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Optimizing Excavator Tooth Selection for Khuut Coal Mining

Bachelor Thesis

Submitted by

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Statutory Declaration

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Optimizing Excavator Tooth Selection for Khuut Coal Mining

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

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Abstract

Nowadays, many of the technological advancements in engineering today rely on minerals like copper, gold, and coal. The mining industry is important in the development of society and these technological phenomena. Excavators are mostly used tools to extract those minerals which break down and load rock ores onto trucks. Excavator bucket teeth are particularly important in coal mining as they facilitate the efficient extraction of coal. To optimize mining operations, it's important to use durable teeth which can withstand harsh mining conditions such as extreme temperatures and rocky landscapes. The main goal of this study is to select the appropriate teeth for mining at Khuut Coal Mining in Dundgobi with the aim of extending teeth's lifespan. Previous teeth used in Khuut mining tend to last approximately 20 days and highlight the need for more durable teeth. The study employs field observations, laboratory testing, and data analysis to evaluate the performance of the bucket teeth and identify the factors that contribute to their longevity. The findings of this study aim to provide valuable insights into the design and selection of excavator bucket teeth for coal mining operations which can potentially benefit other mining industries as well.

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1 Introduction

Mining is essential to modern society which is providing the minerals needed for many engineering innovations including gold, copper, and coal. One common method of mineral extraction is the use of mining excavators which load rock ores onto trucks for transportation *[1]*. When it comes to coal mining, this process requires heavy machinery such as excavators to extract coal from the earth where excavator bucket teeth are important components of these machines. However, selecting the right bucket teeth for mining operations is vital since it can significantly affect the efficiency and productivity of the operation. Without the proper choice of teeth in terms of needs the operations, the machines may not be able to extract minerals as efficiently leading to increased downtime and lost revenue.

Khuut Coal Mining is a mining company located in Dundgobi province which is approximately 150km from the Mandalgobi city and it has been operational for two years. The company has a reserve of 5million tons of bituminous coal. With its modern mining equipment and state-of-the-art infrastructure, the company has been successfully extracting and processing high-quality coal for use in power plants and other industrial applications. They use a range of heavy equipment to extract coal from the mines efficiently including two CAT 349 excavators, two CAT 336 excavators, and one Hyundai 480 excavator. In addition to these, they also have nine dump trucks and two wheel loaders. All of these machines are crucial in facilitating the mining operations and ensuring that the extraction of coal runs smoothly.

Figure 1. Mining Field and Equipment of Khuut coal mining

Selecting the right bucket teeth for operation is a quite challenge for Dundgobi Khuut. The harsh and corrosive environment of coal mining can easily wear out the teeth. Because different types of soil, they have varying abrasive properties. Thus, soil analysis is an important factor in determining the most suitable bucket teeth for mining *(4).* This study aims to evaluate the performance of excavator bucket teeth used at Khuut mining with the aim of selecting teeth that can last longer based on soil analysis.

The research will involve a combination of field observations, laboratory testing, and data analysis to identify the factors that contribute to the durability of excavator bucket teeth, especially those related to soil properties. By doing so, this study can help identify the best bucket teeth for mining operations at Khuut mining which will ultimately enhance their efficiency and productivity in coal mining operations.

1.1 Objective and Research Questions

The objectives of this study are to:

- Determine the most suitable excavator bucket teeth based on their durability and performance considering soil properties and other factors.
- Analyze the material composition of the excavator bucket teeth currently used at Khuut mining
- Provide recommendations on the design and selection of excavator bucket teeth for coal mining operations based on the findings of this study.

To achieve these objectives, we will address the following research questions:

- Which type of bucket teeth is most suitable for coal mining operations at Khuut, with the objective of lengthening their lifespan?
- What is the current material composition of excavator bucket teeth used at Khuut Coal Mining?
- What are the recommendations for the design and selection of excavator bucket teeth for coal mining operations based on the findings of this study?

To answer these research questions, we will conduct a comprehensive study that involves both field observations and analysis. We will collect data from excavator teeth and study soil properties such as abrasiveness, moisture content, and particle size distribution.

1.2 Significance of study

The significance of this research lies in its potential to improve the efficiency and productivity of coal mining operations in Khuut coal mining and other regions by reducing tooth failure and downtime. Excavator teeth are critical tools in coal mining, and frequent tooth wear and failure can result in significant downtime and increased costs for mining companies.

By analyzing soil samples and identifying the specific soil properties that contribute to tooth wear, this research can help design excavator teeth that are optimized for each soil condition. This can reduce tooth wear and failure resulting in less downtime and increased productivity for mining companies.

The significance of this research also lies in its potential to promote sustainable mining practices. By reducing tooth wear and failure, the research can help mining companies optimize their excavation operations leading to improved resource utilization and reduced costs *[16].* Additionally, by developing tooth selection methods based on soil analysis, the research can contribute to the development of more effective and sustainable excavation technologies for mining and other construction applications.

Overall, this research has significant implications for the coal mining industry in Mongolia and other regions. By identifying the factors that contribute to tooth wear and developing tooth selection methods based on soil analysis, the research can contribute to more efficient and sustainable mining practices ultimately leading to cost savings and improved resource utilization.

1.3 Scope and limitations

Scope:

The primary focus of this study is to select suitable excavator bucket teeth for coal mining at Khuut Coal Mining in Dundgobi. It will assess the performance of the existing bucket teeth and examine soil characteristics that lead to wear and tear, explore the design features of various types of bucket teeth and make recommendations for selecting and designing bucket teeth that are best suited for mining operations at Khuut.

Limitations:

There are several limitations to this study. Firstly, the findings may not be applicable to other mining operations or soil types. Secondly, the cost-effectiveness of different types of bucket teeth will not be considered. Thirdly, other factors such as maintenance practices or operator skill will not be assessed for their impact on bucket teeth lifespan. Lastly, the study will only evaluate the excavator bucket teeth and not those used on other mining equipment.

2 Literature Review

2.1 Common types of Excavator used in Mongolia

Excavators are powerful machines commonly utilized in industries like mining, construction, demolition, and forestry. They consist of several main components including a cab, engine, hydraulic system, boom, arm, and bucket which enable them to perform a range of tasks. Depending on the application and terrain, excavators can be operated on wheels or tracks. In the construction industry, they are used for tasks like digging foundations, grading land, and clearing debris.

(a) A crawler excavator *[Figure 2]* is a type of heavy-duty machine that uses tracks which are known as crawlers, instead of wheels for movement. This type of excavator is commonly utilized in demanding applications such as mining, construction, and forestry as the tracks provide enhanced stability on uneven terrain and can navigate through rough or muddy conditions with ease. Crawler excavators are available in various sizes and configurations and they can be equipped with different attachments such as buckets, breakers, and thumbs to improve their versatility and efficiency in performing specific tasks *[6].*

(a) Crawler excavators

(b) Hydraulic excavators

Figure 2. Crawler Excavator [6]

Figure 3. Hydraulic Excavator [6]

(b) Hydraulic excavators *[Figure 3]* are the most common type of excavator used in various applications including construction and mining. They use a hydraulic system to power the machine's movements that allows for precise and efficient operation. The hydraulic system consists of a hydraulic pump, hydraulic fluid,

hydraulic cylinders, control valves, and hoses. Hydraulic excavators come in various sizes ranging from compact mini excavators to large and heavy-duty excavators used in mining and construction applications. They are versatile machines that can be equipped with various attachments to increase their functionality *[6].*

(c) A backhoe excavator *[Figure 4]* is a highly adaptable piece of equipment that integrates a digging bucket and a backhoe. It is often worked in construction, excavation, and landscaping projects. The backhoe is situated on a swiveling platform that can rotate up to 180 degrees whereas the digging bucket is mounted on an arm that can be extended and retracted. Backhoe excavators are more compact and easier to maneuver than larger excavators making them ideal for confined spaces. They can be equipped with different attachments to expand their capabilities *[6].*

(c) Backhoe excavators

Figure 4. Backhoe Excavator [6]

(d) Dragline excavators

Figure 5. Dragline Excavator [6]

(d) Dragline excavators *[Figure 5]* are massive machines designed for extensive excavation projects. It is depended on a dragline which is a large bucket connected to a long boom which is lifted and lowered by cables and pulleys. These excavators are frequently used in mining and massive construction projects. They are capable of moving vast amounts of material at a fast pace, but they need a significant amount of space to operate and are less agile than other excavator types. The operator manages the machine through a control panel in the cab and it can be outfitted with different attachments to improve its usefulness *[6].*

2.1.1 Tooth Types and Functions

Excavator teeth are an essential component of an excavator which is used to dig, scoop and move materials on a job site. The teeth are attached to the edge of the bucket and come in various sizes, shapes, and materials to accommodate different types of excavating tasks. Here is the list of commonly used and sold Mongolia tooth systems imported by BarloWorld (CAT). Teeth are categorized by different tooth shapes.

