NÖHÜ Müh. Bilim. Derg. / NOHU J. Eng. Sci., 2023; 12(4), 1499-1507

Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi
Niğde Ömer Halisdemir University Journal of Engineering Sciences

Araştırma makalesi / Research article

www.dergipark.org.tr/tr/pub/ngumuh / www.dergipark.org.tr/en/pub/ngumuh

The determination of the working life of backhoe-loader bucket teeth showing abrasive wear under the effect of dynamic loads

Dinamik yüklerin etkisi altında abrasiv aşınma gösteren beko-loder kova tırnaklarının çalışma ömürlerinin belirlenmesi

Menderes Kalkat[1,*], Mehmet Bahadır [2], Furkan Yılmaz [3]

[1] Niğde Ömer Halisdemir University, Mechanical Engineering Department, 51240, Niğde Türkiye
[2] Selçuk University, Çumra Vocational School Department of Crop and Animal Production, 42500, Konya, Türkiye
[3] Ankara Technology Development Zone,University District. 1606 th Street. No: 11, CYBERPARK H Blok Ericsson 06800 Bilkent, Ankara, Türkiye

Abstract

Especially in developing countries, the rise of infrastructure works increases the demand for heavy machines. Backhoe loaders: These are small tonnage work machines consisting of a bucket group at the front and a bucket set at the back, which are used in many areas such as infrastructure, road construction, maintenance, and repair in the construction industry. The teeth, which are bolted or welded to the front of the buckets, protect the bucket against the abrasive effects of soil and rocks. The rapid wear of the teeth under great loads is an important cost item in construction equipment. In this study, the stresses under the effect of dynamic loads were tried to be determined in the teeth in the backhoe loader buckets. In this context, it is aimed to determine the wear conditions of two different models of teeth, which are frequently used in the sector, with the help of the discrete element and finite element methods.

Keywords: Backhoe-loader, Tooth, Wear, Discrete element method (DEM), Lifetime

Özet

Özellikle gelişmekte olan ülkelerde altyapı çalışmalarının ön plana çıkması, iş makinalarına olan talebi arttırmaktadır. Beko loderler; inşaat sektöründe, altyapı, yol yapımı, bakım ve onarım gibi birçok alanda kullanılan ön tarafta kova grubu, arka tarafta kepçe grubundan oluşan küçük tonajlı iş makineleridir. Kovaların ön kısmına cıvatalı veya kaynaklı olarak monte edilen dişler, toprak ve kayaların aşındırıcı etkilerine karşı kovayı korurlar. Büyük yükler altında dişlerin çok çabuk şekilde aşınması iş makinalarında önemli bir masraf gideri olarak karşımıza çıkmaktadır. Bu çalışmada, beko-loader kovalarındaki dişlerde, dinamik yüklerin etkisi altında gerilmeler belirlenmeye çalışılmıştır. Bu bağlamda sektörde sık kullanılan iki farklı model dişin, ayrık eleman ve sonlu elemanlar yöntemi yardımıyla aşınma durumlarının belirlenmesi amaçlanmıştır.

Anahtar kelimeler: Beko loder, Diş, Aşınma, Ayrık elemanlar metodu (DEM), Ömür

1 Introduction

In developing countries such as ours, the increase in infrastructure investments raises the importance and demand for heavy equipment. Heavy equipment ise self-propelled or towable machines, tracked or wheeled, used in the superstructure, infrastructure, highway construction, maintenance, and repair in the construction sector, as well as in similar works such as excavation, loading, and spreading of soil in the mining and agricultural sector. Backhoe loaders can also be called backhoe loader tractors (Figure 1). They consist of a bucket group at the front and backhoe attachments at the rear. They are generally used in small demolition and excavation works, low tonnage loading, digging, and trenching works, crushing, and trenching works.

Among the operating costs of all construction equipment, fuel costs are the most common expense. At the same time, operator and attachment costs constitute the next expense item. These costs also apply to backhoe loaders. When attachment costs are considered, the most prominent parts are the teeth, which are bolted or welded to the front of the buckets, preventing the bucket from easily deforming due to the abrasive effects of soil and rocks in different terrain conditions.

