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ANALYSIS OF WEAR FACTORS AFFECTING THE DURABILITY OF DRILLING CONSUMABLES IN A HETEROGENEOUS GEOLOGICAL ENVIRONMENT AT A URANIUM MINE IN NIGER

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ABSTRACT

This study investigates the factors affecting the wear and service life of drilling consumables in a heterogeneous geological environment at an open-pit uranium mine in Niger. Field monitoring was conducted from July to November 2022 to assess cutters, sleeves, hammers, shanks, and pins used on FlexiROC T35, DM45 HP, and Roc L8 drilling rigs. Their operational service lives were compared with theoretical service life and Best Interval performance targets. The results showed that shanks and pins exceeded 130% of their theoretical service life, whereas sleeves achieved approximately 80% of their Best Interval targets and hammers less than 63%. Reduced performance was associated with abrasive wear, variations in thrust and percussion parameters, and jamming related to inadequate cuttings clearance. To improve drilling performance, preventive sharpening intervals of 350 m for 3½-inch cutting bits and 550 m for larger diameters, sleeve rotation and reconditioning, and preventive hammer overhauls were proposed. These measures support target service lives of 3,850 m and 5,500 m for cutting bits and offer estimated annual savings of 3.32–5.45 million CFA francs. Extending consumable service life may also reduce material consumption and metal waste, although the associated environmental benefits require further quantification. Overall, integrating performance monitoring, preventive maintenance, and reconditioning can improve consumable durability, reduce operating costs, and promote resource efficiency in heterogeneous geological environments.

Keywords: Mining Drilling; Drilling Consumables; Geological Heterogeneity; Abrasive Wear; Service Life; Preventive Maintenance.

1 INTRODUCTION

In open-cast mining operations, drilling is a fundamental process that directly determines the overall performance of the production chain. It influences not only operating costs but also the efficiency of downstream operations, notably blasting, loading, transport and crushing fragmentation [1,2,3]. In this context, improving drilling efficiency is a key driver for optimising operational performance and reducing costs. This relies in particular on monitoring operations, analysing field data and adjusting the main controllable parameters, such as rotational speed, thrust force, blowback pressure and the optimal timing for tool replacement [1, 4].

However, drilling performance depends heavily on the durability of the consumables used. The service life of drilling tools results from a complex interaction between the mechanical and geotechnical characteristics of rock formations, operational conditions and the properties of the equipment. In particular, it tends to decrease as the mechanical strength, hardness and abrasiveness of the formations being drilled through increase [1, 5, 6]. Parameters such as unconfined compressive strength, the Cerchar index, Schmidt hardness, equivalent quartz content and drillability indices thus account for a significant proportion of the variability in wear and the drilling advance achieved by the tools [5, 6].

Premature wear of consumables therefore constitutes a significant technical and economic constraint. It leads to a gradual reduction in penetration rate, an increase in downtime and a rise in the frequency of replacement operations, thereby contributing directly to higher drilling costs [1, 7]. From an industrial performance perspective, managing the service life of consumables therefore becomes a key factor in improving net run-out, minimising downtime and reducing the unit cost per metre drilled.

Recent research shows that drilling optimisation becomes more robust when approached in an integrated manner, taking into account geological uncertainties, tool life, operating parameters, operating costs and interactions with the various stages of the drilling-blasting-fragmentation chain [2, 3]. In line with this, optimal replacement models show that even a moderate extension of tool service life can have a significant effect on total replacement costs, provided that decisions are based on the analysis of failure, wear and maintenance data [1].

Furthermore, the development of systems for monitoring wear, predicting failures and estimating the remaining service life of tools confirms the growing importance of preventive, data-driven management. These approaches help to reduce unplanned downtime, improve equipment availability and optimise the overall efficiency of drilling operations [7, 8, 9]. Improving the durability of consumables should therefore no longer be viewed solely as a matter of replacing worn parts, but as a comprehensive issue of managing their life cycle.