(a) Standard

Figure 7. A standard tooth for excavators in general purpose applications.

(b) Heavy-duty

Figure 6. A heavy-duty penetration tooth for wheel loaders for highly abrasive applications

(c) Rock Chisel

Figure 8. A chisel tooth primarily focuses on excavators. It is used in applications where good penetration is required.

(d) Wide or Flared

Figure 9. A flared tooth for general purpose digging and continuous edge applications.

(e) Tiger or Spike

(f) Twin Tiger or Double Spike

Figure 11. A pick tooth for extremely hard to penetrate materials

Figure 10. A twin pick tooth for maximum performance in hard to penetrate materials

(g) Penetration Plus

Figure 12. A heavy tooth for extremely abrasive applications and is primarily designed for excavators

(a) Standard bucket teeth are versatile and suitable for excavating and moving a wide range of soil types including sandy, loamy, and clay soils. However, the effectiveness of these teeth can be influenced by factors such as moisture content, density, and composition of the soil *[31]*.

(b) Heavy-duty bucket teeth are suitable for excavating hard, dense materials like rock, concrete, or heavily compacted soils. They are designed to withstand high-impact, high-abrasion applications and are more durable than standard teeth. Heavy-duty teeth are a good choice for excavating soils that are highly abrasive, have large rocks or boulders, or are densely compacted *[31].*

(c) Rock chisel teeth are designed for excavating hard rock or concrete, making them ideal for soils that are highly compacted or have large rocks or boulders. These teeth have a pointed tip and a flat chisel shape, allowing them to break through hard surfaces more easily *[31].*

(d) Wide or flared teeth are designed for looser and less compacted soils like sandy or gravelly soils. They have a broader shape and are angled outwards, which improves the machine's ability to scoop up and retain material in the bucket *[31].*

(e) Tiger teeth are designed for compacted soils or those with a moderate to high concentration of rocks and gravel. They have a pointed tip with serrated edges that help to penetrate and break up hard soils and rocky surfaces *[31].*

(f) Twin tiger teeth are designed for highly compacted soils or those with a high concentration of rocks and gravel. They are similar in design to tiger teeth but have an additional tooth behind the main tooth for greater digging power and material retention *[31].*

(g) Penetration plus teeth are designed for highly compacted, abrasive or rocky soils. They have a more aggressive, pointed shape that provides greater penetration power and better material retention. These teeth are ideal for heavy-duty excavation applications, such as mining and quarrying, and where digging speed is important *[31].*

2.1.2 Typical ways of teeth failure

Excavator teeth are an important component of construction equipment used to excavate or remove earth and other materials. Some common causes of failure of excavator teeth include:

(a) Wear and Tear

Figure 13. Worn teeth

Excavator teeth are constantly exposed to abrasive materials during excavation which can cause them to wear down over time. The severity of wear depends on several factors, including the type of material being excavated, the hardness of the material, and the frequency and duration of use.

As the teeth wear down, their cutting edges become dull, reducing their effectiveness and requiring more force and energy to excavate the material. This increased force and energy can cause further wear and tear on the teeth and other components of the excavator.

(b) Fatigue

Figure 14. Fatigued teeth

Fatigue is another way that excavator teeth can fail over time. Fatigue failure occurs when a material is subjected to repeated loading and unloading, which can cause small cracks to form and grow over time. In the case of excavator teeth, this can happen due to the repetitive stress of digging and excavating.

As the teeth are used repeatedly, small cracks can develop on the surface of the tooth. Over time, these cracks can grow and deepen, weakening the tooth and eventually causing it to fail. Fatigue failure is often difficult to detect until the tooth fails, as the cracks may not be visible to the naked eye.

(c) Corrosion

Figure 15. Corroded teeth

Corrosion is a natural process in which a metal material such as the steel used to make excavator teeth, deteriorates due to exposure to moisture, oxygen and other environmental factors. Corrosion can cause the teeth to weaken and eventually break or deteriorate over time.

Excavator teeth can be particularly susceptible to corrosion in environments with high levels of moisture such as near water sources or in humid climates. Other factors that can contribute to corrosion include exposure to acidic or alkaline materials, exposure to saltwater, and exposure to other chemicals.

(d) Improper use

Figure 16. Broken teeth

Excavator teeth are designed to handle specific types of materials and applications. Using the teeth for applications outside of their intended use or using the teeth in a way that puts excessive stress or strain on them, can cause them to fail.

Examples of improper use of excavator teeth include using them to pry or lift heavy objects, using them to excavate materials that are harder than the teeth are designed for, or using them at an incorrect angle or position. These actions can cause the teeth to bend, break, or wear down more quickly than they would in normal use.

Excavator teeth are subjected to significant wear and tear during use which can reduce their efficiency and increase the risk of costly equipment failure. There are several factors that contribute to wear and tear of excavator teeth, including:

Soil properties: The properties of the soil being excavated can have a significant impact on tooth wear. Soil abrasiveness, moisture content, and particle size distribution are all factors that can contribute to tooth wear. Research has shown that highly abrasive soils such as those containing high levels of gravel or sand can cause significant tooth wear, while wet soil can cause corrosion and premature wear.

Tooth design and material: The design and material of the excavator teeth can also impact wear and tear. Teeth made from high-quality steel alloys tend to have a longer lifespan than those made from lower-quality materials. Additionally, tooth design can impact the distribution of forces during use, which can affect wear patterns.

Operator behavior: Operator behavior can also contribute to tooth wear. Poor operating techniques such as using excessive force or failing to regularly inspect teeth for damage, can increase the risk of tooth wear and failure.

Maintenance practices: Finally, maintenance practices can also impact tooth wear. Regular inspection and replacement of worn teeth as well as proper cleaning and lubrication can help prevent damage and prolong tooth lifespan *[33]*.

2.2 Soil Classification of Mongolia based on FAO

The FAO soil classification system is a widely used system for classifying soils based on their physical, chemical, and biological properties. It was developed by the Food and Agriculture Organization (FAO) of the United Nations to facilitate communication and exchange of information about soils between different countries and regions. Here is the Map of soil classification across Mongolia by Food and Agriculture Organization-World Reference Base for Soil Resources *[32].*

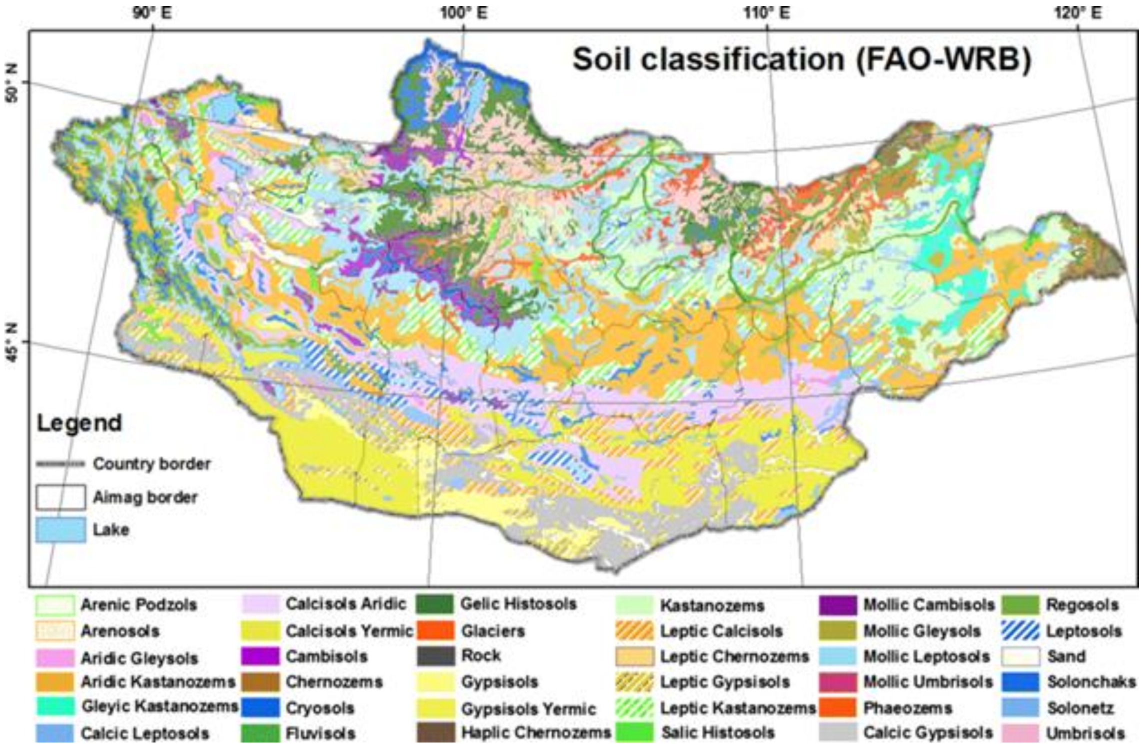

Figure 17.Soil classification by FAO [32]

Based on the information, it appears that Khuut mining is located in the Dundgobi Bayanjargalan soum which is known for having Calcisols Aridic soils. Calcisols are characterized by a high concentration of calcium carbonate in the soil horizon, and may also exhibit physical properties such as a duricrust layer and a low organic matter content.

