Manufacturing Processes, 27(8), 840-845. https://doi.org/10.1080/10426914.2011.648694
7. Susantez, Ç., & Caldeira, A. (2022). Heat transfer modelling and simulation of a 120 mm smoothbore gun barrel during interior ballistics. Defence Science Journal, 72(1). http://doi.org/10.14429/dsj.72.16542
8. Chen, S., Li, Y., Fu, J., Chen, L., & Qian, L. (2023). Reconstruction of transient convective heat transfer coefficients in heat transfer of gun barrels with variable coefficients. Case Studies in Thermal Engineering, 50, 103467. https://doi.org/10.1016/j.csite.2023.103467
9. Xi, S., & Wu, H. (2021). Numerical Calculation and Analysis of Gun Barrel Heat Transfer. In IOP Conference Series: Earth and Environmental Science (Vol. 632, No. 3, p. 032008). IOP Publishing. https://doi.org/10.1088/1755-1315/632/3/032008
10. Zieliński, M., Koniorczyk, P., Surma, Z., Preiskorn, M., & Sienkiewicz, J. (2023). Selected aspects of heat transfer study in a gun barrel of an anti-aircraft cannon. Problemy Mechatroniki: uzbrojenie, lotnictwo, inżynieria bezpieczeństwa, 14(2 (52), 73-86. https://doi.org/10.5604/01.3001.0053.6672
11. Dubey, A., & Sharma, P. K. (2022). Thermal Study of 155 mm Gun Barrel. Defence Science Journal, 72(2), 172. https://doi.org/10.14429/dsj.72.16625
12. Gerber, N., & Bundy, M. L. (1991). Heating of a tank gun barrel: Numerical study (No. BRLMR3932).
13. Dębski, A., Koniorczyk, P., Leciejewski, Z., Preiskorn, M., Surma, Z., & Zmywaczyk, J. (2018). Heat Transfer Calculations in Barrel Cover of 35 mm Naval Armament System Gun. Problemy Mechatroniki: uzbrojenie, lotnictwo, inżynieria bezpieczeństwa, 9(3 (33), 57-74. https://doi.org/10.5604/01.3001.0012.2739
14. Wu, B. (2005). Barrel cooling: a key technology for improving gun performance. Journal of Battlefield Technology, 8(3), 1-5.
15. Gun barrels under different operating conditions. In ASME International Mechanical Engineering Congress and Exposition (Vol. 59452, p. V008T09A081). American Society of Mechanical Engineers. https://doi.org/10.1115/IMECE2019-12083
16. Chen, T. C., Liu, C. C., Jang, H. Y., & Tuan, P. C. (2007). Inverse estimation of heat flux and temperature in multilayer gun barrel. International journal of heat and mass transfer, 50(11-12), 2060-2068. https://doi.org/10.1016/j.ijheatmasstransfer.2006.11.022
17. Chen, S., Wang, X., Shi, Y., & Xu, C. (2024). Transient heat transfer study of small-caliber barrel in continuous fire. International Journal of Thermal Sciences, 196, 108737. https://doi.org/10.1016/j.ijthermalsci.2023.108737
18. Chowdhury, M. S. H., Durjoy, M. S., Siddique, I. J., Hossan, M. A., & Hossain, M. I. (2025). Heat Transfer Analysis in Perforated Pin Fin Heat Sinks Inspired by Sterling Gun Barrel Geometry. Case Studies in Thermal Engineering, 107524. https://doi.org/10.1016/j.csite.2025.107524
19. Mishra, A., Hameed, A., & Lawton, B. (2010). Transient thermal analyses of midwall cooling and external cooling methods for a gun barrel. https://doi.org/10.1115/1.4001607
20. Chaturvedi, E. (2019). Investigating T finned Barrels for Machine Guns: Enhancement in Heat Dissipation and Flexural Rigidity along with Weight Reduction. Advances in Military Technology, 14(1), 59-69.

https://doi.org/10.3849/aimt.01254

21. Podkopaev, I. A., Podkopaev, A. V., & Dolzhikov, V. I. (2023). Modeling of convective heat transfer processes between inhomogeneous gas mixtures and surfaces of a small-caliber artillery barrel. Siberian Aerospace Journal, 24(3), 468-481. https://doi.org/10.31772/2712-8970-2023-24-3-468-481
22. Koniorczyk, P., Zmywaczyk, J., Dębski, A., Zieliński, M., Preiskorn, M., & Sienkiewicz, J. (2020). Investigation of thermophysical properties of three barrel steels. Metals, 10(5), 573. https://doi.org/10.3390/met10050573
23. Ho, C. Y., Powell, R. W., & Liley, P. E. (1974). Thermal conductivity of the elements: a comprehensive review. J. Phys. Chem. Ref. Data, Suppl., v. 3, no. 1, pp. 1-796.