This issue is of particular importance in the context of uranium mining in Niger. This study forms part of the broader context of uranium mining in Africa, where Niger plays a significant role due to the scale of its deposits [10]. This extractive activity is, however, accompanied by growing demands regarding the management of operational impacts, environmental governance and the reduction of risks associated with mining activities [10, 11].

In this context, the assessment of drilling performance can no longer be limited solely to the immediate cost of purchasing consumables. The mining industry now faces growing challenges relating to the prudent use of resources, the reduction of metal waste and the improvement of material and energy efficiency [12, 13]. Extending the service life of components, reusing them, reconditioning them and recycling them are therefore strategies that can reduce the consumption of raw materials and the waste generated, whilst helping to reduce the environmental footprint associated with the production and use of metallic materials [13, 14, 15].

The environmental aspect of the sustainability of consumables is thus closely linked to the principles of the circular economy. By extending the service life of cutting tools, sockets, hammers and other transmission components, and by promoting their remanufacturing or recovery at the end of their life, it becomes possible to reduce the frequency of equipment replacement, the consumption of metallic resources and the quantity of waste generated. This approach also improves the overall eco-efficiency of the drilling system by combining technical performance, cost control and the reduction of environmental impacts [13, 14, 16].

Thus, the scientific challenge is no longer solely to reduce the consumption of drilling components, but to better manage their entire life cycle from an integrated perspective encompassing operational performance, technical and economic optimisation, and environmental sustainability. Despite the recognised importance of geotechnical, operational and economic parameters in the study of tool wear, their integration into a holistic approach that simultaneously addresses the durability of consumables, drilling costs and the reduction of environmental impacts represents a major challenge for mining operations.

It is with this in mind that the present study focuses on the technical, economic and environmental optimisation of the durability of drilling consumables used at the uranium mine in Niger. It aims to analyse the durability of the main drilling consumables, to identify the operational mechanisms responsible for underperformance and deviations in drilling output, and then to propose an optimisation model based on improved field practices, preventive maintenance, wear monitoring and the reconditioning of parts. The objective is to demonstrate that integrated management of cutting bits, sleeves, hammers and drive components can increase effective drilling output, reduce direct drilling costs, limit the production of metal waste and contribute to improving the eco-efficiency and environmental sustainability of the mining system.

2 MATERIALS AND METHODS

2.1 Study framework and geological context

The study was carried out at the mining site, located in the Tim Mersoï basin in northern Niger. The mining operations considered in this study relate to three main deposits or open-cast pits: Artois, Satellite and Taossa, separated by logistical distances of between 4 and 7 km.

The geological formations traversed during stripping and extraction operations exhibit significant lithological heterogeneity, characterised in particular by alternating layers of abrasive sandstone, claystones and hard silicified formations. These geological characteristics are likely to exert significant mechanical and tribological stresses on drilling consumables.

The decision to incorporate the lithological context into the analysis is based on the fact that the service life of drilling tools is closely dependent on the mechanical and abrasive properties of the rocks encountered. The wear of cutting edges can, in particular, be influenced by mechanical strength, hardness, abrasiveness, as well as various geotechnical and tribological indices [6, 17]. More specifically, uniaxial compressive strength, hardness, abrasiveness and equivalent quartz content are important parameters in explaining the variability in the service life and wear of drilling tools [5, 6].

2.2 Drilling equipment and consumables under consideration

The experimental monitoring focused on the rotary percussion drilling rigs in operation at the mine site, which are representative of the production fleet.

The FlexiROC T35 drill rigs – units 457, 458 and 459 – were monitored primarily during overburden removal and fine-seam drilling operations. This equipment primarily uses 3½-inch diameter cutters.

The DM45 HP and Roc L8 drills were considered for larger-diameter drilling operations, carried out mainly during overburden removal work. They use 6-inch and 6¾-inch diameter cutters, combined with down-the-hole hammers (FTH).

The consumables assessed were grouped into two main categories:

- transmission components, comprising T38 shanks and D60 drive pins;
- cutting tools and accessories, comprising 3½-, 6- and 6¾-inch cutters, COP54 and M6 coupling sleeves, and down-the-hole hammers.