The soil specifications for bucket teeth are important to consider in order to select the appropriate material and design for the excavator teeth. Some of the key soil properties to consider include:

- Abrasiveness: The abrasiveness of the soil is a key factor in selecting the appropriate material for the bucket teeth. Highly abrasive soils, such as rock and gravel, require materials with high wear resistance, such as tungsten carbide or alloy steel.
- Hardness: The hardness of the soil can also impact the selection of the bucket teeth material. Hard soils, such as clay and shale, can cause wear and deformation of the bucket teeth. Materials with high toughness, such as boron steel, may be more suitable for these soil types.
- Moisture content: The moisture content of the soil can also impact the performance of the bucket teeth. Wet soils can cause corrosion of the teeth, while dry soils can cause excessive wear. It is important to select a material that can withstand the moisture content of the soil.
- Cohesiveness: Cohesive soils, such as clay, can cause a high level of friction on the bucket teeth, which can cause excessive wear. Materials with low friction, such as tungsten carbide, can be used to reduce wear in these soil types.
- Particle size: The particle size of the soil can also impact the selection of the bucket teeth material. Fine-grained soils, such as silt and sand, can cause erosion of the teeth. Materials with high wear resistance, such as tungsten carbide or alloy steel, may be more suitable for these soil types *[34].*

Overall, the soil specifications for bucket teeth are important to consider in order to select the appropriate material and design for the excavator teeth. A careful analysis of the soil properties can help to optimize the durability, efficiency, and productivity of the excavation operations.

2.3 Simulation Program ANSYS and FEA

ANSYS is a suite of engineering simulation software that is widely used for finite element analysis (FEA) and other types of engineering analysis. ANSYS provides a range of tools for FEA analysis, including ANSYS Mechanical, ANSYS Fluent, ANSYS CFD, and ANSYS HFSS among others.

FEA analysis is a numerical method used to analyze the behavior of structures and systems under different physical conditions. FEA analysis involves dividing a complex structure or system into small, simple parts called finite elements and then solving a set of equations to determine the behavior of each element. By combining the behavior of all elements, FEA analysis can provide a detailed understanding of the overall behavior of the structure or system.

ANSYS provides a range of tools for FEA analysis that can be used to analyze a wide range of physical phenomena including structural mechanics, thermal analysis, fluid dynamics, and more. ANSYS Mechanical, for example, is a finite element analysis tool that can be used to analyze the behavior of structures under various loading and boundary conditions. ANSYS Fluent is a computational fluid dynamics (CFD) tool that can be used to simulate and analyze fluid flow and heat transfer.

The ANSYS software suite provides a range of advanced capabilities and customization options for FEA analysis. ANSYS allows users to define and refine their analysis models, specify boundary conditions, and select the appropriate analysis solver for their specific needs. ANSYS also provides pre- and post-processing tools for FEA analysis, allowing users to visualize and interpret their analysis results.

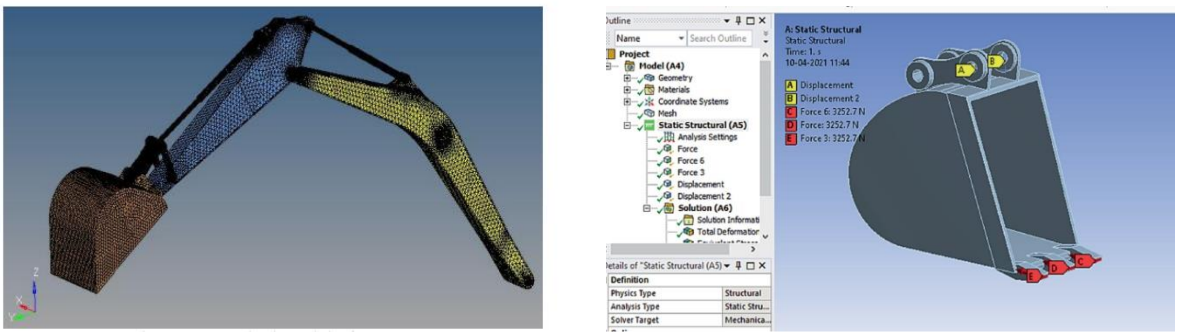

Figure 18 ANSYS Program

In relation to excavator teeth selection for Khuut coal mining, the ANSYS program can be utilized to model the behavior of different types of teeth under various soil conditions and loads.

By utilizing ANSYS software, engineers and researchers can perform FEA to evaluate the stress distribution and deformation of the excavator teeth during operation. This information can be used to optimize the design of the teeth, ensuring their longevity and minimizing the need for frequent replacements. Additionally, ANSYS can be used to model the interaction between the excavator teeth and different types of soils, allowing for the selection of the most appropriate teeth for the specific soil conditions present in Khuut coal mining.

Furthermore, ANSYS can be used to model the effect of different operating parameters, such as the digging force and the angle of the teeth, on the performance of the excavator. This information can be used to optimize the excavation process, reducing the time and cost associated with the mining operations.

3 Methodology

This study aims to select the most suitable excavator bucket teeth for coal mining at Khuut Coal Mining in Dundgobi, with the objective of lengthening their lifespan. The study objectives include evaluating the performance of the current bucket teeth identifying soil properties that contribute to wear and tear, examining the design features of different types of bucket teeth, and providing recommendations on the design and selection of bucket teeth for coal mining operations.

3.1 Soil Analysis of Khuut mining

The soil analysis conducted on the coal mining site in Khuut, located in Dundgobi province, revealed a high content of abrasive materials such as argillite, aleurolite and bituminous coal. These soils pose a significant challenge for the durability of bucket teeth used in the mining operation. Due to their abrasive properties, the bucket teeth are subject to faster wear and failure, which results in increased maintenance and replacement costs.

Bituminous coal

Bituminous coal is a type of coal with high carbon content and low sulfur content, making it a popular fuel source for power generation, heating, and industrial processes. *[33]* With a density of 1.3 g/cm³, bituminous coal is a relatively dense material that can put a lot of strain on standard bucket teeth when excavating.

Figure 19. Bituminous coal

Argillite

Argillite is a fine-grained sedimentary rock that is primarily composed of clay minerals such as illite, kaolinite, and smectite. It is a low-grade metamorphic rock that has undergone changes in temperature and pressure due to geological processes over time. Argillite is typically gray, greenish-gray, or black in color and has a waxy or greasy texture *[33].* Its density 1.4 g/cm³ which is relatively dense soil.

Figure 20. Argillite Rock

Aleurolite

Aleurolite is a sedimentary rock that is made up of a mixture of clay minerals and sand grains. It is formed from the weathering and erosion of pre-existing rocks and can be found in areas such as river beds, coastal regions, and desert regions. Aleurolite has a variety of colors and textures, depending on the relative proportions of clay and sand *[33].* Its density 2.3 g/cm³.

Figure 20. Aleurolite Rock

Argillite and aleurolite are two types of sedimentary rocks commonly found in geological formations. Argillite is a fine-grained rock that is predominantly composed of clay minerals such as illite, kaolinite, and smectite. It is often gray in color and has a smooth texture. Aleurolite, on the other hand, is a type of sandstone that contains a high percentage of clay minerals, usually around 25-50%. It has a distinctive reddish-brown color and a grainy texture *[33].*

The presence of argillite and aleurolite in soil can be problematic for the durability of bucket teeth. These materials have abrasive properties that can wear down the teeth quickly leading to increased maintenance costs and downtime.

3.2 Field Analysis

Khuut Mining Company extracts bituminous coal using modern equipment such as CAT 349 excavators, two CAT 336 excavators, and one Hyundai 480 excavator. Bituminous coal is known for its high energy density and low ash content, making it a choice for industrial processes and power generation.

Figure 21. Extracted Coal in Khuut mining

The rock fragmentation can vary in size at different mining sites. Generally speaking, the size can range from extremely fine to somewhere. Due to this, the wear and tear on the bucket teeth can vary on a large scale depending on where the digging is taking place. Figure 20 shows an example of how the rock fragmentation can look at different excavation sights.

