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Investigating and modelling of highly stressed firearms parts

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Abstract. Recently, there have been too many Pulemyot Kalashnikova Modernizirovannyi (PKM) machine gun bolts that have failed during the firing process. Due to the increased temperature, higher propellant gas pressure, and thermal accumulation, the bolt body is exposed to sever circumstances for ablating, corroding, and erosion. In this paper, the reasons of failure of PKM bolts during firing were evaluated first based on metallurgical experiments. Then, analysing the failure is done by create an accurate finite element model of the bolt body, calculating the cyclic fatigue life and safety factor, determining the causes of failure and be verified showing that failure locations are exactly as shown in the photographic record. the original bolt dimensions were measured using laser scanning, and a CAD model of the bolt was created. Photographic records, visual inspection, chemical analysis, SEM, and hardness measurements, all these metallurgical experiments have been done. The stress distributions and fatigue behavior of the failed bolt are both determined using the Finite Element Method (FEM). This study suggests that fatigue played a role in bolt failure. Furthermore, SEM examinations reveal that the materials contain dimple fractures. The bolt's fatigue life was decreased by these dimpled fractures.

1. Introduction

Pulemyot Kalashnikova Modernizirovannyi (PKM) [1] is the upgraded Russian Kalashnikov machine gun, which represents the most significant power of fire and also meets those variations of need during combat. It is considered a General-Purpose Machine Gun (GPMG) that has been in service since 1969. Even now, its enhanced variations are still made (see 'figure 1'). A catastrophic number of 54mm machine gun bolts have failed prematurely during the firing process (field experience). In many cases, fatigue failures of cyclically thermos-mechanical loaded parts initiate at such unfavourable locations, especially barrel, and bolts, numerous investigations on various dynamic components of fatigue failure analysis have been conducted. However, not enough research has been done on the fatigue failure analysis of PKM bolts.

Figure 1. PKM 7.62mm Machine Gun [1].

Sen [2] Analyzed Fatigue fractures of the semi-auto shotgun mechanism were studied using finite element analysis and an experimental setup. This study looked at the fatigue fracture behavior of locking component specimens. To determine the integrity of the broken locking block, an assessment that comprised a visual inspection, chemical and metallurgical analyses, hardness measurements, and an investigation of the fracture surface was conducted. The modelling of the locking portion was done using Pro/Engineer software. The stress distributions and fatigue behavior of the locking block are both calculated using the finite element program ANSYS/ LS-DYNA and ANSYS Workbench, respectively. It was determined through this study that the locking block's mode of failure was a ductile fracture. The shattered surface has several voids, according to SEM analysis. The failure of the locking block was mostly caused by these voids. ANSYS/ LS-DYNA and ANSYS Workbench software were used to do the dynamic analysis and fatigue behavior study of the locking block of the semi-auto shotgun, respectively. The locking block's fillet radius, which is where all the specimens' cracks are found, is where the most stress is found, according to the observation. Hua, B. B et al. [3] used FEM dynamic analysis to determine the maximum stress that the breech would experience throughout the recoil process, and the computed results showed that the breach strength design satisfied the necessary standards. By examining the geometry of the failed bolt, testing its metallurgy, performing stress analysis using the finite element method to identify the critical regions for crack initiation, and suggesting a new material bolt that has undergone chemical, metallurgical analysis, hardness measurements, and stress analysis and been compared to the original bolt. The primary cause of the catastrophic failure of the 54-mm machine gun bolt under firing conditions was investigated in this study. Yang, X et al. [4], The distribution and amount of the breech mechanism's dynamic stresses when they are impacted have been acquired with LS-DYNA after the impacting dynamic stresses of an automatic weapon's major components (a breech mechanism) have been evaluated and investigated. The dynamic stress study demonstrated that the breech mechanism's strength is appropriate. Ibrahim, D et al. [5] analyzed the failure of the semi-automatic shotgun locking block. To investigate the causes of failure, the cracked surface and locking block shape were examined. Utilizing ANSYS Workbench 11.0, the stress distribution of the locking block was carried out. It was found that incorrect material choice, improper heat treatment, and dimensional geometry issues are the causes of locking block fracture.

According to ANSYS Workbench analysis, overloading resulted in plastic deformation in the part's critical zones. Yu, V. Y et al. [6] performed a geometric element analysis using ProMechanica in order to determine the stress distribution of the M16 rifle bolt due to the firing process. The fracture surface was examined using both an optical stereomicroscope and a scanning electron microscope with the intention of determining failure initiation and failure mode. The fracture of the Ml6 bolt resulted from a cumulative effect of high stress concentrations at the fillet radius and the additional stress concentration imposed by the presence of localized pitting at the surface.

Following a thorough analysis of earlier studies, which addressed the failure of some components of weapons and military equipment, it reveals that the use of experimental work and modelling is the best way to analyze the failure that affects parts of weapons and military equipment, as metallurgical investigation describes the shape of the failure, its place of origin, its direction, and the loads that led to the occurrence of this failure. While, still needed to precisely determine the timing of the failure and whether it is the result of an assumed lifetime, or that the failure occurred before reaching the default lifetime. Conducting that, an accurate and proven analysis of the failure of the PKM machine gun bolt body requires a study using experimental work and finite element modeling.

The time dependent internal ballistic parameters have been calculated in this study because all previous studies that dealt with the failure study of this key component in small arms, in general, did not take into account the effect caused by thermal accumulation and considered the repetition of this effect during the high rate of fire as the main reason for the fatigue failure of this part.

