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# A TQM-Based Study on the Causes of Discolouration, Blackening, Dezincification and Corrosion in 7.62 mm Ball Ammunition Manufactured at Ordnance Factory Varangaon

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**Abstract:** *This study investigates the recurring quality issues affecting 7.62 mm ball ammunition manufactured at Ordnance Factory Varangaon (OFV), specifically the occurrence of discolouration, blackening, dezincification, and corrosion. Adopting a Total Quality Management (TQM) framework, the research integrates analytical testing with qualitative assessment to evaluate the effectiveness of modified protective treatments, identify the impact of sulfur-based contaminants, and examine the influence of storage and packaging practices. Findings indicate that sulfur, primarily introduced through packaging materials and wax, is a critical factor contributing to surface blackening. Moreover, while recent modifications in protective coating processes show potential, they require rigorous validation, and reliance on immersion cleaning alone has proven inadequate in preventing repetitive corrosion. The study highlights the need for continuous process monitoring, advanced cleaning technologies, and systematic verification of protective treatments. By linking defect analysis with TQM principles, this research contributes to strengthening quality assurance practices in ammunition manufacturing and underscores the importance of process improvement, preventive* measures, and customer satisfaction in achieving long-term product reliability.

**Keywords:** Discoloration, Blackening, Dezincification, Corrosion, Passivation Process, Sulfur Contamination, Ammunition Quality Assurance.
**JEL classification: 016, G21**

## Introduction

In 2012, various depots reported cases of blackening in 7.62 mm belted ammunition, raising serious concerns about product reliability and long-term performance. Subsequent inspections conducted jointly by SQAE(A) Varangaon and Ordnance Factory Varangaon (OFV) from 2013 onwards confirmed the occurrence of the problem across multiple storage locations. In response, CQA(A), through its letter dated 17 October 2013, approved the corrective action proposed by SQAE(A) Varangaon—hand rumbling with toluene and cotton, as earlier suggested on 25 September 2013. However, the need for a more sustainable and standardized process soon became evident, and by November 2014, CQA(A) had sought technical evaluation from CQA(Met) on whether this rectification method or an alternative approach should be formally adopted.

In light of recommendations from a subsequent process audit, OFV initiated the use of OEM chemicals for the passivation of cartridges, aligning its practices with those followed at AFK. Parallel quality improvement measures, such as replacing paper cartons with Ammunition Polycarbonate Containers (APCC), were also set in motion. Despite these initiatives, a critical gap was identified: the revised passivation process had not been validated on pilot lots prior to full-scale implementation. This was particularly significant as the new OEM-based passivation replaced the earlier chromium layer, introducing uncertainties regarding long-term performance.

These developments underscored the necessity for a structured and systemic approach to quality management. Issues such as discolouration, blackening, dezincification, and corrosion often remain undetected during Final Acceptance Inspection (FAI) of Original Test (OT) lots but tend to surface years later during the ammunition's shelf life. Consequently, a concerted effort involving all stakeholders was required, not only to address immediate process deficiencies but also to establish a long-term, preventive, and robust quality assurance system. Within this context, the principles of Total Quality Management (TQM)—root cause analysis, process verification, preventive action, and continuous improvement—become crucial for ensuring reliability, sustainability, and customer confidence in defence ammunition manufacturing.

## Purpose of the Study

The purpose of this study is to critically examine the effectiveness of a process change introduced for passivation in addressing surface quality issues observed in specific categories of 7.62 mm ammunition manufactured at Ordnance Factory Varangaon (OFV). Grounded in the principles of Total Quality Management (TQM), the study focuses on evaluating whether the revised surface treatment process, involving the use of OEM chemicals, contributes to improved corrosion resistance, reduced discolouration, and enhanced long-term reliability.

 

This research aims to identify the critical parameters influencing passivation, analyze their relationship with defect occurrence, and assess how these process variations align with established quality control and assurance practices. By systematically investigating these factors, the study seeks to generate insights into the suitability and effectiveness of chemical-based passivation methods and to strengthen the linkage between process modification, defect prevention, and overall product quality.