Figure 1. Backhoe loader

Teeth are parts subject to high rates of wear under heavy loads. The strength and efficient use of the tines is very important. Teeth are mounted according to the tonnage and bucket capacity of backhoe loaders. They are usually made of hot cast iron and reinforced with different features such as heat treatment or coating. If the design patterns and wear characteristics of the teeth are not aerodynamically

* Sorumlu yazar / Corresponding author, e-posta / e-mail: mkalkat@nigde.edu.tr (M. Kalkat)
Geliş / Recieved: 08.07.2023 Kabul / Accepted: 31.08.2023 Yayımlanma / Published: 15.10.2023
doi: 10.28948/ngmuh.1324598

appropriate, the forces on the teeth with the effect of dynamic loads force the bucket and thus the backhoe-loader. This increases fuel consumption by operating inefficiently.

The scope of this study is to determine the stresses occurring under dynamic loads in backhoe loaders, which are used in many places such as construction and agriculture. Additionally, the study will examine the wear on the teeth of three different models that are used in buckets with a capacity of 1 m3, which is the most frequently used capacity in the sector. The study will employ the discrete element method.

2 Material and methods

This study was carried out with a 66 KW, 8760 kg standard tire-wheeled backhoe loader, with a front loader lift breakout force of 54 KN and a slope breakout force of 60.48 KN (Figure 2).

Figure 2. Backhoe loader and working environment taken as reference in the analysis

The width of the front loader bucket, which will be analyzed, and where the teeth are mounted with a bolt connection, is 2240 mm. The capacity is 0.96 m^3. The bucket is made of Hardox 450 material, and the drawings of the bucket are given in Figure 3.

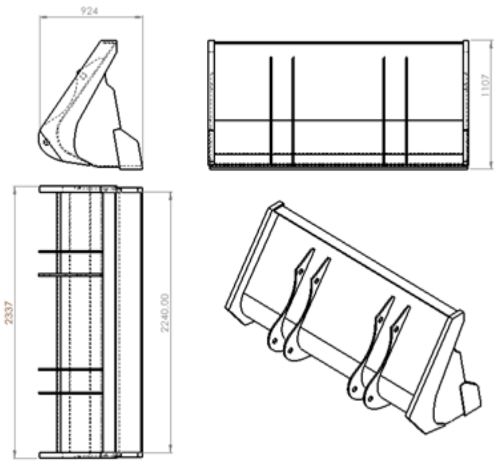


Figure 3. Technical dimensions of the bucket

The selection of teeth to be analyzed was made by considering the most frequently used models in the sector. The models were then drawn by taking the measurements of teeth from two different models that were obtained from companies selling construction machinery and equipment (Figure 4).

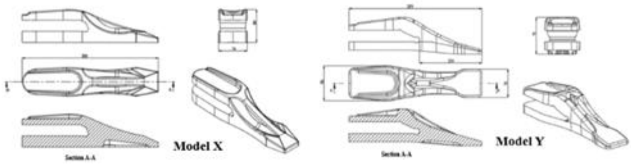


Figure 4. Technical drawings of two different models X and Y teeth used in the analysis

The chemical and mechanical properties of the teeth of the two different models are given in Table 1 and Table 2.

Table 1. Chemical properties of the teeth (Metalon steel casting company)

% C	% Si	% M	% P	% S	% Cr	% Ni	% V	% B
0.27	0.25	1.2	0.014	0.016	0.2	0.8	0.009	0.004

Table 2. Mechanical properties of teeth (Metalon Steel Casting Company)

Mass density (Kg/m^3)	Minimum yield strength (MPa)	Minimum tensile strength (MPa)	Extension (%)	Impact resistance (C ve KVJ)	Hardness (HV)
7.850	1.250	1.600	8	-40.20	500

The hardness values of the teeth are HV 500. The wear coefficient of the martempered AISI 4140 material, which has a hardness value of approximately 430 to 463 HV, was given as 2.78x10^{-5} mm^3/Nm in the master' s thesis study conducted by Gencer [1] in 2020. This value was taken as a reference in the analysis.