This selection enabled an analysis of the durability of the main consumables directly involved in the transmission of drilling energy and in the interaction between the equipment and the rock mass.

2.3 Data collection protocol and operational monitoring

The experimental protocol was based on direct monitoring of drilling operations and the analysis of production and maintenance data available on site. This approach combines the observation of operational parameters, the monitoring of tool performance and the analysis of wear and failure histories, in line with the approaches used in studies on the performance and service life of drilling tools [1, 6, 18].

2.3.1 Assessment of the application of standard drilling parameters

The effective application of standard drilling parameters was assessed using instrumented observation sheets and recordings made directly in the equipment cabs.

The main parameters monitored included:

- Thrust pressure;
- Impact pressure;
- Blowback or flushing pressure.

The readings from the pressure gauges on each drill rig were recorded during operations in order to identify the frequency and magnitude of fluctuations relative to the nominal ranges defined by the maintenance department.

Monitoring of operational parameters is justified by their influence on the dynamic response of the drilling system and on tool wear mechanisms. Parameters relating to thrust, rotation and impact energy can indeed alter the stresses applied to the tools and influence their behaviour in service [17, 19].

2.3.2 Monitoring the durability of consumables and the quantities produced

The service life of consumables was monitored on a daily basis by analysing the FI12 work order forms and recording the linear measurements in a dedicated database.

For each consumable monitored, the cumulative linear measurement was calculated from the time it was put into service until its withdrawal, replacement or scrapping following accidental damage. The data was cross-referenced and validated against the consolidated production data provided by the Mine and Operations Control (MCO) department.

The main performance indicator used in this study is the actual linear distance covered by each consumable, expressed in metres per tool prior to its withdrawal from service. This indicator allows for a direct assessment of the relative consumption of tools and provides a relevant basis for analysing their service life and operational performance [1, 6].

2.3.3 Analysis of the mechanisms underlying underperformance

The data collected were used to identify the main factors associated with variations in the durability and performance of consumables. The analysis focused on the relationship between the length of drilling completed, the conditions under which the tools were used, compliance with standard drilling parameters, and the various types of wear or damage observed.

Particular attention was paid to situations where operations deviated from standard parameters, instances of premature wear, accidental damage, jamming, and the early replacement of consumables.

This analysis made it possible to distinguish between limitations associated with geological and lithological characteristics and those potentially linked to operational conditions and maintenance practices. This distinction represents an important step in identifying ways to improve the service life of the tools.

2.3.4 Modelling of technical, economic and environmental optimisation

The optimisation process was developed using an integrated approach combining improvements to the technical durability of consumables, a reduction in direct drilling costs and improvements to the eco-efficiency of operations.

This approach is based on the principle that data relating to the service life, failures and replacements of tools can be used to determine operating and replacement conditions that balance performance with cost control [1].

2.3.5 Assessment of the potential for technical optimisation

The assessment of the potential for improving the service life of consumables was based on three main intervention mechanisms: optimisation of cutting edge sharpening, geometric restoration of sleeves, and preventive maintenance of down-the-hole hammers.

2.3.5.1 Optimisation of the sharpening interval for cutting edges

Improvements to the service life of cutting edges were investigated by adjusting the preventive resharpening interval. The analytical model was established using the technical resharpening charts employed on site.

The analysis involved, in particular, comparing the observed regrinding practice – which may take place after drilling distances exceeding 1,200 m – with target preventive intervals of 350 m and 550 m. This approach aims to limit excessive degradation of the carbide buttons and reduce the risk of chipping or irreversible wear.

2.3.5.2 Geometric restoration of the sleeves

The potential for extending the service life of the sleeves was assessed using two restoration mechanisms.

The first involves periodic angular rotation to distribute stresses and reduce asymmetric wear.

The second involves hard surfacing of worn areas to restore the functional geometry of the components. An additional thickness of 3 mm on the outer diameter was incorporated into the restoration model.

2.3.5.3 Preventive maintenance of down-the-hole hammers

Optimising the durability of down-the-hole hammers was based on a preventive reconditioning strategy triggered at a drilling depth threshold of 8,000 m.