Figure 21. First picture shows where smaller rocks are residing, while second shows sight a where coarser/larger rocks are residing

3.2.1 Excavator Teeth Model

In the site mining of Khuut, GC505-4113 336 RC (Penetration Plus) and GC331-4089 349 RC are operated by the CAT 349 and CAT 336 excavators.

Figure 22. Current used model teeth

The Penetration Plus GC505-4113 336 RC excavator teeth model is a robust and heavy-duty mining equipment that is designed to excavate various types of soil and rock including cemented gravel, sedimentary rock, and poor shot rock. This excavator teeth model is known for its exceptional hardness which is rated at 48-52 HRC. This means that the teeth are incredibly tough and resistant to wear and deformation.

The alloy steel material used in the construction of these teeth provides the necessary strength and toughness required to withstand extreme conditions and high levels of wear and tear. This makes them a reliable option for use in high-impact trenching, excavating loading, and moderate to high impact areas.

Moreover, the Penetration Plus GC505-4113 336 RC teeth are specifically designed to operate in densely compacted material because of their unique self-sharpening design and shape. These teeth weigh in at 19kg making them suitable for use in large-scale mining operations.

When it comes to excavator teeth applications, these teeth are highly versatile and adaptable. They are compatible with various excavator models and can be installed and removed easily as needed. In particular, the Penetration Plus GC505-4113 336 RC teeth are effective in extreme soil and rock condition making them a preferred option for mining applications.

Overall, Penetration Plus teeth are a specialized type of excavator teeth that are designed to deliver outstanding performance in difficult soil and rock conditions. These teeth are constructed using high-strength steel and are characterized by a sharp, pointed tip that enables them to penetrate through dense or hard soils and rock with ease.

Properties	Alloy steel Hardox 400
Density (kg/ m3)	7850
Modulus of elasticity (MPa)	2.1*105
Poisson's ratio	0.29
Yield strength (MPa)	1000
Ultimate tensile strength (MPa)	1250
Impact toughness (J)	30
Brinell hardness	370-500

Table 1. Properties of Penetration Plus teeth

3.2.2 Performance Analysis

After analyzing the work order data of the Caterpillar 349 excavator's teeth over the past year, it has been determined that their average lifespan is around 19 days. This indicates that, on average, the teeth of the Caterpillar 349 excavator need to be replaced every 19 *(figure 25)* days and change of teeth occurs after processing approximately 9200 tons of soil *(figure 26)*. due to wear and tear from usage.

Figure 23. Average lifespan of current teeth by days

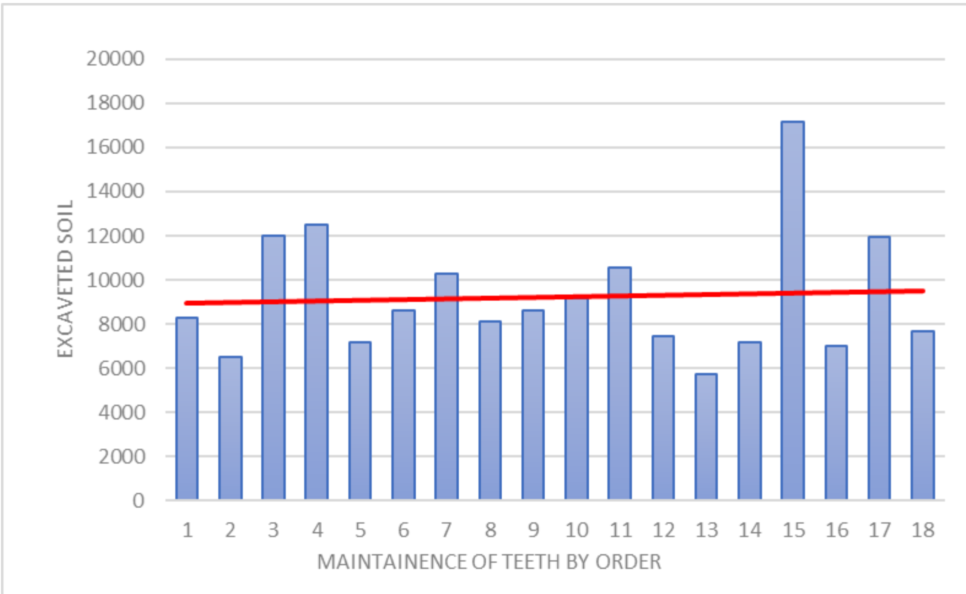

Figure 24. Average lifespan of current teeth by ton

This information is crucial in developing an effective maintenance plan for the Caterpillar 349 excavator, as it provides insight into the frequency of tooth replacement and enables accurate budgeting for replacement parts and associated expenses. Overall, these findings can help ensure that the Caterpillar 349 excavator *(21)* remains in optimal working condition, maximizing its productivity and minimizing downtime.

Figure 25. Teeth changing process

3.2.3 Digging Force Calculation According to Standard SAE J1179

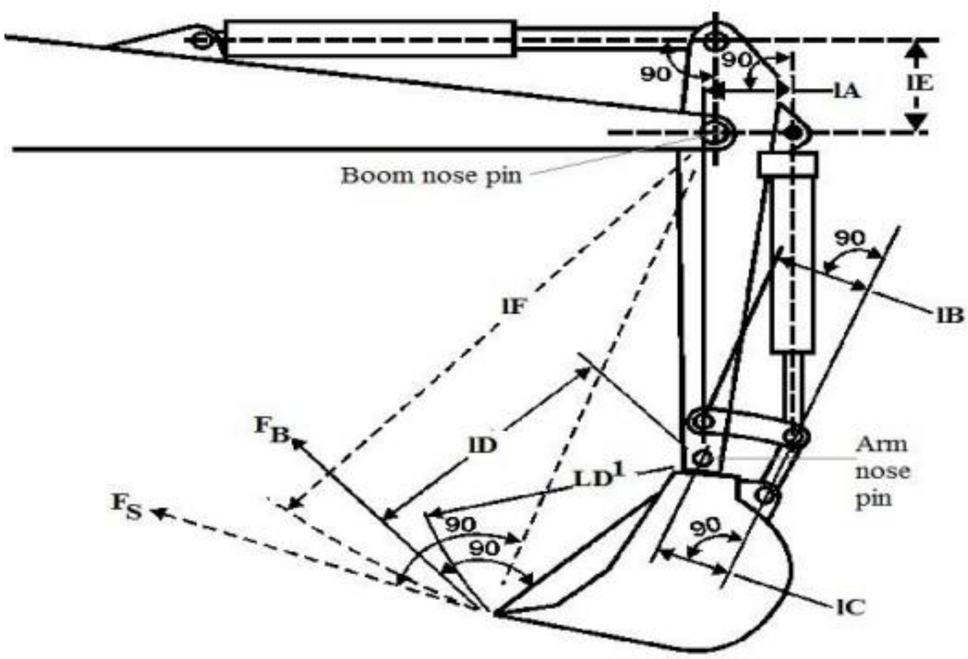

Figure 26 Determination of digging forces by following the standard SAE J1179

Digging forces are classified into bucket curling force and arm curling force. Bucket curling force is the force generated at the tip of the bucket due to bucket cylinder and arm crowd force is the force generated at the tip of the bucket due to arm cylinder. Generally digging force is calculated at maximum breakout condition of the linkages.

Maximum breakout condition is the condition at which the excavator generates maximum digging force. Total three standards are available to calculate digging force one of which is SAE standard. Fig.1 shows the measurement of bucket curling force FB, arm crowd force FS, the other terms in the figure IA, IB, IC, ID, ID1 , IE, and IF shows the distances of different part. Bucket curling force is tangent to tip radius of bucket and it's generated by bucket cylinder. It's given by

$$F_B = \frac{Bucket\ cylinder\ force}{l_D}\left(\frac{l_A \times l_C}{l_B}\right)$$

Equation 1 Bucket curling Force (1)

Where, Bucket cylinder force = (Working pressure) × (End area of bucket cylinder)

If the end diameter of the bucket cylinder = DB (mm) and the working pressure is P (MPa) and other distances are in mm then (1) can be written as:

$$F_B = \frac{P \times (\pi/4) {D_B}^2}{l_D}\left(\frac{l_A \times l_C}{l_B}\right)$$

Equation (2) determines the value of the bucket curl or breakout force in 'N'. Now let us determine the maximum radial tooth force due to arm cylinder FS. Maximum tooth force due to arm cylinder is the digging force generated by the arm cylinder and tangent to arc of radius dF. The arm shall be positioned to obtain the maximum output moment from the arm cylinder and the bucket positioned as described in the case of maximum bucket curl force (Max. bucket tangential force). While calculating maximum force FS occurs, when the axis in the arm cylinder working direction is at a right angle to the line connecting the arm cylinder pin and the boom nose pin as shown in Fig. 1.

$$F_S = \frac{Arm\ cylinder\ force \times l_E}{l_F}$$

$$F_S = \frac{P \times (\pi/4) {D_A}^2 \times l_E}{l_F}$$

Equation 2 Arm Crowd Force(2)

Where, l_F = bucket tip radius (l_D) + arm link length and DA = end diameter of the arm cylinder.