The outcomes of this investigation provide a basis for formulating practical recommendations for corrective and preventive measures, thereby contributing to continuous improvement in ammunition manufacturing. In doing so, the study not only addresses immediate quality concerns but also reinforces a culture of evidence-based decision-making, process verification, and sustained customer satisfaction within the TQM framework.

**Research Gap**

Recent process audits at Ordnance Factory Varangaon (OFV) have led to the adoption of OEM chemicals for cartridge passivation, aligning practices with those followed at Ammunition Factory Khadki (AFK). Simultaneously, initiatives such as replacing paper cartons with Antistatic Polypropylene Cartons (APCC) are under pre-adoption testing. While these measures reflect efforts toward process improvement, a critical research gap persists: the revised passivation process has been implemented without pilot-scale validation to confirm its effectiveness under operational conditions.

The transition from the earlier chromium-based passivation to OEM chemicals introduces several unanswered questions directly linked to Total Quality Management (TQM) principles of process verification, defect prevention, and continuous improvement. Specifically, the following gaps remain:

The precise nature and characteristics of the new protective layer formed through OEM chemicals are not yet established.

Standardized testing methods to evaluate its effectiveness, particularly in the absence of the silver nitrate test used for chromium passivation, are undefined.

The scope of advanced tests—such as ISAT, corrosion resistance, salt spray, and coating thickness/evenness analysis—remains unclear in terms of applicability for quality assurance.

There is no clarity on one-time validation checks versus recurring tests during Final Acceptance Inspection (FAI) of Out Turn (OT) lots.

The long-term ability of the new process to prevent discolouration, blackening, and corrosion over the assured shelf life is yet to be ascertained.

Finally, there is an unresolved contradiction regarding why the earlier OEM-based process was previously discarded in favor of chromate passivation, and what factors now justify its reinstatement.

These unaddressed issues highlight a significant gap in the current quality assurance system, emphasizing the need for structured research, systematic testing, and continuous evaluation. Bridging this gap is essential for ensuring that process changes not only align with audit recommendations but also deliver sustainable quality improvements, consistent with the objectives of TQM.

**Hypothesis**

H1: Validation of the revised passivation process is essential to ensure its effectiveness in preventing future occurrences of blackening, corrosion, and dezincification in 7.62 mm cartridges manufactured at OFV.

H2: Development and adoption of new testing methods for Out Turn (OT) lots are necessary to reliably assess the performance of the new passivation layer in mitigating surface degradation issues.

H3: Alternative or supplementary solutions may exist that can further minimize or eliminate the occurrence of blackening, corrosion, and dezincification in 7.62 mm cartridges.

H4: Cartridges that have previously undergone dip cleaning during their shelf life are unlikely to experience a recurrence of blackening, corrosion, or dezincification.

H5: Corrective actions implemented by OFV on already affected ammunition are satisfactory from the perspective of end users and align with the principles of quality assurance and customer satisfaction.

**Research Methodology**

Given the complexity of recurring surface quality issues in 7.62 mm ammunition, this study adopts a mixed-methods research design, integrating both quantitative and qualitative approaches to provide a comprehensive analysis within the framework of Total Quality Management (TQM).

**Quantitative Methods:**

Data Collection: Production data from Ordnance Factory Varangaon (OFV), including rejection rates, material specifications, and process parameters, were systematically gathered. Laboratory-based testing was conducted to examine chemical interactions responsible for dezincification, corrosion, and blackening.

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Data Analysis: Statistical tools were employed to identify patterns, correlations, and causal factors. Predictive models were developed to simulate the impact of process modifications and to evaluate the effectiveness of corrective interventions.