This strategy involves the early replacement of wear parts using a cost-effective kit before a major failure occurs. It also includes improving the conditions for clearing and cleaning the platforms in order to reduce the risk of jamming and the downtime associated with operational incidents.

2.4 Technical and economic assessment

The economic analysis was carried out on the basis of the stripping and extraction programme, corresponding to a total volume of 20 million tonnes and requiring approximately 320,500 linear metres of drilling.

Direct costs were calculated by isolating the item relating to drilling consumables and by comparing observed operating conditions with the proposed optimisation scenarios.

The technical and economic assessment focused in particular on:

- The effective drilling length achieved per consumable;
- The replacement frequency;
- The potential for extending service life;
- The projected reduction in parts consumption;
- The reduction in costs associated with consumables;
- The impact of maintenance and reconditioning activities.

Data relating to tool service life and failures were thus used as the basis for analysing opportunities to optimise replacement costs and operational reliability [1].

2.5 Environmental assessment and eco-efficiency analysis

The environmental dimension of the study was assessed indirectly using an eco-efficiency approach that links operational performance to resource consumption and the undesirable impacts associated with drilling activities. This approach takes into account, in particular, the inputs utilised by the system, the energy consumed and the various undesirable outputs generated during operations [20, 21].

In this study, environmental eco-efficiency was assessed using three main indirect indicators:

- Specific diesel fuel consumption, expressed in litres per metre drilled;
- Potential direct carbon dioxide (co_2) emissions associated with fuel consumption during drilling operations;
- The quantity of metal waste avoided, estimated on the basis of the reduction in the number of consumables discarded thanks to improvements in their service life, maintenance and refurbishment.

Reducing drilling times under off-parameter conditions, minimising jamming incidents and reducing lost footage or secondary drilling operations are therefore potential levers for improving energy efficiency. From this perspective, improved operational performance can help to reduce specific fuel consumption per metre drilled and, indirectly, the associated CO_2 emissions.

Environmental optimisation has also incorporated a strategy of reducing metal waste at source. Extending the service life of cutters, sleeves, hammers and other transmission components, combined with their preventive maintenance and refurbishment where technically feasible, helps to reduce the frequency of replacement and the quantity of scrapped parts.

Thus, the eco-efficiency assessment has made it possible to integrate technical, economic and environmental considerations into a single approach to analysing the sustainability of drilling consumables.

3 RESULTS

3.1 Operational performance and durability of drilling consumables

The experimental monitoring carried out on the FlexiROC T35, DM45 HP and Roc L8 drilling rigs enabled a quantitative assessment to be made of the performance and durability of the main drilling consumables used on site. The observed performance was compared with the initial service life predictions, expressed in terms of the Best Interval (BI).

The results are presented in Table 1, which summarises the drilling distances achieved by the various consumables as well as their performance levels relative to the theoretical targets.

Table 1: Comparative assessment of the operational performance and drilling distances achieved by the drilling consumables on site.

Tool category	Specification / Machine	Projected Footage / BI (m)	Average actual footage (m)	Achievement Rate (%)	Main Cause of Scrapping / Findings
Shanks	T38	4,000	> 5,200	> 130 %	Normal tribological wear; overloading of the power transmission.
Pins	D60	5,000	> 5,000	> 100 %	Uniform wear of the threads under correct lubrication.
Cutting edges	3½" (Flexiroc T35)	3,500	3,500 – 4,000	100 – 114 %	Target reached; premature fractures in the splines and chipping of the pins.
Cutting edges	6" & 6¾" (DM45 / Roc L8)	5,000	5,000 – 5,500	100 – 110 %	Nominal service life reached; increased abrasive wear in the mining sector.
Sockets	COP54 & M6	5,000	4,000	80 %	Premature reduction in outer diameter due to abrasive ground conditions and blow-out pressure.
Hammers	Down-the-hole hammers (FTH)	13,000	< 8,272	< 63 %	Premature scrapping due to jamming in the borehole following incomplete clearance of the platform.