To match the simulations with reality, a pool (8 m long, 4 m wide, and 4 m high) of the heap pools in the crusher quarries was modeled. As a reference for the analysis, the filling and unloading process for a backhoe loader in the crusher quarry was recorded on video, and so that the filling and unloading times were determined. Based on the recorded videos, the bucket motion simulation was simulated, and the analysis process was applied for each different model tooth. To calculate the average diameter of the bulk materials used in the analysis, fifty granular gravel materials of different sizes were taken from the crusher quarry (Figure 5). The width, length, and height of the samples were measured, and the average diameter value was calculated as 35.22 mm. The Rocky DEM program, which is a Discrete Element Method (DEM) software, was used to determine the dynamic loads and wears of three different models of teeth under mechanical stresses.

The discrete element method is a numerical modeling method based on the standards of Newton' s second law of motion and force-displacement laws. This method involves monitoring particle interactions at each contact and modeling particle motion for each particle (Boac et al., 2014 [2]). This model generates particles with physical and mechanical properties of the material depending on the information parameters given to the model. The basic principles of the discrete element method are to update the position of each element in the simulation based on the interactions between the elements during the simulation time.

Figure 5. Dimensional properties of the mucus materials taken as samples

Figure 6 shows the main concept of the computational cycle for the discrete element method.

The study aims to develop an algorithm for detecting and measuring the contact forces between particles in a granular material. The objective of the research is to create a method for detecting and quantifying the contact forces among particles in a granular substance through an algorithm. The primary goal of this study is to establish an algorithm that can accurately detect and measure contact forces between particles within a granular material.

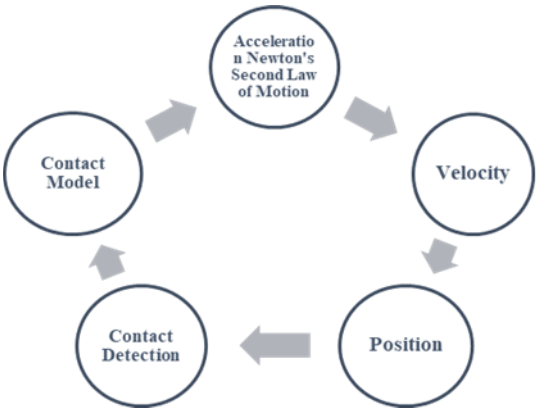


Figure 6. Computational cycle of the discrete element method (Yilmaz, F., 2021 [3])

2.1 Wear model

Archard's law of wear proves that the wear rate is proportional to the sliding velocity and normal contact force. In other words, the wear of a material is determined by the size, velocity, friction coefficients, and collision energy of the impacting particles (Wang et al., 2021 [4]). As a result, the volume loss of the material is associated with the work done by the frictional forces on the material' s surface and can be expressed as Equation (1):

$$V = k\frac{F_\tau . s_\tau}{H} \tag{1}$$

V: Total volume of material worn from the surface (mm^3),
F_τ: The tangential force applied to the surface (N),
s_τ: The sliding distance on the surface (mm),
H: The hardness of the material exposed to wear (MPa),
k : It is a dimensionless empirical constant

2.2 Literature review

One of the studies related to the teeth of construction machinery was conducted by Bahadır M. and Tekeli M. [5] in 2018. In their study, they designed a new tooth model pattern for a 10-ton excavator loader bucket using computer-aided design and manufactured it after conducting analyses using the finite element method. They determined the field performance of the newly designed tooth and observed the wear conditions on the teeth after 300 hours of operation.

The thesis study conducted by Yılmaz F. [3] in 2023 aims to determine the wear, fatigue, and working life of teeth used in 1 m^3 capacity buckets under dynamic loads in backhoe loaders. In this study, tooth wear was analyzed using the discrete element method, and the work life of the teeth was determined using the finite element method. The results of the study revealed that the majority of wear on the teeth occurs around sharp edges and small contact areas.

In his thesis study conducted by Öz S. [6] in 2022, the effects of dynamic loads on backhoe loader digging teeth were determined on three different types of soils and three different tooth groups using the finite element method. The study aimed to analyze the stresses and deformations on the teeth caused by dynamic loads.

In the study conducted by Özdoğan M. [7] in 2003, it was determined that the purpose of attaching bucket teeth is to enhance the bucket' s ability to penetrate rock or loosened rock. It was found that in order to increase the digging force of the bucket, teeth with smaller cutting widths should be used. However, if such a problem does not exist, it is recommended to prefer wider and longer-lasting teeth for extended wear life.