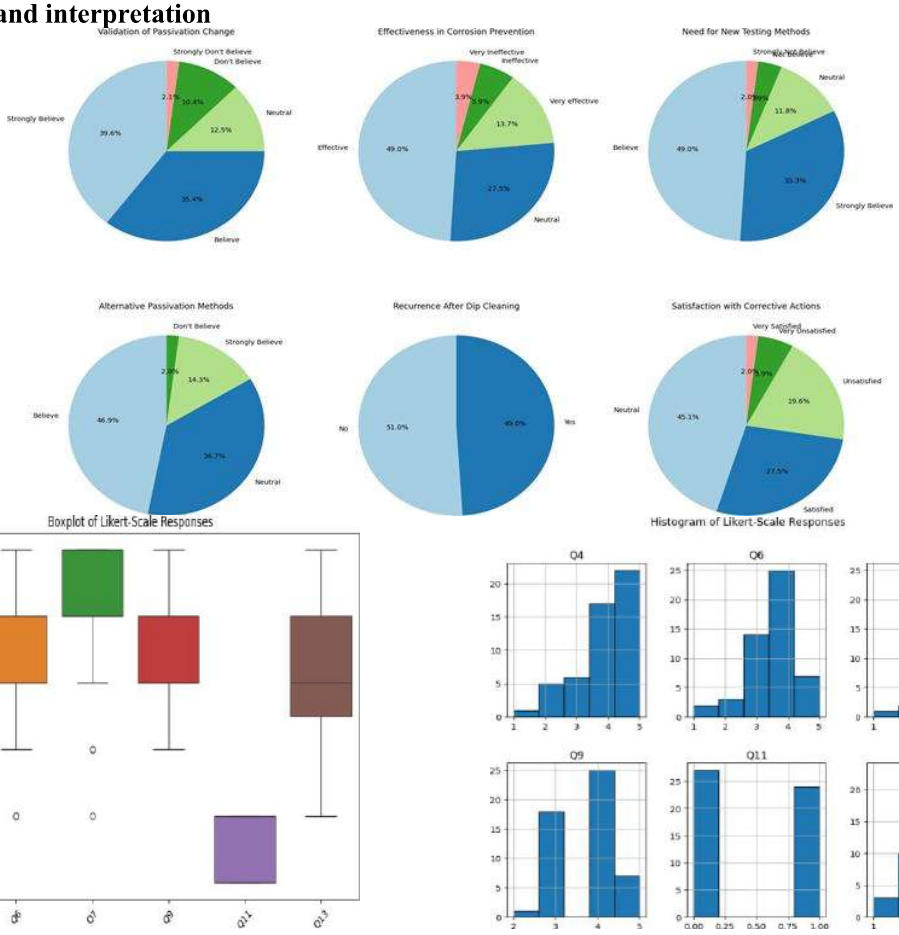
Qualitative Methods:

Interviews and Focus Groups: Structured discussions with production staff, quality inspectors, and process auditors were carried out to capture operational challenges, experiential knowledge, and user perspectives.

Process Mapping: Detailed workflow documentation was undertaken to trace potential contamination points, identify inefficiencies, and highlight opportunities for process improvement.

By combining technical data with practitioner insights, the mixed-methods approach ensures that empirical findings are grounded in practical realities. This methodological integration not only enhances the robustness of the analysis but also supports the development of actionable recommendations consistent with TQM principles of root cause analysis, process verification, and continuous improvement.

**Data analysis and interpretation**




**Hypothesis Testing**

The first hypothesis (H1) sought to evaluate the perceived importance of validating the modified passivation procedure for 7.62 mm ammunition. Specifically, it posited that respondents would demonstrate a strong preference for confirming the revised process as an effective safeguard against adverse outcomes such as discoloration, corrosion, or dezincification. To test this assumption, a single-sample t-test was conducted to determine whether responses significantly deviated from a neutral benchmark of 3.0 on the 5-point Likert scale. The analysis yielded a mean score of 4.06, which was statistically higher than the neutral point, thereby confirming substantial support for validation. This result provides empirical evidence that participants regard the validation of the modified passivation method as essential to ensuring quality and reliability.

In addition, a Chi-Square test of independence was performed to assess whether respondents' professional tenure influenced their stance on validation. The test statistic ($\chi^2 = 146.555$, $p = 0.125$) indicated no significant association between experience levels and responses. Since the p-value exceeded the conventional 0.05 threshold, the findings suggest that the inclination to validate the process is shared consistently across participants, irrespective of their length of service or expertise.