Analysis of the results highlights significant variability in performance across different categories of consumables. Two main patterns of behaviour were observed: transmission components, which outperformed the initial targets, and cutting tools and accessories, which exhibited more variable performance.

3.1.1 Performance of transmission components

The drilling components, consisting mainly of T38 shanks and D60 pins, delivered the best performance observed during the monitoring period. The drilling lengths achieved exceeded the theoretical values defined in the Best Interval, with achievement rates of over 130 per cent.

These results reflect the high durability of these consumables under the operational conditions observed at the site. The T38 shanks and D60 pins thus constitute the category of consumables with the highest performance levels amongst the equipment studied .

3.1.2 Cutting edge performance

The results obtained for the cutting tools generally show that the performance targets set for the various tool categories have been met. However, differences were observed between the drilling units.

Comparative monitoring of the FlexiROC T35 drill rigs shows, in particular, that unit 459 has a lower output than units 457 and 458. This difference is linked to more frequent fluctuations in thrust and percussion parameters observed during operations.

The results thus highlight variability in the durability of the cutting bits depending on the conditions of use of the equipment and the stability of the operational parameters.

3.1.3 Performance of drive sleeves

The drive sleeves are underperforming compared with the targets initially set. The average length observed is approximately 4,000 m, compared with a forecast of 5,000 m, corresponding to an average performance shortfall of around 20 per cent.

Drill sleeves therefore represent a category of consumables with significant potential for improvement. The main issues observed relate to the gradual wear of stressed areas and the deterioration of their functional geometry during drilling operations.

3.1.4 Performance of down-the-hole hammers

Down-the-hole hammers are the category of consumables with the lowest performance relative to theoretical targets. The results show that their actual service life remains below 63 per cent of the expected service life.

Analysis of the monitoring records shows that scrapped hammers were mainly taken out of service as a result of irreversible jamming. These failures are mainly associated with the conditions under which the platforms are cleaned and with rock fragments or other materials falling onto the drill string.

The results thus show that failures of down-the-hole hammers are one of the main factors reducing the overall durability of the consumables studied.

3.2 Technical and economic optimisation of the sustainability of consumables

Based on the results of operational monitoring and the annual extraction programme, requiring approximately 320,500 linear metres of drilling, an optimisation scenario was developed.

This scenario is based primarily on improving preventive maintenance practices, adjusting sharpening intervals, refurbishing worn parts and carrying out preventive reconditioning of consumables.

- The results of the analysis identified three main areas for optimisation:
- Adjusting the sharpening interval for cutting edges;
- Restoring and extending the service life of sleeves;
- Preventative maintenance and reconditioning of down-the-hole hammers.

3.2.1 Optimisation of the sharpening pitch of the cutting edges

The modelling results show that adjusting the sharpening interval is one of the key factors in improving the service life of cutting edges.

The practices observed correspond to sharpening intervals of up to 1,200 to 1,400 m. Modelling of shorter preventive intervals has made it possible to estimate an improvement in the potential cumulative service life of the cutting edges.

The results obtained are presented in Figure 1.