In the study conducted by Kalpak S. et all. [8] in 2015, it was found that the maximum stress on the teeth occurs due to maximum contact, and they determined that it is possible to avoid this stress by redesigning the bucket tooth.

In the study conducted by Khan S. et all. [9] in 2015, it was observed that bucket teeth are subjected to abrasive wear due to the abrasive nature of soil particles. As a result, the study concluded that this condition reduces the working life of excavator bucket teeth to 72-120 working hours.

In the study conducted by Suryo S. H. et all. [10] in 2020, the aim was to optimize a commonly used bucket tooth design in the industry to achieve a lighter design that could provide nearly the same durability as the original tooth. Various tests, such as tensile testing, chemical composition testing, and micrographic testing, were conducted to determine the type of material used. Subsequently, a linear static simulation was performed to determine whether the design could be achieved through topology optimization. Based on the results of the linear static simulation conducted using the finite element method, the maximum value of Von-Mises stress was observed to be 653.17 MPa. This value was found to be below the yield strength of AISI 4140 material, which is 1528 MPa, indicating that the design is safe and can be optimized to a certain extent.

In their study conducted in 1993, V. A. Polovinko and A. I. Fedulov [11] examined the wear on the teeth used in KG-5, KG-12, and KG-15 excavators for mining operations in the northeastern regions of Russia. They stated that the tooth wear obtained at the critical wear stage did not have any impact on the excavator' s performance. The main features and dimensions of the tooth were developed based on the fundamental characteristic points of the wear resistance curves of the mass-produced wedge-shaped teeth. They emphasized that improving the design parameters of the tooth by bypassing the critical wear stage is an effective way to increase the wear resistance of the excavator tooth. They achieved a 40% improvement in wear resistance with their newly designed tooth.

In their study, Vlastimil Moni, Petr Klouda, Tomáš Miletič, František Helebrant, Luboš Donát, Jan Blata, and Michal Řehoř (2019) [12] emphasized the importance of excavator bucket teeth that directly interact with the extracted rock in mines and their geometries. Through their study, conducted under the TH03020368 project number of the TAČR EPSILON program, they aimed to extend the working life of excavator cutting bodies. With their research on tooth number 2673 and ESCO Super V39VYH, they aimed to discover the optimal tooth shape and geometry for different mining conditions.

In their study, Virag and Szirbig S. [13] (2012) investigated the effects of lateral forces on bucket teeth during the operation of excavators, backhoe loaders, and similar construction machinery. Through finite element analysis, they obtained the stress and displacement distribution in the teeth. The analysis revealed that as the lateral forces increased, the maximum stresses decreased.

In their study, Marko Popović, Ivan Milićević, Goran Marković, Milan Marjanović, and Vojislav Vujičić [14] (2020) used Evans' two-dimensional model to calculate the stresses that would occur in the ERS 1000 tracked excavator tooth under the existing excavation conditions in the Tamnava West Open-Pit Mine in Serbia. This model is a simple rock-breaking model used to obtain initial data for tooth design by subjecting the excavator to different forces. The maximum static load calculation for the tooth is based on data obtained from laboratory tests. The analysis consists of two stages. In the first stage, a laboratory test was conducted, which involved loading the tooth until it fractured, and the resulting forces and strains were monitored. The external load direction and movement were designed to mimic real field conditions, while the load intensity was increased until the cutting tooth fractured. In the second stage, considering the laboratory test conditions, the maximum force generated before the physical prototype fractured was measured. By comparing the results obtained from these two stages, the validation of the calculation model was ensured, and at the same time, the maximum static force that the tooth can withstand before fracturing was measured.