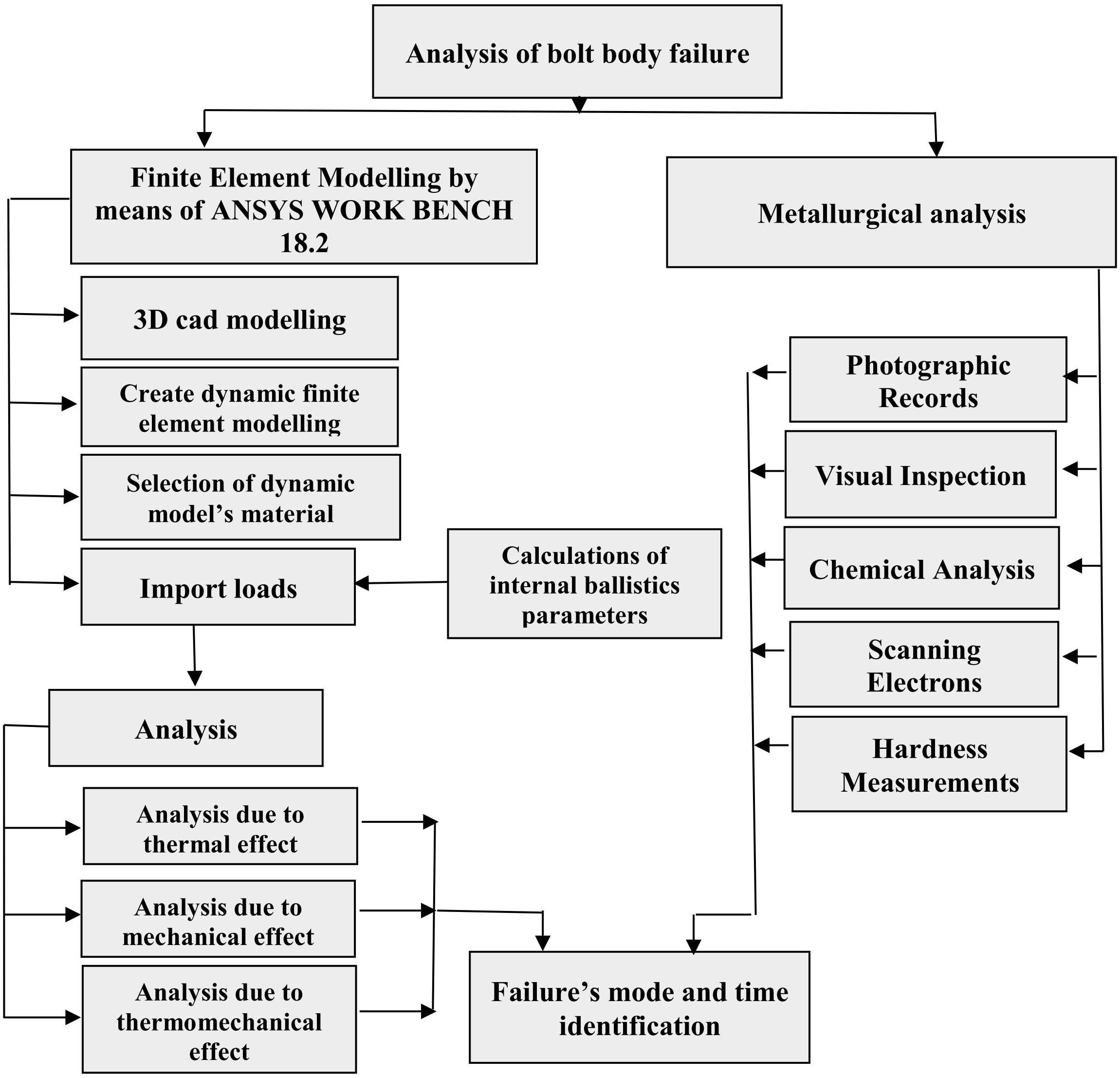


Figure 2. Analysis of bolt body failure procedures.

The main objective of this work is to create an accurate finite element model of the bolt body, analyse the failure of the bolt body by calculating the cyclic fatigue life and safety factor, determine the main cause of failure and verify that the failure locations are exactly as shown in the photographic record. Evaluating earlier researches that focused on the study of mechanical part failures. The sequence of analysis methodology of bolt body failure is as shown in 'figure 2'.

2. Metallurgical Analysis

When submitting a failed firearm component for analysis, all information on the material, manufacturing process, mechanical properties, loads applied, and loading conditions, as well as the component's life at the time of failure, must be recorded. With the available knowledge now, the intended performance of the defective component may be compared to the expected results. The component's life information would be useful in determining whether the failure was premature or whether the component had a sufficient amount of service life remaining before failing.

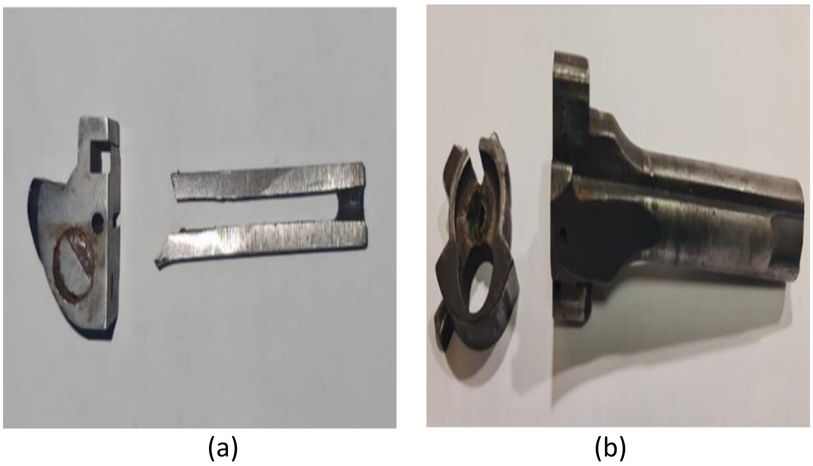
A metallurgical investigation and a finite element analysis of the failed bolt were employed in this study. (1) The metallurgical analysis would identify the crack origin and the failure mechanism; these are the objectives of the methodology used. The results of the metallurgical investigation would also show if the material's mechanical properties were insufficient for the bolt's intended use. (2) The finite element approach would show whether the bolt had any elevated stresses that might have aided in the initiation and spread of cracks.

The bolt body, which is deteriorating while the other components continue to function as intended. 'Figure 3' depicts the failed bolt body that was the focus of my investigation whereas. Figure 4 depicts a new bolt body that hasn't been used yet this is evident to us from the failure that struck the bolt body's face (see 'figure 3'), which includes some segments with erosion and others with fractures. Another issue with the lug of the bolt body, which is the part that rotates the bolt body at a specific angle and causes the barrel lock to tighten when rounds are fired.

Figure 3. Failed bolt body.

Figure 4. A new bolt body.