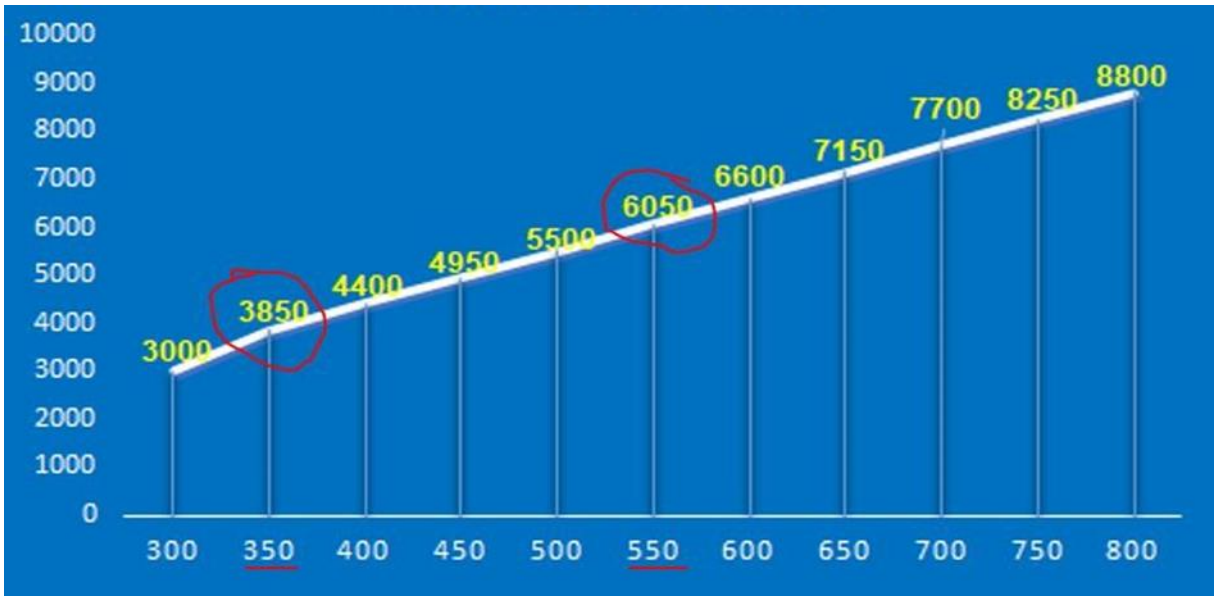


Figure 1: Estimated cumulative service life of cutting edges as a function of the preventive sharpening interval.

For 3½-inch cutting edges, applying a preventive sharpening interval of 350 m results in an estimated cumulative service life of 3,850 m, corresponding to an improvement of approximately 10 per cent.

For 6-inch and 6¾-inch cutters, applying a sharpening interval of 550 m results in an estimated potential of 6,050 m. Under the conservative scenario adopted for the technical and economic analysis, a value of 5,500 m was used.

The results thus show that reducing the intervals between sharpening operations increases the potential service life of the cutting edges.

3.2.2 Optimising the service life of bushings

Two complementary technical solutions have been adopted to improve the durability of the drive sleeves.

The first solution involves the periodic angular rotation of the skirt, which distributes the stress zones and limits asymmetric wear. The estimated increase in service life achieved by this approach ranges from 15 to 20 per cent, corresponding to approximately 800 to 1,000 metres of additional service life.

The second solution involves hard surfacing to restore worn areas and extend the service life of the components. The restoration scenario involves adding an extra 3 mm to the outer diameter.

These results show that restoring the sleeves is a technical solution that extends their service life and reduces the frequency of component replacement.

3.2.3 Optimising the maintenance of down-the-hole hammers

The findings regarding down-the-hole hammers show that improving their service life depends primarily on reducing damage caused by jamming and on implementing preventive maintenance.

The optimisation scenario involves more thorough cleaning of the platforms in order to minimise material fallout and reduce the risk of the drill string becoming jammed.

Furthermore, preventative reconditioning of the hammers has been proposed once a drilling depth of 8,000 m has been reached. This operation involves the preventative replacement of wear parts using a cost-effective kit.

Implementing this strategy is estimated to yield a potential gain of an additional 3,250 m per unit.

3.2.4 Summary of technical and economic benefits

The various optimisation scenarios applied to cutting bits, sleeves and hammers make it possible to extend the potential service life of consumables and reduce the frequency with which they need to be replaced.

The results relating to technical gains, revised targets and financial impacts are summarised in Table 2.

Table 2: Summary of technical optimisation levers, revised sustainability targets and associated financial impacts.