For the case study:

l_A = 678 mm, l_B = 609 mm, l_C = 536 mm, l_D = 1891 mm, l_E = 730 mm, and l_F = 3362 mm

Working pressure P = 350 bar or 35 MPa D_A = D_B = 150 mm

Bucket curl or breakout force $\mathbf{F_B}$ **= 195.2 kN**

Arm crowd force or digging force $\mathbf{F_S}$ **= 134.4 kN**

Figure 27 Cat 349

Considering bucket have 4 teeth, therefore total force applied on each tooth end is 195.2 kN / 4 = **48.8 kN**

3.2.4 FEA Analysis on Teeth and Bucket

Static structural analysis was performed for an excavator bucket in order to see the stresses are within the limits. Structural optimization is performed for an excavator bucket in order to reduce the weight. Normal stresses is used as a criterion in determining the onset of failure in ductile materials, and the materials in the presented study for the parts of the bucket are of ductile materials, so the design of all parts should be on the basis of Normal stresses acting on the parts

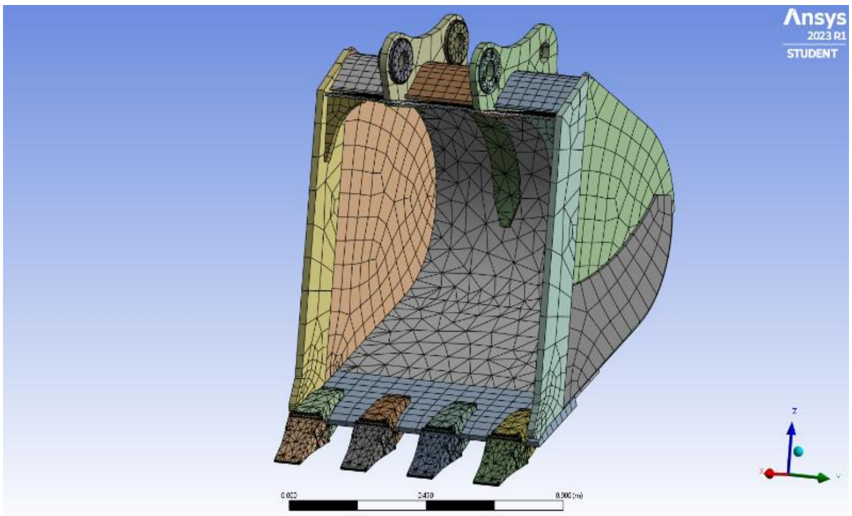

Figure 28 Meshed view of the Bucket

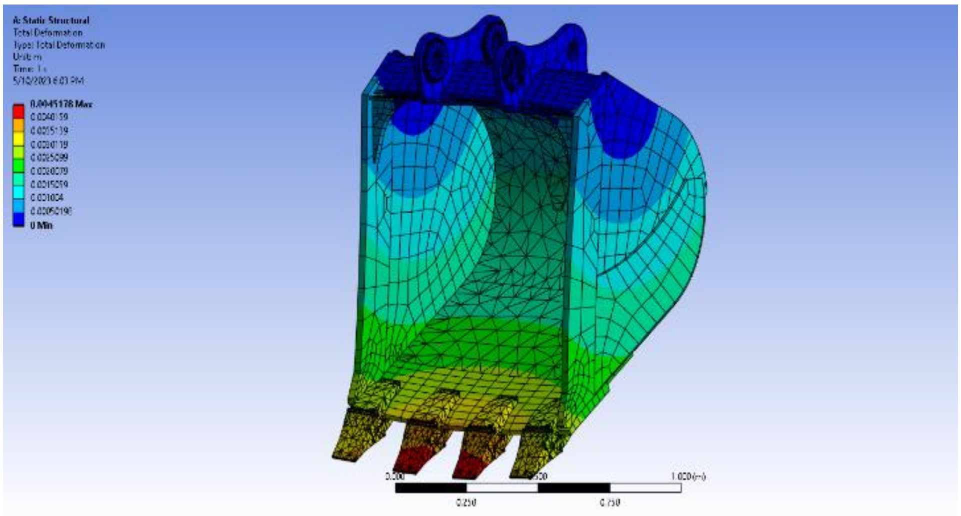

Figure 29 After force exerted on the teeth

The results of the ANSYS simulation program indicated that after applying a force of 48.8 kN on each of the Penetration Plus teeth, the maximum deformation obtained was around 0.4mm, which signifies a significant wear and tear of the teeth after just one excavation. This finding highlights the importance of selecting appropriate excavator teeth for a specific soil type and mining site, as the wrong choice of teeth can result in a shorter lifespan of the teeth and increased costs for the mining operation. Therefore, it is crucial to carefully consider the soil conditions and material properties of the site before selecting excavator teeth. In the case of Khuut coal mining site, where the soils are primarily composed of argillite and aleurolite, it is recommended to use rock-chisel teeth or heavy-duty teeth for maximum wear resistance and durability. By making the right choice of excavator teeth, the mining operation can reduce costs and improve efficiency, ultimately leading to a more profitable and sustainable mining operation.

3.3 XRF Analysis

XRF element analysis is a one of the tools used to analyze the behavior of materials, and commonly used to evaluate the performance and strength of materials. When excavating, the bucket teeth of an excavator are crucial for efficiency and productivity. *(33)* Therefore, it's important to choose the right material for bucket teeth to ensure they last long and are durable. This study aims to evaluate the material properties of excavator bucket teeth using X-ray fluorescence (XRF) to determine if they're suitable for use in coal mining.

Figure 30. XRF analyzer

The experiment was conducted in the GMIT Processing Laboratory. XRF analysis is a quick and accurate way to determine the elemental composition of materials, including major, minor, and trace elements. This study used XRF analysis to detect the presence of aluminum and iron in excavator bucket teeth which are commonly used in their manufacturing. The results of this analysis will help to identify areas for improvement to increase the lifespan and durability of different types of bucket teeth used in coal mining operations. Overall, XRF analysis is a cost-effective and efficient tool for analyzing materials without the need for sample preparation.

3.3.1 Element Analysis of Teeth

To analyze the elemental composition of the excavator teeth, samples were prepared by cleaning their surfaces to remove any visible debris or contamination. A handheld XRF spectrometer was then used to conduct XRF analysis, which involved exciting the atoms in the sample with X-rays and measuring the characteristic X-ray emissions from each element present. Through this process, the XRF analysis provided information on the elemental composition of the teeth, including the concentration of iron, aluminum, and silicon. The results were then recorded and analyzed to determine the properties and quality of the excavator teeth.

Figure 31. Tested teeth by XRF

In this study, XRF analysis was conducted on teeth samples to determine their elemental composition. The results showed that the samples contained high concentrations of iron (Fe), silicon (Si), potassium (K), and magnesium (Mg). The highest concentration was observed for Fe, with approximately 70% of the total composition. Si, K, and Mg also showed significant concentrations. These results can provide valuable insights into the materials used for excavator teeth and their potential effectiveness for various applications. Further studies are necessary to determine the relationship between the elemental composition of teeth and their performance in different soil types.

Elements	Percentage	$\pm 2\sigma$
Fe	70.25	1.47
Al	11.88	0.39
Si	7.82	0.15
Mg	2.97	1.75
K	2.23	0.05
Cr	1.62	0.08
Others	3.23	0.12