Two samples of the failed bolt were prepared for all metallurgical analysis, chemical analysis, SEM, and hardness measurements, by taking a longitudinal section in one of the samples and a horizontal section in the other sample (see 'figure 5').



(a) (b)

Figure 5. "(a)" longitudinal section. "(b)" Horizontal section.

2.1. Photographic records

The failed bolt was captured on camera in its as-received condition. Care must be used when taking pictures to capture various angles of the broken bolt. For future use, close-up views of the failed or defective region and the fracture surface should also be captured.

Figure 6. Close-up of a fractured bolt.

Figure 7. Failed bolt with worn lugs.

‘Figure 6’ makes it very evident that there are corrosion and cracking around the position where the firing pin moves to impact the bullet, which initiates the firing. Additionally, ‘Figure 7’ shows the locking lugs exhibit some wear, which affects the movement and completeness of the locking mechanism.

2.2. Visual inspection

With the aid of a digital microscope outfitted with LED lighting and a 1000X magnification, a clear visual examination of the failed bolt surface was carried out. A failed bolt body and a brand-new one.

As shown in ‘figure 9’, obtained from the store were both visually inspected the new bolt body had a coating of paint on it, which was evident upon examination and was likely applied for storage purposes see. Regarding the failing bolt block, it was evident from it that use had worn away the paint covering and covered with corrosion (see ‘figure 8’).

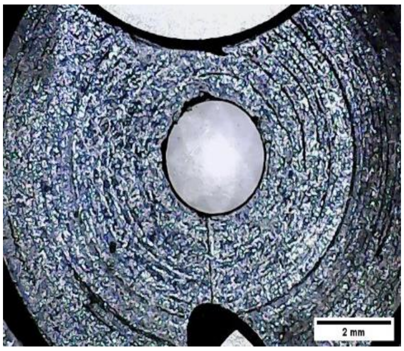


Figure 8. A clear visual inspection of the new bolt surface.

Figure 9. A clear visual inspection of the failed bolt surface.

Through Visual Inspection, the location of the beginning of the crack is reached, which helped, during SEM's work, to quickly locate the crack, and the rest of the surface was completely oxidized and covered by corrosion.

2.3. Chemical analysis

One of the problems in analyzing the failure of this important part is that the chemical composition of the material from which the bolt is made is unknown. Therefore, determining the chemical composition is an important step in the way of analyzing bolt failure, as it bears its significance in knowing whether the selection of the material was as per the specification or not. It may be determined whether or not there is a significant difference in the chemical composition of the failed bolt, allowing for a more precise study of bolt failure.

Table 1 provides information about the material's chemical composition. According to the results of the chemical composition investigation, the bolt is made of alloy structural steel Cr - Ni - Mo type TOCT 4543 Grade 25X2H4BA. The available mechanical properties are Tensile strength, $\sigma_b \geq 1080$ MPa, Yield strength, $\sigma_y \geq 930$ MPa, [7]

Table 1. Chemical analysis of new and failed Machine gun bolt:

elements	Material specifications	Percent composition of new bolt	Percent composition of fractured bolt
c	0.21 ~ 0.28	0.274	0.28
Fe	0.91 ~ 0.93	92.1	91.45
Si	0.17 ~ 0.37	0.335	0.29
Mn	0.25 ~ 0.55	0.308	0.363
Cr	1.35 ~ 1.65	1.59	1.64
Ni	4.00 ~ 4.50	4.45	4.64
W	0.80 ~ 1.20	0.524	0.94
Mo	0.09 ~ 0.15	0.138	0.091

It is clear from the results that the chemical composition of the new bolt and failed bolt is within the acceptable range. There is almost no significant difference in the chemical composition between the new body and the failed one. It is crucial to understand chemical composition while creating a transient thermomechanical model. The fact that the chemical composition has not changed is crucial evidence that fatigue is the root cause of the failure.

2.4. Scanning electron microscope (SEM)

The fatigue fractographic analysis of the failed bolt was performed using a scanning electron microscope (inspect F50-FEI Company) [8]. See 'figure 10 (a, b)' the surface of the failed bolt was examined in the area surrounding the position of the firing pin by a scanning electrons microscope (SEM), which located the location of the crack initiation and the direction of their growth. It also shows the failure mode, see 'figure. 10 (c, d)', the presence of a dimpled fracture, which confirms that the bolt body went under plastic deformation as a result of its exposure to high cyclic loads due to the high rate of fire.

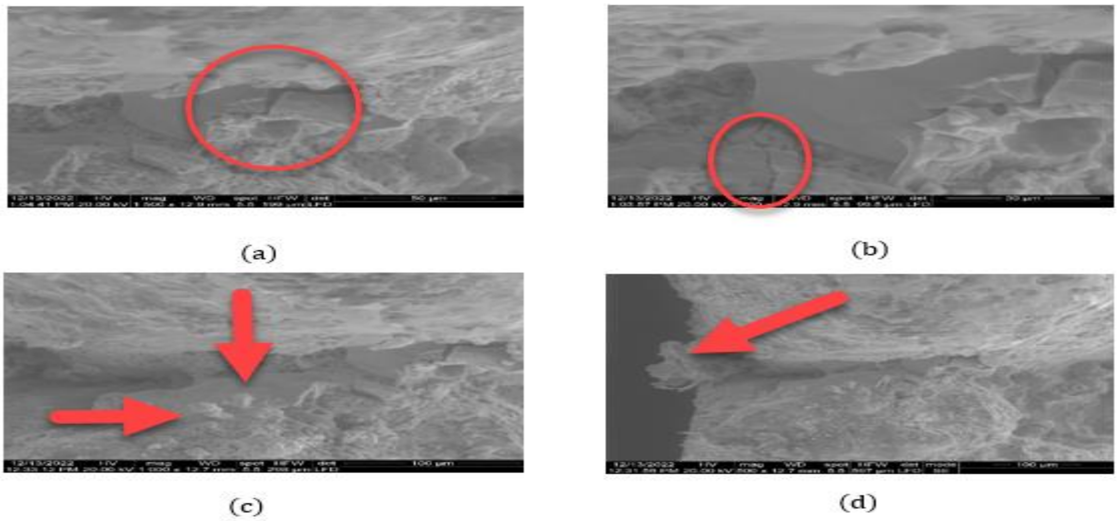


Figure 10. ”(a, b)” crack initiation. “(c, d)” SEM views of dimpled fracture.