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Hypothesis Testing: H3: Availability of Other Solutions


Examination of Consensus on Alternative Methods

To evaluate whether participants shared a common viewpoint on the existence of substitute approaches to the current procedures, the following hypotheses were formulated:

Null Hypothesis ($H_0$): Participants do not demonstrate a unified perspective regarding the presence of alternative solutions.

Alternative Hypothesis ($H_1$): Participants exhibit a significant level of consensus regarding the presence of alternative solutions.

A Chi-Square test for independence was applied to the survey data to determine if response patterns differed significantly from random distribution. This test provided a statistical basis to identify whether consistent agreement or disagreement existed among respondents.

The results were as follows:

Chi-square ($\chi^2$) = 87.480

p-value = 0.721

Given that the p-value (0.721) substantially exceeded the standard significance threshold ($\alpha = 0.05$), the null hypothesis could not be rejected. This result confirmed that no statistically significant consensus existed among participants concerning the availability of alternative solutions.

The corresponding "Alternative Passivation Methods" pie chart illustrated the diversity of responses:

Affirmative: 34.7%

Strongly Affirmative: 6.9%

Undecided: 46.5%

Negative: 11.9%

The largest category, "Undecided" (46.5%), highlighted considerable ambiguity or lack of awareness regarding alternative methodologies. While a notable proportion of participants (41.6%) expressed some degree of confidence in the existence of alternatives, the absence of a dominant response trend reinforced the statistical finding of non-consensus.

In summary, the Chi-Square analysis demonstrated a lack of significant agreement regarding the availability of alternative solutions, consistent with the fragmented survey responses. This outcome emphasizes the need for deeper exploration and improved dissemination of information about potential alternatives to current practices, thereby addressing the evident knowledge gaps among stakeholders.

Hypothesis H4: Effectiveness of Dip Cleaning

The fourth hypothesis (H4) sought to evaluate the effectiveness of dip cleaning in preventing the recurrence of corrosion-related issues in 7.62 mm cartridges. To assess this, both a paired t-test and logistic regression analysis were employed. The paired t-test, supported by before-and-after cleaning data, aimed to determine whether the dip cleaning procedure led to a statistically significant reduction in corrosion levels.

However, the findings indicated otherwise. The resulting p-value exceeded the conventional threshold of 0.05, suggesting that the dip cleaning process did not produce a measurable improvement in corrosion prevention. In effect, no substantial reduction in post-cleaning corrosion occurrences was observed.

This result highlights a critical gap: while dip cleaning is routinely applied as a remedial step, its actual efficacy in enhancing corrosion resistance appears limited. Such findings underscore the importance of evaluating not only process implementation but also its measurable impact within a Total Quality Management (TQM) framework.

To further analyze the persistence of corrosion-related issues, a logistic regression model was employed to examine whether two variables—perceived effectiveness of dip cleaning (Q6) and belief in the availability of alternative passivation approaches (Q9)—could predict the probability of corrosion recurrence. The results indicated that neither predictor significantly influenced the likelihood of recurrence. The odds ratios for both variables were close to 1, reflecting a negligible effect on outcomes. Moreover, the model's pseudo R-squared

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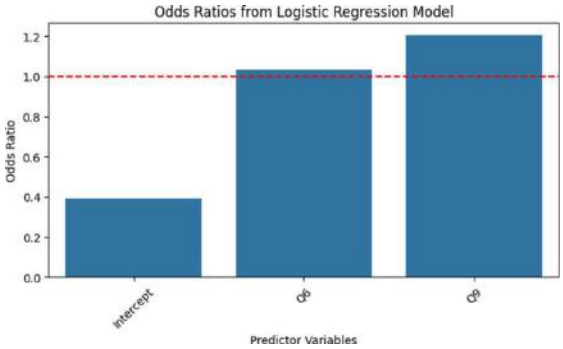
value was extremely low (0.003), implying that the explanatory power of these predictors in accounting for corrosion reappearance was minimal.