Table 2. Composition of current teeth of Khuut coal minig

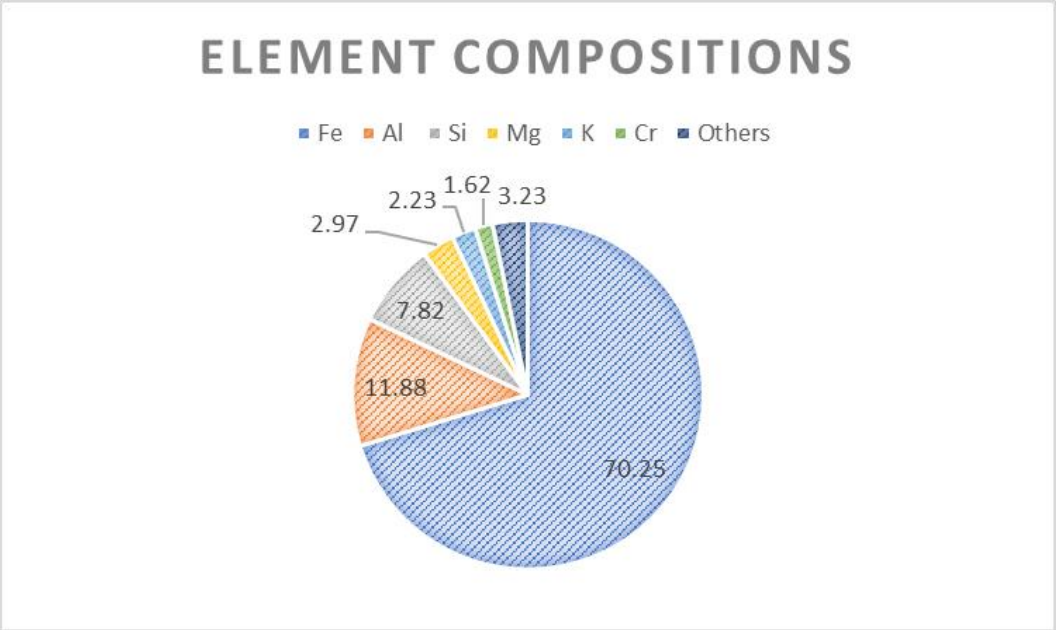

Figure 32. Elements compositions by diagram

3.2.2 Limitations of study

There are a few limitations to keep in mind when interpreting the results of this study. Firstly, we only analyzed one specific type of excavator teeth using X-ray fluorescence (XRF) analysis. While this type of excavator teeth is commonly used in Khuut area and it is possible that other models or materials may have different properties that affect their wear resistance and failure patterns. Therefore, our findings are not generalizable to all excavator teeth and caution should be exercised when applying the results to other situations.

In addition, XRF analysis only provides information about the elemental composition of materials not considering their mechanical properties. Although we were able to identify the chemical elements present in the excavator teeth, we were not able to measure their hardness or other mechanical properties that may affect their wear resistance and toughness. Because of this limitation, we face lack of why excavator teeth fail and how we can prevent it.

Moreover, we had scarce of observation the hardness of the excavator teeth due to a lack of a suitable hardness tester. Hardness is a key mechanical property that affects the wear resistance and toughness of materials and that is known to be an important role in the failure of excavator teeth. Without this information, we do not completely understand the reasons for teeth failure or accurately predict their longevity.

In conclusion, there are limitations to the methodology when interpreting the results. Future research is supposed to aim to address these limitations and provide a more comprehensive understanding of the mechanical properties and failure mechanisms of excavator teeth in different contexts.

4 Results and Discussion

The results of this study reveal key findings regarding the excavation process and the performance of the penetration plus type teeth used in Khuut coal mining. The penetration plus teeth have been observed to have a lifespan of approximately 19 days corresponding to excavating around 9200 tons of soil. During excavation, each tooth experiences a significant force of approximately 48.8 kN when it comes into contact with the soil. Therefore, ANSYS simulation program was utilized to assess the behavior of the teeth indicating a deformation of approximately 0.4 mm after the teeth penetrate the ground.

XRF analysis of the penetration plus teeth demonstrates a high content of iron (Fe) along with significant amounts of aluminum (Al), silicon (Si), magnesium (Mg) and potassium (K). This composition, particularly the presence of iron, contributes to the teeth's durability and resistance to wear. However, it is important to note that the soil conditions at Khuut coal mining site primarily consist of argillite and aleurolite which are a mixture of soft and hard soils containing high levels of gravel and stones. Additionally, the mining operation involves extracting bituminous coal.

The combination of these soil conditions, the presence of bituminous coal, and the use of only one type of penetration plus teeth in Khuut mining which does not perform well in harsh mining condition and it has resulted in a shorter lifespan for the teeth than anticipated. The abrasive and chemically aggressive nature of the soil coupled with the limited suitability of penetration plus teeth for such conditions contributes to frequent tooth replacements and increased maintenance costs.

Therefore, it is strongly recommended that Khuut coal mining considers utilizing different types of teeth based on the specific soil conditions encountered during excavation. By selecting tooth types that are more suitable for abrasive and chemically aggressive soils, the efficiency and effectiveness of the excavators can be improved. This approach would lead to a reduced frequency of tooth replacements, minimized downtime and lowered costs associated with tooth failure.

In conclusion, the results of this study emphasize the importance of selecting appropriate tooth types for excavators working under harsh mining conditions. The results can be useful in improving the performance and efficiency of excavators at Khuut coal mining site. By considering the soil conditions and the type of coal present at the mining site, mining companies can select tooth types that are optimized for their specific conditions, thereby reducing maintenance costs and improving the efficiency of their operations. The findings of this study can be useful not only for improving the performance and efficiency of excavators at the Khuut coal mining site but also for other mining sites in Mongolia and around the world with similar soil conditions. Overall, selecting appropriate tooth types for excavators working under harsh mining conditions is critical to ensure the smooth operation of mining activities and to reduce costs associated with tooth replacements and downtime.

Conclusion

Based on the soil conditions of Khuut coal mining site which includes highly abrasive soils such as Argillite and aleurolite, it is important to carefully select the appropriate teeth for the excavator. Because Penetration Plus is only teeth used in the mining, it lasts shorter than as it expected. Therefore, after careful consideration of the soil conditions, it is recommended that rock-chisel teeth or heavy-duty teeth could be suitable options for harder rock side of the Khuut coal mining.

Rock-chisel teeth are designed to handle hard rock and abrasive soils making them a strong candidate for the Khuut coal mining site. These teeth are characterized by their chisel-shaped tips which provide excellent penetration and cutting ability in hard and abrasive soils. The chisel design also helps to minimize tooth wear ensuring that the teeth can last longer and require less frequent replacement.

Another suitable option for Khuut coal mining site is heavy-duty teeth. These teeth are used for maximum wear resistance and durability in tough soil conditions including abrasive soils. They are typically made from high-strength materials such as tungsten carbide which can withstand the abrasive forces of the soil and reduce tooth wear.

To conclude, Rock-Chisel is highly recommended and Heavy-Duty teeth can be alternative in Khuut coal mining, and further research and testing may be necessary to determine the optimal excavator teeth for other excavation conditions and materials.

Recommendation

According to this study, it was found that Rock-Chisel and Heavy-duty teeth are the most appropriate choice for the Khuut mining site due to the harsh soil conditions and heavy workload of the excavator equipment. The use of those teeth will ensure longer lifespan and reduced downtime resulting in increased productivity and cost savings for the mining operation.

Therefore, it is highly recommended that the Khuut coal mining site should consider switching to Rock-Chisel and Heavy-Duty teeth for their excavator equipment to optimize their operations and achieve maximum efficiency.

Teeth type	Wear Life	Impact	Penetration	Application				
				Clay	Sand	Gravel	Hard Rock	Rock
Penetration Plus	Medium	Medium	High	✓		✓	✕	
Rock-Chisel	High	Low	Medium	✕		✕	✓	✓
Tiger	Low	High	High	✓		✓	✕	✓
Penetration	Medium	Medium	High	✓		✓	✕	✓
Standard	High	Medium	Low	✓	✓	✓	✕	✕
Twin-Tiger	Low	High	High	✓		✕		✓
Heavy-Duty	Low	High	High	✕	✕	✓	✓	✓

Table 3. Application of teeth types

Wear life

Different materials can have varying impacts on the wear life of excavator teeth. Sand is highly abrasive, whereas rocks, dirt, and other materials that are excavated or loaded onto the excavator can affect the wear life of the teeth depending on their quartz content. The teeth will last longer before requiring replacement if the wear surface area is larger. These types of excavator teeth are well-suited for loading and material handling applications, but may not be as effective for excavation or trenching, as they require high penetration and impact. In cases where hard, compacted ground needs to be penetrated, large wear surface areas tend to be less efficient. *(34)*

Penetration

The efficiency of an excavator tooth during penetration is determined by the amount of surface area that comes into contact with the ground. A tooth with a large width and balled surface area requires extra power from the excavator to penetrate the material, resulting in increased fuel usage and stress on all parts of the machine. An ideal tooth design is one that is self-sharpening and can continue to sharpen itself as it wears. For tight, compacted, rocky, or frozen ground, pointed "V" teeth, also known as 'Twin Tiger Teeth', are required for efficient digging and trenching. Although they enable the bucket to power through the material easily, their service life is shorter and they are unable to deliver a smooth bottom to the hole or trench due to their smaller size. *(34)*

Impact

Bucket teeth that possess high impact resistance are capable of withstanding penetrating shocks and high breakout forces. They are particularly well-suited for digging and trenching applications when using an excavator, backhoe, or other machinery with high breakout force, particularly in a rocky environment or rock quarry. *(34)*

Material specification

The selection of bucket teeth material specifications is a crucial factor for the efficiency and productivity of excavation operations. The appropriate material should be chosen based on the soil type, excavation task, and the equipment being used.