2.5. *Hardness measurements*

The hardness of the bolt’s lug and head were measured at more than one point scattered in separate positions to see if it was affected by the high rate of firing or not. This measurement was carried out using the Rockwell hardness tester. Bolt’s head and body hardness are within the ranges of (42 and 44) HRC which is the same range of the original bolt before failure, see ‘figure 11’.

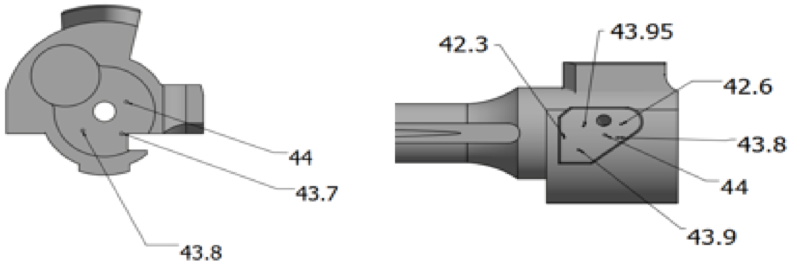


Figure 11. Hardness measurements’ of failed bolt.

3. Finite Element Modelling

A component that is prone to fatigue failure has been subjected to several minor loads that stress it below the yield strength, unlike a component that is simply overstressed and fails because the yield or ultimate strength is exceeded. Through a variety of causes, including the development of microscopic cracks or slippage along macroscopic limits, damage starts to build up [9]. The stress on the bolt body head is not excluded from only one shot since this machine gun does not fire from its magazine separately but rather at a very high rate of fire.

The stress distribution in the failed bolt under the loads and limitations of operational circumstances were calculated using the finite element code ANSYS workbench 18.2.

Information on life, damage, and safety factors is provided through fatigue analysis. The term "fatigue life," which is used in fatigue testing, describes how materials behave when subjected to cyclic loads in terms of deformation and failure. The equivalent number of cycles is used to calculate the amplitude of the tolerated stress. The Safety Factor is the ratio of the stress at which a component will fail to the actual stress experienced by the component. The failure is studied, and its reasons are established, by evaluating the data supplied regarding the Fatigue Life and Safety Factor under the effect of temperature only, pressure on its own, or under the impact of thermomechanical cyclic loads.

3.1. Creation of dynamic model of bolt body by ANSYS WORK BENCH 18.2.

Because the lacked documented information about these dimensions from the machine gun's original factory, it was necessary to acquire a new bolt body that had never been assembled in the machine gun before beginning the first stages of final element modelling in order to make an accurate and detailed dimension. The measurements were made using a coordination measuring machine Nikon Altera 15.10.8, equipped with a laser scanning with an accuracy of 0.05μm and then converted to a CAD model using NX12 CAD CAM sophisticated software due to the intricate form and design of the bolt body.

Building a FEM model in accordance with the geometric model is the first step. When the extractor is holding the bullet's rim in this position, the peak of stresses at a material is determined by a non-linear material property during the time from the start of the firing process until the empty cartridge is ejected outside the machine gun.

Meshing is a crucial component of any finite element analysis because analysis requires that the model be divided up into a finite number of elements for better result accumulation. The issue is separately solved by the program for each element, and the answer is then given for the entire body. Therefore, the outcome will be more accurate the more factors there are [10]. A three-dimensional finite element model of the bolt body with 13187 3-D elements (SOLID187), considering meshing sensitivity and time consuming. This element is a - 10-Node Tetrahedral Structural Solid elements. 0.006 m element size is used to conduct the stress analysis. 'Figure 12'. Shows the bolt body's finite element model.

The mechanical and thermal failure mechanisms are the subject of fatigue analysis. Differences in the coefficient of thermal and mechanical expansion are responsible for the majority of thermo-mechanical stresses that lead to fatigue failure. When the component is subjected to cyclic loads and strains that result in irreversible damage, fatigue failures will happen. The beginning of fatigue cracks and their spread under cycle load are the two main factors that cause fatigue failure.

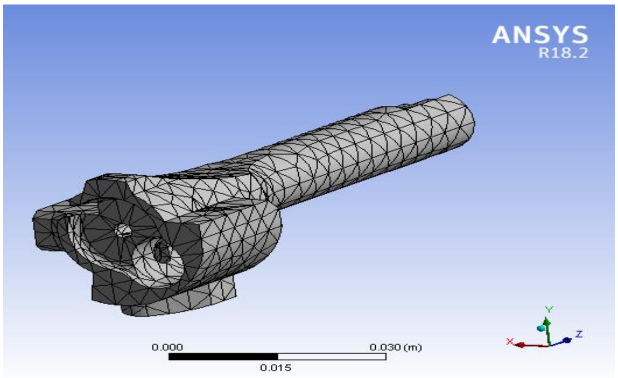


Figure 12. Meshing dynamic finite element model.

The selection of material comes next. For the body of the bolt, Cr-Ni-Mo alloy structural steel of type TOCT 4543 Grade 25X2H4BA was employed. The material behaviour was modelled using a linear isotropic material theory. The bolt could have the following material characteristics: Density = 7.850 kg/m3, Poisson's Ratio v = 0.3, and Young's Modulus E = 200 GPa.

Based on the Goodman fatigue theory and the properties of the material, it is possible to predict the fatigue life at a specific stress ratio (alternating and mean stresses) (ultimate strength, SU, and endurance strength, Se). The Goodman equation is used to determine the fatigue life of the bolt body and is written as [11]:

$$\sigma_m = \frac{\sigma_{max}+\sigma_{min}}{2} \quad (1)$$

$$\sigma_a = \frac{\sigma_{max}+\sigma_{min}}{2} \qquad (2)$$

In this study, the fatigue life, and safety factor of the bolt body due to the thermomechanical effect are analyzed using the finite element transient model under the environment of ANSYS Workbench 18.2.