Consumables	Initial Target (m)	Optimised Item / New BI (m)	Gain de Métrage (%)	Technical Action Lever	Estimated Annual Savings (FCFA)
3½-inch cutting blades	3,500	3,850	+ 10 %	No preventative sharpening at 350 m.	Reduction in replacement stock
6-inch/6¾-inch cutting blades	5,000	5,500	+ 10 %	No preventative sharpening at 550 m.	Reduction in replacement stock
Sockets	5,000	5,000 – 5,800	+ 25 à 45 %	Angular rotation (Option A) / Hard resurfacing +3 mm (Option B).	425,600 (Option A) to 2,128,000 (Option B)
FTH hammers	13,000	13,000	+ 57 % *(vs réel)*	Rig refurbishment and economy kit at 8,000 m.	1,729,000
TOTAL PROJECT	--	--	--	Overall fleet optimisation	3,323,446 FCFA (Conservative) to 5,451,446 FCFA (Optimistic)

3.3 Operational constraints affecting drilling performance

3.3.1 Impact of travel between operational areas

An analysis of drilling operations shows that the net productivity of the equipment is influenced by the spatial layout of the mining areas.

The Artois, Satellite and Taossa pits are separated by distances ranging from 4 to 7 km, requiring regular transfers of drilling equipment on truck-mounted rigs.

Operational data show that a move results in an average downtime of around one hour. These transfer times reduce the actual time available for production and affect the fixed cost per linear metre drilled.

3.3.2 The influence of geological conditions on the performance of consumables

The results also show that the performance of the tools varies depending on the lithological conditions encountered during operations.

In areas characterised by harder formations, particularly in certain parts of the Artois mining block, more rapid wear of the cutting elements was observed.

Difficulties associated with cleaning the boreholes also constitute a significant operational factor. When debris is not fully removed, material can fall back into the annulus and cause the drill string to jam.

These conditions are associated with an increased risk of damage and premature withdrawal of the hammers and cutters.

3.4 Results relating to the environmental eco-efficiency of drilling operations

3.4.1 The impact of drilling quality on downstream operations

The results highlight the impact of the quality of drilling operations on several stages of the mining process.

In particular, controlling hole geometry and adhering to drilling parameters influence the quality of blasting and fragmentation.

Over-drilling and excessive hole diameters are associated with increased explosives consumption. Conversely, excessively wide drilling grids can lead to insufficient fragmentation and the formation of blast stubs.

The presence of blocks larger than the permissible size also poses a constraint on loading and transport operations. The operational limits considered in this study are 1.5 m in the overburden and 0.80 m in the mining face.

Oversized blocks may require additional secondary drilling (FO2), leading to an increase in equipment operating time.

3.4.2 Potential for improving eco-efficiency and reducing CO_2 emissions

The results of the technical and operational analysis show that several optimisation measures offer potential for improving the eco-efficiency of drilling operations.

Improving tool durability, maintaining an appropriate penetration rate and reducing secondary drilling operations help to limit unproductive equipment running times.

Reducing lost footage due to jamming, damage and secondary drilling also helps to reduce the overall equipment running time.

No direct measurements of gaseous emissions were carried out during the study. However, the reduction in operating hours and in specific diesel fuel consumption per metre drilled indicates potential for reducing direct carbon dioxide (CO_2) emissions associated with drilling operations.

The results also show that the refurbishment of sleeves and the reconditioning of hammers help to extend the service life of consumables and reduce the number of parts scrapped.

These actions thus help to reduce the production of metal waste and strengthen the environmental aspect of optimising drilling consumables.

4 DISCUSSION

The results highlight significant differences in durability between the drive components and the cutting tools directly involved in rock fragmentation. The superior performance of the T38 shanks and D60 pins, with achievement rates exceeding 130%, may be explained by their lower direct exposure to abrasive wear compared with the cutting tools. This observation is consistent with previous studies showing that the service life of drilling tools is strongly influenced by the mechanical and abrasive properties of rock formations, particularly their compressive strength, hardness, and abrasiveness [5, 6]. Abrasion is a major mechanism of tool degradation and can lead to edge blunting, groove formation, cracking, and localized fracture of active components [17, 22].

The differences in performance observed between the drilling rigs, particularly the lower performance of the FlexiROC 459, further highlight the influence of operating conditions on consumable durability. Variations in feed force, rotational speed, and impact parameters can affect drilling-system performance and accelerate wear mechanisms [17, 19]. Under the geological conditions of the uranium mine studied in Niger, appropriate control of operating parameters therefore appears essential for limiting premature wear and improving the service life of drilling consumables.