- Carbon Steel: Carbon steel is a common material used for bucket teeth due to its strength and durability. It is a cost-effective option that can be used for general purpose digging in soil types that are not too abrasive.
- Alloy Steel: Alloy steel is a type of steel that contains other elements such as manganese, chromium, and nickel which increase its strength and hardness. It is often used for excavating in abrasive soil conditions.
- Tungsten Carbide: Tungsten carbide is a very hard and dense material that is highly resistant to wear and abrasion. It is often used in the construction of excavator teeth because of its high strength and durability.
- Boron Steel: Boron steel is a type of steel that has been heat-treated to make it stronger and more wear-resistant. It is often used in the construction of excavator teeth because of its high strength and toughness.
- Cast Iron: Cast iron is a hard and brittle material that can be used for bucket teeth in soil conditions that are not too abrasive. It is not as durable as other materials and may require more frequent replacement.
- Austempered Ductile Iron (ADI): ADI is a type of ductile iron that has been heat-treated to improve its strength and wear resistance. It is often used for excavating in highly abrasive soil conditions. *[33]*

Teeth should be based on a careful analysis of the soil type, the excavation task, and the specific equipment being used.

Prevent Excessive Deterioration

Effective maintenance practices are crucial for reducing the wear and tear of excavator teeth and ensuring their optimal performance. Previous research has identified several maintenance practices that can help reduce tooth wear, including:

- Regular inspection: Regular inspection of excavator teeth is essential for identifying wear and damage before they become serious issues. Operators should inspect teeth before and after each use to ensure they are in good condition and replace any worn or damaged teeth as necessary.
- Proper cleaning: Proper cleaning of teeth is also important for reducing wear and preventing corrosion. Operators should use appropriate cleaning agents and ensure all debris is removed from teeth before storage.
- Lubrication: Lubrication can help reduce the friction between teeth and soil, which can reduce wear. Operators should apply lubricant to teeth before use and ensure teeth are properly lubricated during use.
- Tooth protection: Tooth protection measures, such as installing wear caps or shrouds, can help reduce wear on the most vulnerable areas of teeth. Wear caps can be replaced when worn, protecting the tooth from damage.
- Operating techniques: Proper operating techniques can also help reduce tooth wear. Operators should avoid using excessive force or dropping the bucket that causes impact damage to teeth *[33]*.

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Appendices

Experiment	Compositions of element						
	Fe	Al	Si	Mn	K	Cr	Others
1	77.59	3.32	2.90	0.99	5.31	1.46	3 ± 2
2	65.52	5.12	3.16	3.45	6.21	3.11	3 ± 2
3	70.32	3.42	5.22	3.41	4.32	2.67	3 ± 2
4	71.27	4.68	3.11	5.21	4.13	1.24	3 ± 2
5	78.23	5.68	6.22	2.37	1.24	4.21	3 ± 2
6	76.61	4.71	4.23	2.55	1.23	5.56	3 ± 2
7	79.57	4.79	4.51	4.39	2.83	5.05	3 ± 2
8	68.04	4.22	4.53	1.78	1.31	3.19	3 ± 2
9	78.79	4.58	3.61	1.22	2.52	5.26	3 ± 2
10	69.36	5.17	2.87	4.24	1.09	2.36	3 ± 2
11	72.34	3.77	2.67	0.17	3.38	5.68	3 ± 2
12	73.01	5.71	2.85	2.83	4.72	5.85	3 ± 2
13	77.4	5.91	2.67	1.77	4.4	2.06	3 ± 2
14	74.92	5.23	3.02	5.14	1.32	5.29	3 ± 2
15	77.03	3.52	3.42	2.94	3.52	2.28	3 ± 2
16	76.11	5.37	3.63	5.57	5.46	1.02	3 ± 2
17	72.87	3.92	3.13	0.92	3.12	3.29	3 ± 2
18	74.43	5.98	4.18	5.27	4.24	4.9	3 ± 2
19	76.08	3.66	4.7	3.28	5.5	4.83	3 ± 2
20	71.52	5.54	4.63	5.61	2.26	2.09	3 ± 2
21	78.22	4.53	3.53	3.87	2.27	5.89	3 ± 2
22	77.88	5.79	2.76	0.9	5.7	2.69	3 ± 2
23	68.54	3.35	2.22	5.41	0.92	5.53	3 ± 2
24	75.19	5.23	4.81	3.96	2.52	4.77	3 ± 2
25	75.56	4.51	4.58	3.71	5.16	2.31	3 ± 2
26	71.89	3.81	4.08	2.25	0.31	2.57	3 ± 2
27	72.15	4.27	3.33	1.88	5.44	4.2	3 ± 2
28	69.03	5.48	2.91	2.09	4.73	4.75	3 ± 2
29	76.64	4.39	2.8	3.8	5.89	3.6	3 ± 2
30	68.91	5.51	2.81	3.39	5.1	4.12	3 ± 2
31	66.88	4.23	2.21	1.47	5.84	2.96	3 ± 2
32	79.81	5.28	3.54	5.31	2.99	0.48	3 ± 2
33	66.73	4.04	3.13	2.31	3.54	3.21	3 ± 2
34	77.87	3.41	3.07	2.17	2.81	3.33	3 ± 2
35	81.23	4.98	3.46	1.34	2.09	3.13	3 ± 2

Table 4. XRF experiment data

Хүснэгт 7-2. Засвар техникийн үйлчилгээний ажлын хөдөлмөр зарцуулалт, 1 дахь жилд

№	Тоног төхөөрөмжийн нэр	Засвар техникийн үйлчилгээний төрөл									Засвар техникийн үйлчилгээний төрөл								
					Их засвар		Урсгал засвар (ТҮ-3)				Урсгал засвар (ТҮ-2)				Урсгал засвар (ТҮ-1)				
		Тоног төхөөрөмжийн тоо, ширхэг /ажлын/	Тоног төхөөрөмжийн нийт жин, тн	Тоног төхөөрөмжийн жилд ажиллах хугацаа маш-цаг (гүйлт,км)	Засвар хоорондын хугацаа маш-цаг /гүйлт, км/	Засварын тоо	Засвар, ТҮ хоорондын хугацаа, маш-цаг /гүйлт, км/	Засвар, ТҮ-ний тоо	Нэгж засвар ТҮ-ний хөдөлмөр зарцуулалт /хүн-цаг/	Бүгд хөдөлмөр зарцуулалт, хүн/цаг	Засвар, ТҮ хоорондын хугацаа, маш-цаг /гүйлт, км/	Засвар, ТҮ-ний тоо	Нэгж засвар ТҮ-ний хөдөлмөр зарцуулалт /хүн-цаг/	Бүгд хөдөлмөр зарцуулалт, хүн/цаг	Засвар, ТҮ хоорондын хугацаа, маш-цаг /гүйлт, км/	Засвар, ТҮ-ний тоо	Нэгж засвар ТҮ-ний хөдөлмөр зарцуулалт /хүн-цаг/	Бүгд хөдөлмөр зарцуулалт, хүн/цаг	Жилийн нийт хөдөлмөр зарцуулалт, хүн/цаг
1	Экскаватор, Hyundai R500LC	1	48.8	3,056	10,000	0.3	5,000	0.6	8,180.2	0.4	2500	1.2	2,045.0	1.5	1000	3.1	327.2	9.3	**11.2**
2	Экскаватор, Doosan 800	1	77.0	7,181	10,000	0.7	5,000	1.4	3,481.6	2.1	2500	2.9	870.4	8.2	1000	7.2	139.3	51.6	**61.9**
3	Экскаватор, Doosan 500	1	50.0	7,181	10,000	0.7	5,000	1.4	3,481.6	2.1	2500	2.9	870.4	8.2	1000	7.2	139.3	51.6	**61.9**
4	Экскаватор, Hyundai R520LC	1	65.0	7,181	10,000	0.7	5,000	1.4	3,481.6		2500	2.9	870.4	8.2	1000	7.2	139.3	51.6	**59.8**
5	Экскаватор, R2900LC	1	29.3	6,112	10,000	0.6	5,000	1.2	4,090.1	1.5	2500	2.4	1,022.5	6.0	1000	6.1	163.6	37.4	**44.8**
6	Экскаватор, R3000LC	1	30.0	300	10,000	0.0	5,000	0.1	83,333.3	0.0	2500	0.1	20,833.3	0.0	1000	0.3	3,333.3	0.1	**0.1**
7	Автосамосвал, MT86, 60 тн	8	464.0	51,588	10,000	5.2	5,000	10.3	484.6	106.5	2500	20.6	121.2	425.8	1000	51.6	19.4	2,661.3	**3,193.6**
8	Автосамосвал, Howo	2	28.0	11,474	10,000	1.1	5,000	2.3	2,178.8	5.3	2500	4.6	544.7	21.1	1000	11.5	87.2	131.7	**158.0**
9	Угтуурт ачигч, Liugong	1	14.0	11,144	10,000	1.1	5,000	2.2	2,243.4	5.0	2500	4.5	560.8	19.9	1000	11.1	89.7	124.2	**149.0**
10	Бульдозер, Shantui SD16	1	9.2	5,495	10,000	0.5	5,000	1.1	4,549.4	1.2	2500	2.2	1,137.3	4.8	1000	5.5	182.0	30.2	**36.2**
11	Бусад	10	50.0	10,000	10,000	1.0	5,000	2.0	2,500.0	4.0	2500	4.0	625.0	16.0	1000	10.0	100.0	100.0	**120.0**
	Бүгд	**28**	**865.3**			12.1				**127.9**				**519.8**		120.7		**3,248.8**	**3,896.5**