3.2. Internal ballistics solution

Internal ballistics parameters have to be calculated since they represent the thermomechanical loads applied on the PKM bolt during the firing process. There are many different techniques to be used in solving the main task of I.B., the most used technique is that one known as ″MODIFIED CHARPONNIER- SUGOT′S″ [12, 13].
The I.B solution is divided into four periods as follows:

1. Ignition period. 2. Burning period. 3. Expansion period. 4. Additional action period.

The first three periods describe the solution inside the barrel while the fourth period solves the task during projectile motion outside the barrel until the pressure inside the barrel reaches atmospheric pressure.

3.2.1.Solution of the first period

The solution of this period is determined by choosing a suitable initial pressure (P0) to get the initial relative burnt mass (ψ0) and the initial relative burnt thickness (Z0).

3.2.2.Solution of Second Period

Using the Modified Charbonnier Method, the relative burnt thickness (Z) is chosen as an independent parameter. This period is divided into 100 sections to get the values of Projectile velocity (V_P), Projectile travel (X_P), Gas pressure (P), Gas temperature (T), and Time (t, by solving the following equations:

$$V_P = \frac{S.e_1}{\mu.U_1}(z - z_0) \qquad (3)$$

$$\Delta X_i = \frac{B_1}{B_2}(B_3 + X_i).\Delta Z \quad , \quad X_{i+1} = X_i + \Delta X_i \qquad (4)$$

$$\mathbf{P} = \frac{F.\omega.[\psi - \xi_o(Z-Z_o)^2]}{W_0 + S.X - \alpha.\omega.\psi - \frac{\omega}{\rho}(1-\psi)} \qquad (5)$$

$$T = T_V\left(1 - \frac{\xi_o(Z-Z_o)^2}{\psi}\right) \qquad (6)$$

$$\Delta t_i = \frac{\mu}{S}.\frac{\Delta v_i}{\overline{p_i}} \qquad (7)$$

3.2.3.Solution of Third Period

For the pre mentioned ballistics parameters of the end of burning will be the initial values for the third period. By solving the following equations:

$$V = \sqrt{\frac{2\,F.\omega}{\mu(k-1)}\left[1 - \frac{T}{T_V}\right]} \qquad (8)$$

$$X_{i+1} = X_{i+1} + \left[\frac{X_M + X_K}{n}\right] \qquad (9)$$

$$P = P_K * \left(\frac{C_K}{C}\right)^k \quad , C = CK + S.\, \Delta X \qquad (10)$$

$$T = T_K[\frac{C_k}{C}]^{k-1} \quad , C = CK + S.\, \Delta X \qquad (11)$$

$$\Delta ti = \frac{\mu}{S} . \frac{\Delta v_i}{\overline{p_i}} \qquad (12)$$

3.2.4. Ballistic Calculations Results:

The results are plotted in 2-D figures, the most important of these results are those representing the variation of pressure with time, and the variation of temperature with time. See ‘figure (13, 14)’.

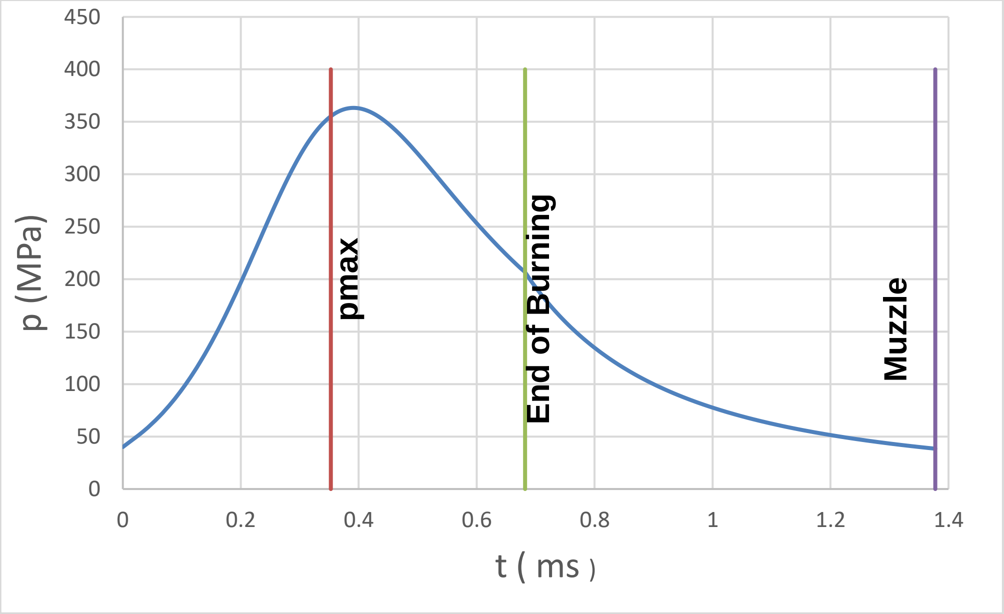


Figure 13. Pressure time curve

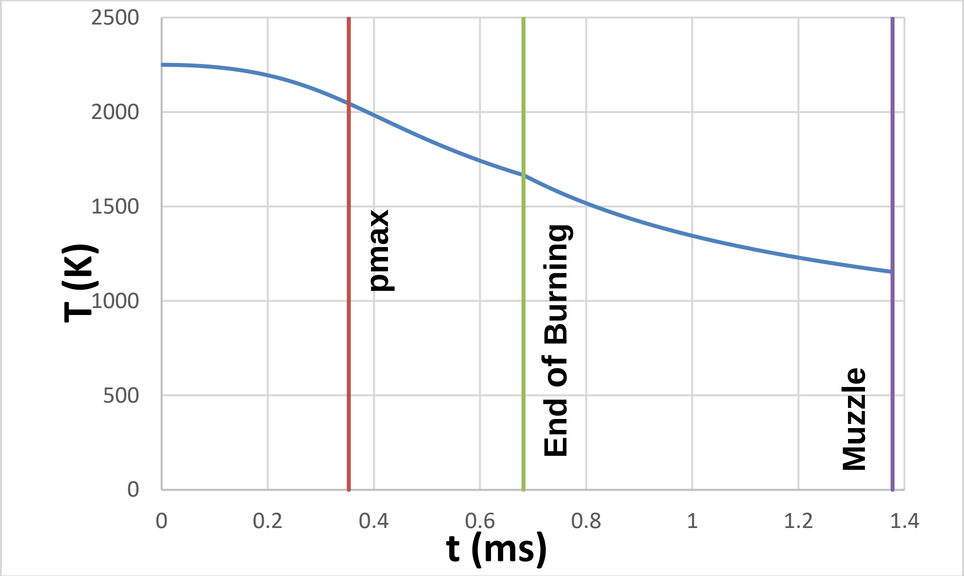


Figure 14. temperature time curve.