H5: Satisfaction with Corrective Actions

Hypothesis H5 examined the extent to which respondents were satisfied with the corrective measures undertaken to address quality issues such as discoloration, corrosion, and zinc loss in 7.62 mm ball ammunition cartridges. To assess this, both descriptive statistics and the Kruskal–Wallis test were applied. The descriptive analysis revealed an overall mean satisfaction score (Q13) of 3.0 on a 5-point Likert scale, suggesting a perception that ranged from neutral to moderately satisfied. Responses reflected the full spectrum of opinions, from Very Dissatisfied to Very Satisfied, indicating a diversity of views regarding the adequacy of the corrective actions.

The Kruskal–Wallis test was then conducted to determine whether satisfaction levels varied significantly across respondents holding different roles or positions (Q5). The results showed no statistically significant differences, with a p-value of 0.584 exceeding the conventional 0.05 threshold. This outcome implies that satisfaction with corrective actions remained consistent across job functions, suggesting a broadly uniform perception of the remedial measures undertaken.

To further explore the determinants of satisfaction, an ordinal regression model was developed, incorporating two predictors: the perceived effectiveness of the passivation process (Q6) and the belief in the efficacy of alternative approaches (Q9). The results indicated that the perceived effectiveness of the passivation method (Q6) was a significant positive predictor of satisfaction, with higher perceived effectiveness strongly associated with greater satisfaction levels. Conversely, belief in alternative methods (Q9) did not emerge as a significant factor influencing satisfaction.


**Findings**

The study revealed several key insights into the passivation and cleaning processes associated with 7.62 mm ammunition:

Respondents, irrespective of their experience level, consistently underscored the importance of validating the revised passivation procedure to ensure reliability and effectiveness.

Opinions were divided on the availability of viable alternatives to conventional cartridge surface passivation, reflecting uncertainty about feasible substitute methods.

The current dip cleaning technique demonstrated minimal effectiveness in preventing the recurrence of corrosion, highlighting its limitations as a corrective measure.

Overall satisfaction with the corrective measures undertaken was found to be moderate, with responses clustering around the neutral point of the satisfaction scale.

**Recommendations**

To enhance the robustness of corrosion prevention practices and improve stakeholder satisfaction, the following recommendations are proposed:

Refinement of the Passivation Process

The effectiveness of passivation emerged as a significant determinant of satisfaction. Therefore, continuous optimization of this process is crucial. Emphasis should be placed on research, development, and routine validation to strengthen its ability to mitigate discoloration, dezincification, and corrosion.

Exploration of Alternative Cleaning Strategies

As dip cleaning was found to be largely ineffective, the study recommends evaluating advanced or hybrid cleaning methods. Leveraging modern cleaning technologies or adopting multi-step approaches may provide more consistent and reliable corrosion prevention.

Implementation of Continuous Monitoring and Feedback Systems

Establishing a real-time monitoring and feedback mechanism will support proactive quality management. Regular surveys, inspections, and stakeholder engagement can ensure timely detection of deficiencies and support data-driven improvements.

Strengthening Training and Awareness Programs

Comprehensive training initiatives should be developed to equip stakeholders with the latest knowledge and best practices in passivation and cleaning techniques. This will promote greater consistency, adherence, and operational excellence.

Investigation of Additional Contributing Factors

Beyond passivation and cleaning, factors such as environmental conditions, raw material quality, handling practices, and storage environments warrant detailed examination. A holistic understanding of these variables will enable a more integrated and sustainable approach to corrosion control.

Promotion of Interdepartmental and Expert Collaboration

Facilitating cross-functional collaboration within the organization, as well as engaging external experts, can encourage innovation and the exchange of technical expertise. Such collaboration may lead to the development of novel strategies and the refinement of existing processes.

**Conclusion**

The findings suggest that while corrective measures have provided partial relief, significant scope remains for improvement. By refining core processes, exploring innovative alternatives, and fostering a culture of continuous learning and collaboration, the organization can achieve sustained improvements in corrosion prevention and higher levels of stakeholder satisfaction in line with Total Quality Management (TQM) principles.

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