Table 5. Work order of Khuut coal mining

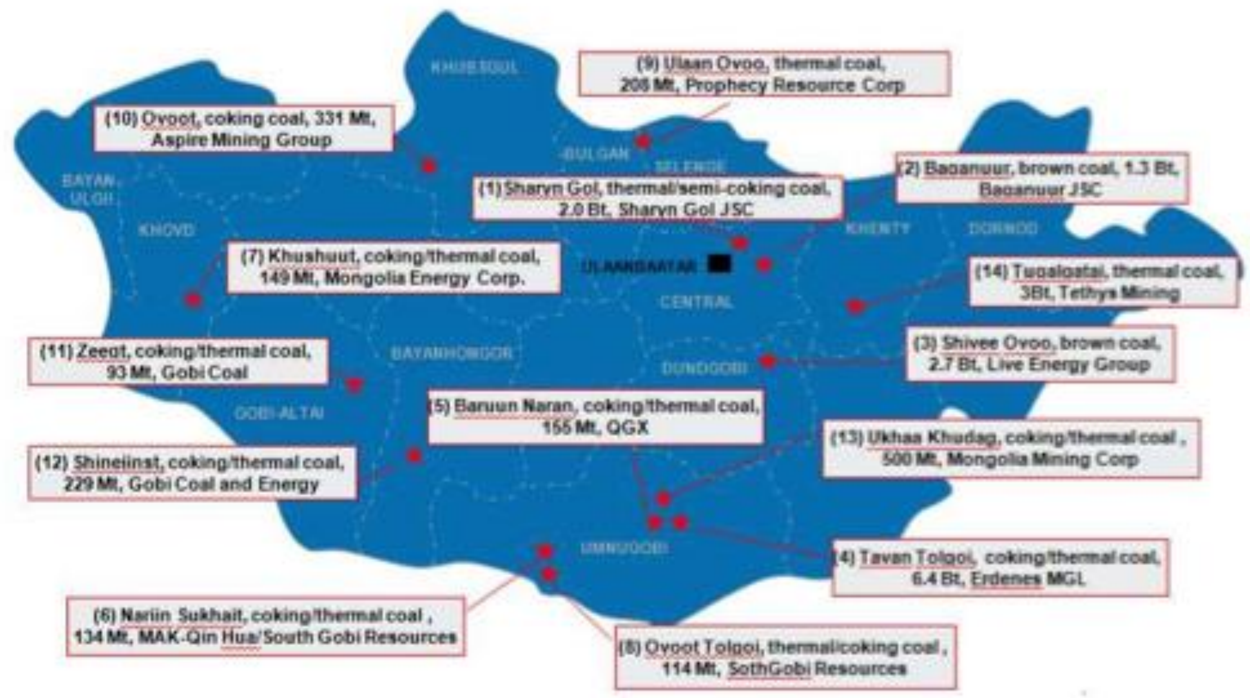
Хөөтийн хонхор-2 нүүрсний уурхайн хөрсний голлох чулуулаг нь алевролит, аргиллит, элсэн чулуунаас бүрдэж байна. Ордын хэмжээнд тархалтаараа нэлээд дээгүүрт орох алевролит нь хар бараан, харсаарал өнгөтэй, нэгэн төрлийн найрлагатай, шахалтын бат бэхийн хязгаар нь 70-80 МПа, бат бэхийн коэффициент нь проф. М.М.Протодьяконовын ангиллаар f=5-7 байгаа нь дунд зэрэг тэслэгдэх зэрэглэлд хамаарагдна. Уулын ажлыг жигд найдвартай явуулах үүднээс хөрсний 30 хувьд өрөмдлөг тэсэлгээний ажил хийнэ.

Хүснэгт 5-18.Чулуулгийн физик-механик шинж чанар

№	Чулуулгийн нэр	Эзлэхүүн жин, т/м^3	Шахалтын бат бэх, МПа	Суналтын бат бэх, МПа	Дотоод үрэлтийн өнцөг, град	Пауссоны коэффициент	Юнгийн модуль, кг/см^3 10^5	Бат бэхийн коэффициент, М.М.Протодьяконовын ангиллаар	Бат бэхийн коэффициент, Бароны ангиллаар
1	Алевролит	2.5	70-77	12	31	0.28	0.1	5	5
2	Аргиллит	2.5	52-88	4-7.1	32	0.3	0.11	5	6
3	Нүүрс	1.4	15	1.2	28-34	0.43	0.18	3	3

Table 6. Soil analysis of Khuut coal mining

MAJOR COAL DEPOSITS IN MONGOLIA



Note:
(8) – (14): numbers indicate resources as reported by the companies
(1) - (7): numbers indicate reserves as defined by China Reality Research
Source: World Bank, US Geological Survey, Ministry of Fuel and Energy of Mongolia and China Reality Research

Figure 31. Major coal deposits in Mongolia

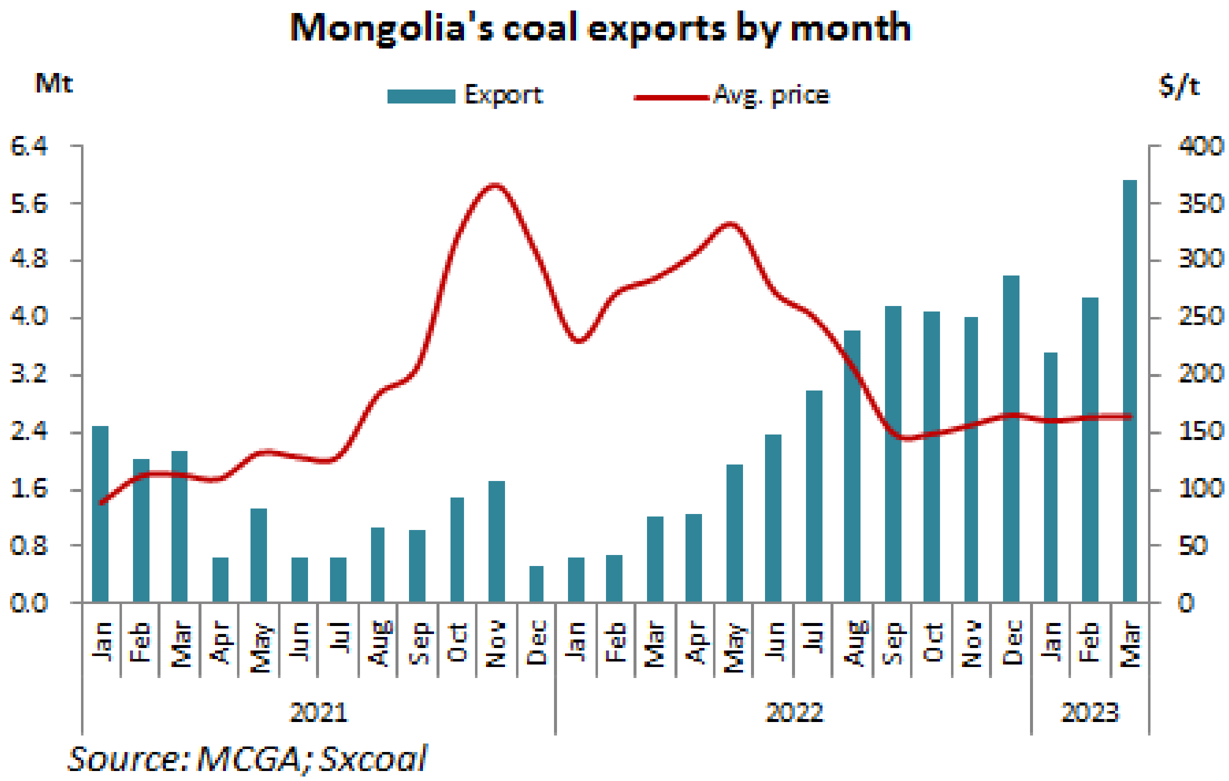


Figure 32. Mongolia's coal exports by month