The most significant of these results are pressure changes with time and variation of temperature with time, because they represent the accumulation of thermo-mechanical loads that cause stress resulting from a single bullet on the bolt body.

Since one cycle of loading typically occurs for one bullet, fatigue is typically not a problem.

However, machine gun bolts go through a lot of cycles and fatigue is a big factor in its design [14].

Using these findings and understanding the machine gun's cycle of operation and how its high rate of firing distinguishes it.

3.3. *Import loads affecting on bolt body.*

The stresses on the bolt body are completely reversed cyclic stresses from the pressure and temperature caused by firing a full magazine of 100 rounds after calculating the pressure and temperature produced by firing one shot from the PKM machine gun. If the design was done properly, there is enough margin before a fatigue failure will arise when the maximum number of firings is compared to the weapon's design fatigue life [14].

The third step is applying boundary conditions and loading. The calculations of the internal ballistics show that the pressure and heat produced by the motion of the projectile directly affect the parts of the weapon, especially the bolt.

The function cycle of the machine gun is the time period for firing one shot, and it takes 1.4 milliseconds from the calculations of Internal Ballistics, of which actually 0.25 milliseconds is the actual time required for the projectile to exit the barrel, and the rest of the period is in which the lock is loosened by the bolt, the parts return to the back, the empty casing is knocked out, a new round is filled, and a new round is moved. Once again to seal the barrel.

From the calculations of Internal Ballistics, the temperature starts from 2300 and decreases until it reaches 1300 degrees Celsius (see ‘figure 15’). Cycle is repeated with each shot. Heat here is one of the main loads that affect the parts of the weapon and results in stresses that transfer and change with time. Therefore, the loads resulting from firing 100 rounds represents a transient thermal cyclic load in 25.751 sec as in the ‘figure 15’.

Heat is not only the load that results from the movement of the projectile until it exits the pipe, but there is pressure whose value changes with time and it represents a mechanical load transient that affects the bolt body and its value changes during one cycle from 30 MPa up to 355 MPa and decreases until it reaches 30 MPa Pascal (see ‘figure 16’), and this cycle is repeated with each shot. The load resulting from the firing of 100 rounds is a transient mechanical cyclic load in25.751 sec, as shown in ‘figure 16’.

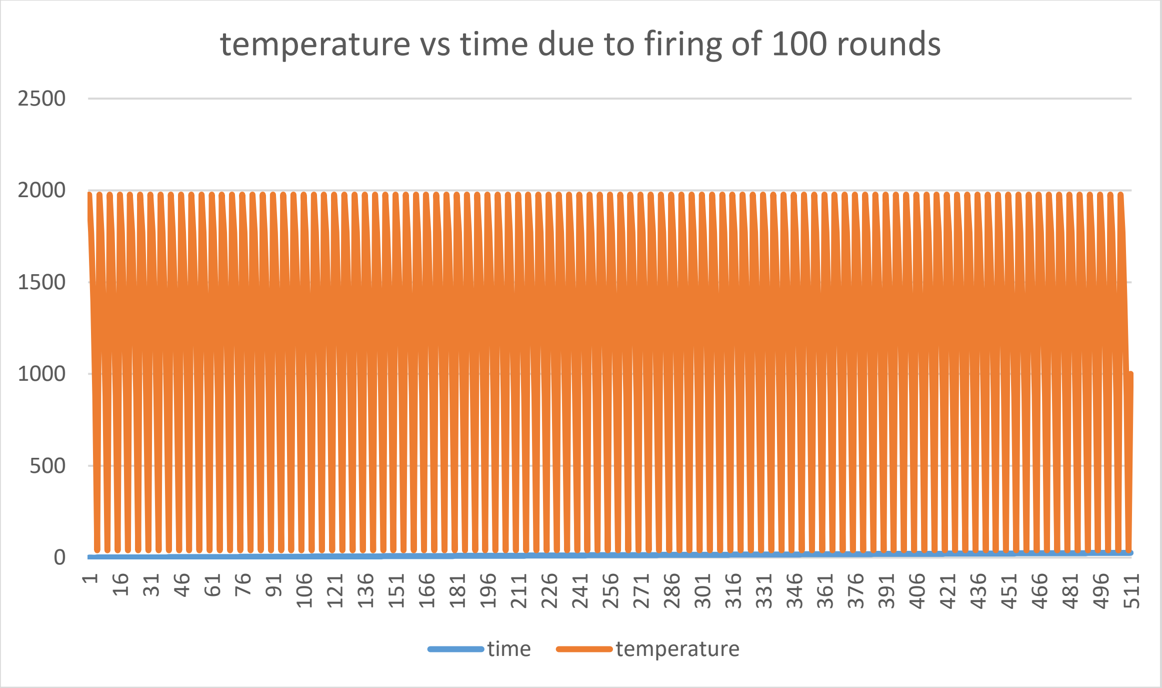


Figure 15. Temperature changes over time due to firing of 100 rounds.