The sleeves and down-the-hole (DTH) hammers exhibited the lowest performance. This finding may be associated with the stresses imposed by hard and abrasive rock formations, which can reduce effective drilling length and accelerate consumable degradation [7, 23]. The limited service life of the DTH hammers is particularly noteworthy because their performance depends on several factors, including internal design, air consumption, impact frequency, and the balance between impact and rotation parameters [7, 23]. In addition, the jamming incidents recorded at the site highlight the importance of maintaining clean drilling platforms and ensuring the effective removal of cuttings to minimize operational interruptions and associated equipment stresses.

From a technical and economic perspective, the results suggest that consumable durability could be improved through preventive maintenance rather than by continuing to use components until failure. Previous research on the optimization of replacement intervals indicates that effective maintenance strategies require a balance between replacement costs, progressive performance deterioration, and the risk of unexpected failure [1]. In this context, preventive sharpening of cutting edges, the rotation and reconditioning of sleeves, and the restoration of DTH hammers represent potential strategies for extending service life and improving consumable management.

The potential benefits of more frequent sharpening are also consistent with research indicating that effective tool management should balance productivity and wear rather than maximize component use before intervention [18].

Similarly, monitoring the drilling distance achieved by each consumable and documenting failure histories can help establish replacement and reconditioning intervals adapted to actual operating conditions [1]. Restoration and reconditioning may also offer significant benefits, as previous studies have shown that improvements in component geometry, materials, and operating conditions can extend the service life of equipment subjected to demanding mechanical conditions [7, 23].

Nevertheless, the environmental implications of the present study should be interpreted cautiously. Restoring sleeves and reconditioning hammers may extend component service life and reduce metal waste, in line with the principles of resource efficiency and circularity [13], [21]. Furthermore, reducing secondary drilling, jamming incidents, and equipment downtime could potentially lower diesel consumption per unit of drilling output. However, this environmental benefit remains an indirect inference because fuel consumption and CO_2 emissions were not measured directly in the present study [1, 18].

Overall, optimizing the durability of drilling consumables at the uranium mine investigated in Niger offers potential technical, economic, and environmental benefits. The findings indicate that improved control of drilling parameters, preventive maintenance, and appropriate reconditioning practices may extend consumable service life and reduce replacement requirements. From an environmental perspective, these measures could contribute to reducing metal waste and material consumption. However, further investigations involving direct measurements of diesel consumption, expressed in litres per metre drilled, and CO_2 emissions, expressed in kilograms per metre drilled, are required to quantify and confirm these potential environmental benefits.

5 CONCLUSION

This study assessed the durability of drilling consumables used at a uranium mine in Niger and examined potential strategies for improving their technical, economic, and environmental performance. The results revealed substantial differences in service life among consumable categories. T38 shanks and D60 pins achieved the best performance, whereas sleeves and down-the-hole hammers showed comparatively lower performance against the established targets.

The findings indicate that consumable durability is influenced by the interaction between geological conditions and operational factors, including rock abrasiveness, drilling parameter stability, and cuttings removal. These results highlight the importance of systematic performance monitoring and preventive maintenance in reducing premature wear and operational interruptions.

The proposed optimisation measures, including preventive sharpening of cutting edges, sleeve restoration, and timely hammer reconditioning, offer practical options for extending consumable service life and reducing replacement requirements. Their effectiveness should be evaluated under actual operating conditions to determine the most appropriate maintenance intervals and quantify the resulting economic benefits.

From an environmental perspective, extending component service life and reconditioning consumables may reduce material consumption and metallic waste. Potential reductions in fuel consumption and associated CO_2 emissions through fewer operational interruptions and less secondary drilling remain to be confirmed through direct measurements. Future studies should therefore quantify diesel consumption per metre drilled and CO_2 emissions per metre drilled to assess these potential benefits.

Overall, this study provides a practical basis for developing a preventive management strategy for drilling consumables adapted to the operating conditions of the mine investigated. The approach may also be relevant to other mining operations with comparable geological and operational conditions, subject to further validation.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that they have no competing interests.

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