In their study, Zhigui Ren, Haoran Sun, Yongyong Liang, Yayin He, and Minghao Feng [15] (2020) discussed that the excavator bucket suffers damage before reaching its theoretical lifespan during the excavation process. Based on the theory of continuous orbit, a three-segment continuous orbit was selected, in which the bucket and the arm alternately excavate in the normal excavation orbit. They analyzed the strength of the bucket structure under two different excavation force loads by calculating the Theoretical Digging Force (TDF) and Limit Digging Force (LDF) on the excavation orbit. They compared the strength results with the results of the bucket's constrained mode and free mode analyses. The three-dimensional model created for the analysis consisted of 226.572 elements and 419.837 nodes. When applying the load to the bucket, the maximum tangential force of the TDF and the maximum LDF for each orbit are taken as external loads. To prevent excessive calculation errors caused by stress concentration, the concentrated force is distributed to multiple nodes. According to the simulation results, it was observed that the bucket's stress and deformation were in the same position when subjected to the external loads of TDF and LDF, respectively. It can be observed that the ear plate and the rear support plate of the bucket are subjected to the highest stress at the welding location. As a result, considering the normal force and resistance moment in the selected normal excavation orbit, it is generally shown that the LDF is largerthan the TDF and that the effect of the LDF load on the bucket structure strength is also greater.

2.3 Wear analysis

In simulations, the average equivalent diameter of bulk materials is assumed to be 35 mm. The particle sizes are randomly generated by the Rocky DEM program within a range of 0.75 to 1.5 times their actual size to achieve realism. The discrete element behavior model used for the analyzed teeth consists of the Hysteretic Linear Spring model for normal force, the Linear Spring Coulomb limit model for tangential force, and a rolling resistance coefficient of 0.18. The Archard wear model is employed for the wear analysis. In the discrete element method, the mesh sizes for all the teeth mounted on the bucket are set to 5 mm to ensure accurate detection of the analysis. Before starting the analysis, the angle of repose of the sample gravel materials was applied in the simulation environment in terms of accuracy and the closest to the reality of the results, so that the Rocky DEM program was also calibrated.

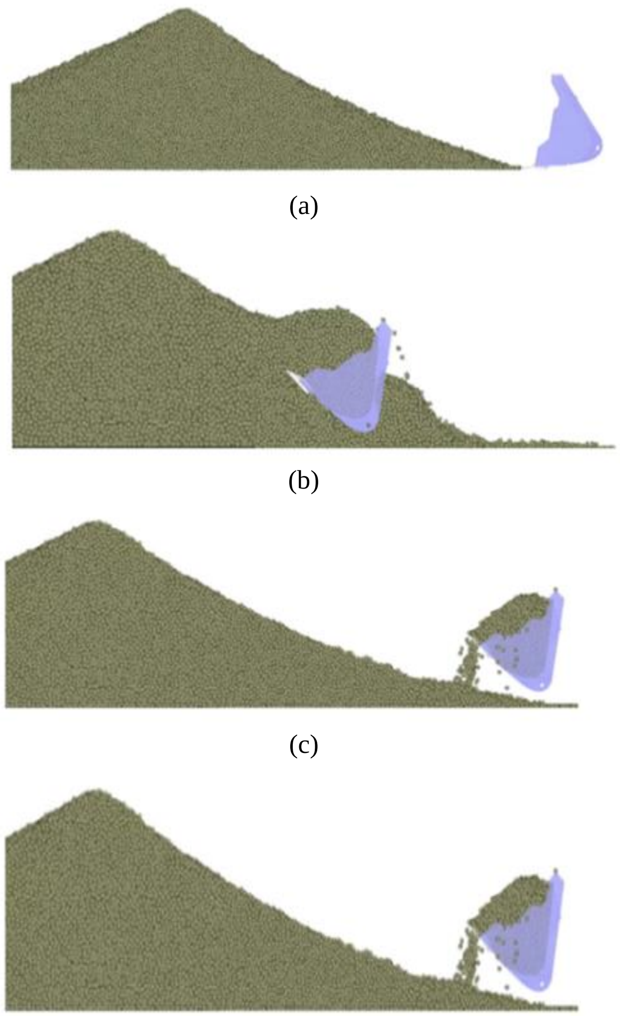
The other parameters used in the discrete element method simulation are obtained from existing literature sources. These parameters are based on data and findings reported in the relevant literature.

The mechanical properties of the rock particles (gravels) used in the simulations are provided in Table 3.

The analysis was applied to each bucket tooth group in the same manner and for the same duration. The total duration between the start and end of the bucket movement is 8 seconds, and it was repeated three times. The total analysis time, including the idle movement of the bucket, is 45 seconds (Figure 7).