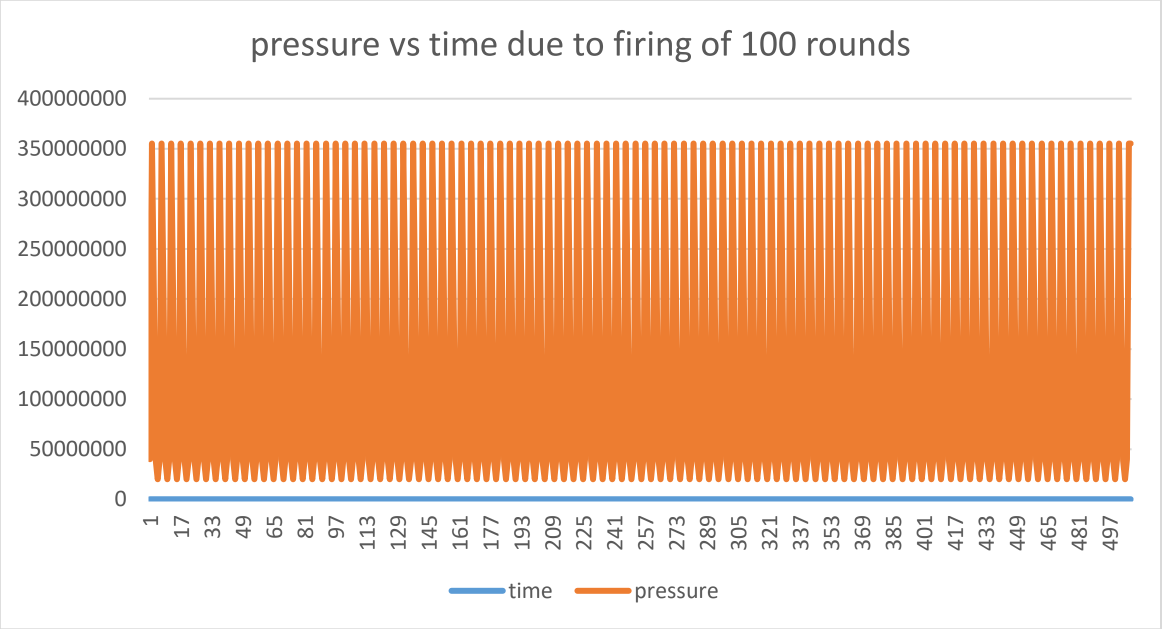


Figure 16. Pressure changes over time due to firing of 100 rounds.

From the metallurgical investigations, it was found that the fatigue failure occurred in locations affected by heat and others affected by mechanical pressure. Therefore, in order to accurately determine the cause of the failure, failure of the bolt body will be analyzed due to thermomechanical effect, these loads change with time, and as a result of the movement of the projectile, Therefor, they are transient cyclic loads result in the generation of repeating and fluctuating stresses.

In this research, an accurate and verified transient finite element model will be created and use it to investigate the fatigue life, and safety factor due to thermomechanical loads in the context of ANSYS Workbench 18.2 [15].

3.4. Analysis of Bolt's fatigue failure due to the thermomechanical loads

Temperature and pressure variation over time brought on by PKM machine gun high rate of fire where The temperature ranges from 228.03 °C to 1947.7 °C and the pressure is 20 MPa and 355 MPa at their lowest and highest points, respectively. They create thermomechanical loads their effect will be determined by Fatigue Life, and Safety Factor Analysis.

The lug of the bolt body is the portion that moves the bolt to make the bolt body lock and unlock, therefore it is the part that comes into contact with the machine gun body, is exposed to the majority of the mechanical load, and will be Fixed Support during the failure analysis of the bolt body (see ‘figure 17’).

100 bullets are fired by the machine gun in 25.751 seconds. A change in temperature during this time causes thermal accumulation in all of the bolt body's sections. (See ‘figure 18)’ reveals that the face of the bolt body, through which the temperature reaches 1000.1 degrees Celsius, is the highest portion in which thermal accumulation occurs. Because of the thermal effect, fatigue Life, fatigue Damage, and safety factor will be examined.

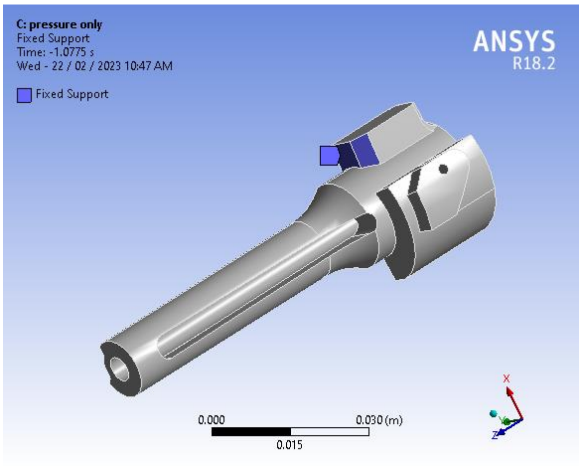


Figure 17. Fixed support (lugs)

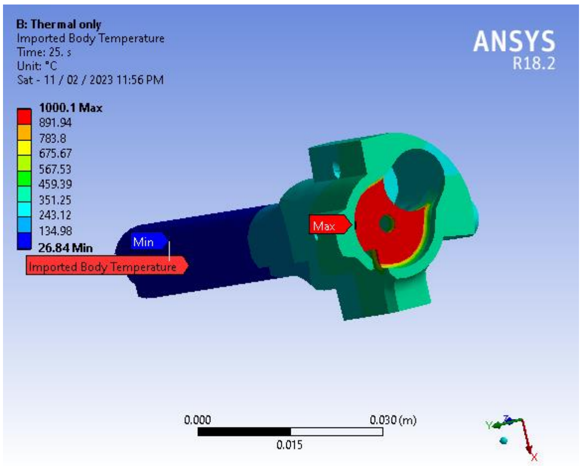


Figure 18. Imported body temperature at (bolt face) after 100 bullet.

The Boundary Condition is represented according to the function cycle of the machine gun in the face of the bolt body, as the heat generated from the rim of the bullet is distributed in this location. Also find that the lug represents the Boundary Condition because it bears the largest part of the mechanical load. As mentioned in Section 3.2, pressure and heat are the largest loads affecting the parts of the machine gun.

Thermomechanical loads lead to the Equivalent (von Mises) stresses being for the whole bolt body, as seen in ‘figure 19’. The lug of the bolt body has the maximum equivalent (von Mises) stresses, with a value of 1436.9MPa, and the face of the bolt body has equivalent (von Mises) stresses, with a value of

2129.5MPa, these two values are higher than the material's yield strength which is 930MPa. As a result, these locations are the most susceptible to failure of the bolt body segments.