Table 3. Mechanical properties of rock particles (Gravel)

Particle properties (Gravel)	
Density (kg/m^3)	2666.67
Bulk density (kg/m^3)	1600
Elastic modulus (N/m^2)	1E+08
Poisson's ratio	0.3
Equivalent sphere diameter (mm)	35
Coefficient of rolling resistance	0.18
Static friction coefficient (gravel-gravel)	0.8
Dynamic friction coefficient (gravel-gravel)	0.72
Coefficient of restitution (gravel-gravel)	0.3
Static friction coefficient (cast steel-gravel)	0.7
Dynamic friction coefficient (cast steel-gravel)	0.65
Coefficient of restitution (cast steel-gravel)	0.3



(a)

(b)

(c)

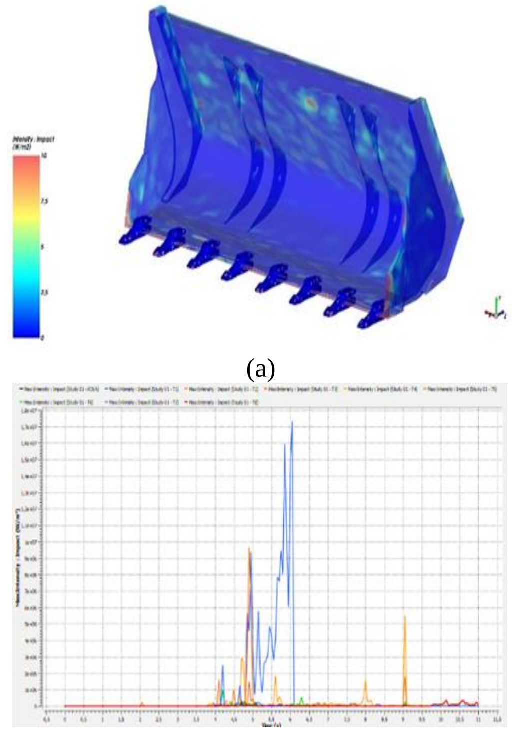
(d)

Figure 7. Three - repetition bucket movement simulation (a: bucket position in 3 seconds, b: bucket position in 6.3 seconds, c: bucket position in 8.3 seconds, d: bucket position in 11 seconds)

3 Results and discussions

3.1 Wear analysis and values for model X teeth

A wear analysis was conducted for Model X teeth, and the wear regions (Figure 8a) and wear amounts (Figure 8b) for all teeth attached to the bucket were determined through DEM analysis for Model X. The wear amounts of the three most heavily worn teeth were visualized and depicted in the figures.



(a)

(b)

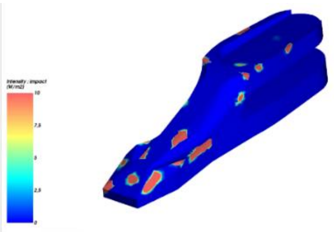
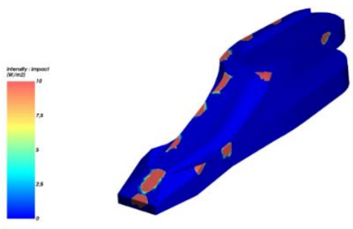
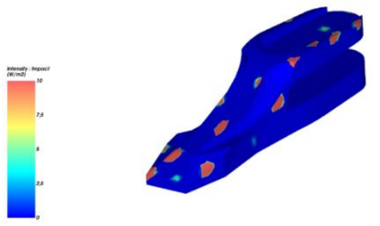
Figure 8. (a):wear regions on the bucket and model X teeth and (b):wear values on the bucket and model X teeth

In Table 4, the maximum wear amounts of all X model teeth are displayed.