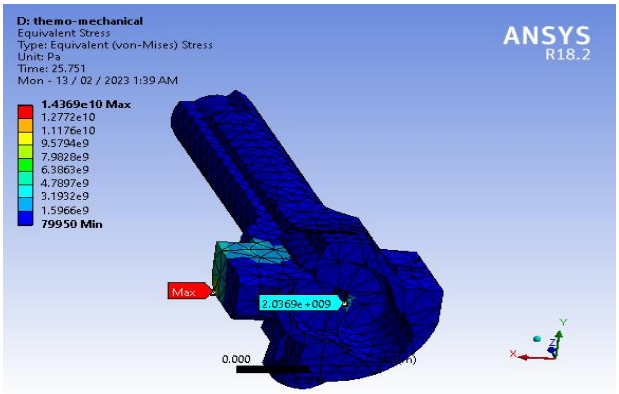


Figure 19. The Equivalent (von Mises) stresses being for the whole bolt body due to thermomechanical loads.

According to a Fatigue Life study of the bolt body portions, the lug is the portion that can withstand the fewest cycles before failing or the least element of the bolt body that can endure firing a number of bullets equal to 546.78 before failing as shown in ‘figure 20’. A total of 546.78 cycles have been performed by this portion. The face of the bolt body is the segment that can withstand For a small number of shots, compared to the rest of the parts of the Bolt Body, it is equal to 3075.4, and this means that the life expectancy for this part is equal to 3075.4, and it is concluded from these values that they are the first two parts that will be exposed to failure as a result of their exposure to thermo-mechanical stresses resulting from cyclic Loads arising from the high rate of fire.

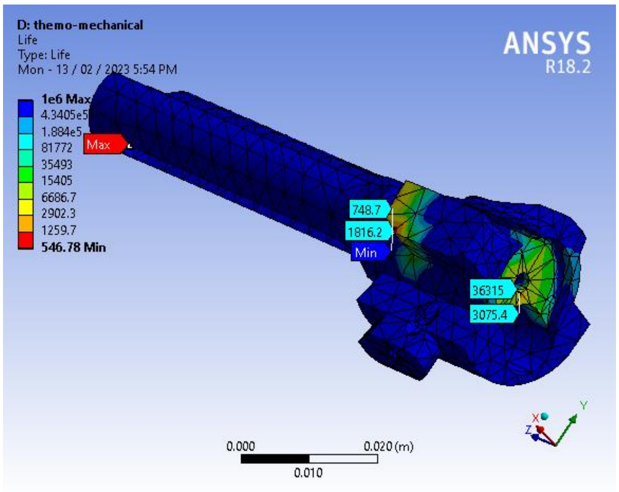


Figure 20. Fatigue life analysis of bolt body due to thermomechanical loads.

Safety factor analysis of the segments of the bolt body shows that the lug of the bolt body is the least of the safety factor segments of the bolt body as seen in ‘figure 21’ and is equal to 0.10829. The face of the bolt body equals to 0.18954. This implies that these segments are not the most failing, but rather the earliest segments. It was revealed by the findings of my fatigue analysis that the failure was caused by thermomechanical loads rather than only thermal accumulation or mechanical loads. The maximum portions in fatigue life and safety factor, which emerged concurrently as a result of thermomechanical loads, provided as confirmation of this.

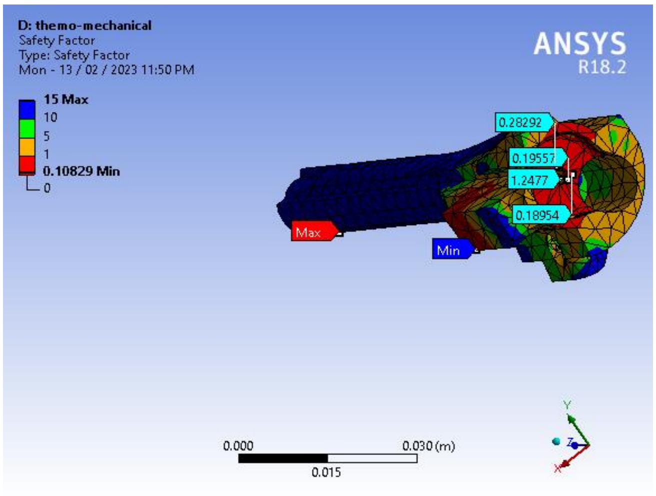


Figure 21. Safety factor analysis of bolt body due to thermomechanical loads.

4. Conclusions

After carefully examining earlier studies that dealt with the analysis of the failure of mechanical parts, especially those exposed to thermomechanical cyclic load, the failure analysis appropriate procedures are followed to assess the failure of the PKM bolt body, Which was caused by a thermomechanical cyclic loads resulting from the high rate of fire, which relied on firstly, metallurgical experiments to know the chemical composition, mechanical properties and their impact by the failure, macro examination of The failed part, SEM of the location where the crack initiated and the direction of the crack propagation, and the mode and type of failure, which is the most decisive test for the prediction of the type of mode of the failure, hardness measurements to evaluate the impact of failure on mechanical properties Secondly, to determine the precise timing of the failure, the primary cause of the failure, which part the failure occurred in first, and the best course of action to overcome this failure, the results were obtained by an accurate and verified finite element transient model can be relied on analyzing another failed parts The findings of this study lead to the following conclusions:

- Visual inspection virtually allowed us to locate the crack's beginning, which was helpful while SEM was being used.
- The results show that the failed bolt has chemical compositions that is inacceptable range according to the standard specifications. There is hardly any observable variation in chemical composition. Knowledge of chemical composition is essential.
- according to SEM data that show the commencement of a crack, the direction in which this crack is propagated, and the appearance of a dimpled fracture, which reveals that the bolt body underwent plastic deformation as a result of its exposure to high cyclic loads brought on by the high rate of firing.
- Hardness measurement show that there were no significant differences between the the failed bolt readings, and that were between (42 and 44) HRC. The absence of any hardness change during use or even after failure confirms that the steel is martensitic.
- The most significant result have obtained by applying modelling as a technique for failure analysis is the creation of an accurate and verified finite element transient model.
- My fatigue study' results showed that thermomechanical stresses, not just thermal accumulation or mechanical loads, were to cause the failure. This was supported by the lowest portions of fatigue

damage and the highest portions of fatigue life and safety factor, both of which occurred simultaneously as a result of thermomechanical loads.

- Modelling results are achieved and proven results by metallurgical experiments and are identical to reality compared to photographic records and are reliable in analyzing the failure of any part subjected to a thermomechanical cyclic load.

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