Table 4. Maximum wear amounts of all model X teeth

Model X teeth	BUCKET	**T1**	T2	T3	**T4**
Maximum wear amount (W/m^2)	2.76E+05	**1.73E+07**	1.64E+06	1.49E+06	**5.50E+06**
Model X teeth	**T5**	T6	T7	T8	
Maximum wear amount (W/m^2)	**9.67E+06**	1.01E+06	2.50E+06	3.63E+05	

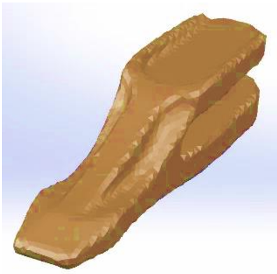
The mass loss amounts in the three teeth where wear is most common are given in Table 5 at the end of the analysis period. In Figure 9, wear regions observed on T1, T5, and T4 teeth during moments of maximum wear are displayed.

T1
Wear regions associated with T1 tooth

T5
Wear regions associated with T5 tooth

T4
Wear regions associated with T4 tooth


Worn regions of the T1 tooth

Worn regions of the T5 tooth

Worn regions of the T4 tooth

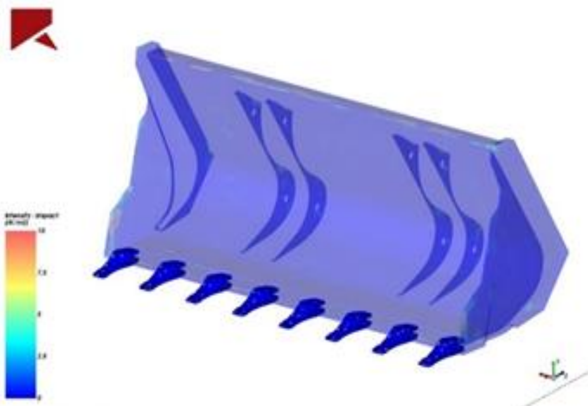
Figure 9. Wear regions observed on T1, T5 and T4 teeth during the moments of maximum wear.

Table 5. Mass loss observed on these teeth at the end of the analysis period.

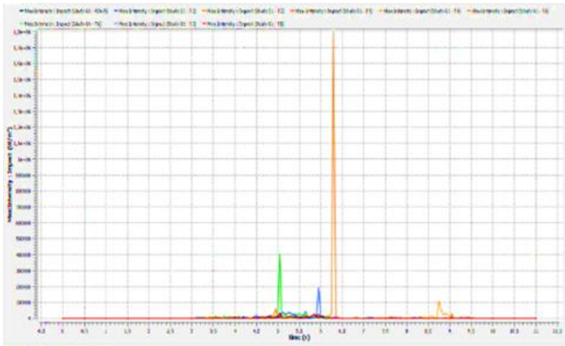
Mass losses in T1, T5 and T4 threads	Teeth with the most severe wear	T1	T5	T4
	Pre-experimental tooth volume (mm^3)	319.293,01		
	Pre-experimental tooth mass (kg)	2.506		
	Post-experimental tooth volume (mm^3)	314.417, 83	314.425, 47	314.907, 00
	Post-experimental tooth mass (kg)	2,46818	2,46824	2,47202
	Wear amount in one hour (kg)	~ 3,01803. 10-3	~ 3,02075. 10-3	~ 2,71160. 10-3

3.2 *Wear analysis and values for model Y teeth*

A wear analysis was conducted for Model Y teeth, and the wear regions (Figure 10a) and wear amounts (Figure 10b) for all teeth attached to the bucket were determined through DEM analysis for Model Y



(a)



(b)

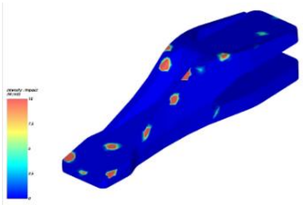
Figure 10. (a):wear regions on the bucket and model Y teeth and (b):wear values on the bucket and model Y teeth

As can be seen from Table 6 and Figure 10, the wear is predominantly observed on the T2 tooth, followed by T6 and T1 teeth (Figure 11)

The mass loss amounts and ratios in the three teeth where wear is most common are given in Table 7 at the end of the analysis period.

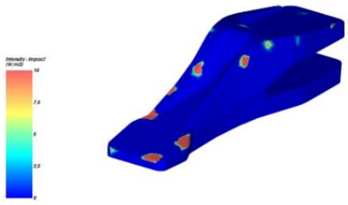
Table 6. Maximum wear amounts of all model Y teeth

Model Y teeth	BUCKET	T1	T2	T3	T4
Maximum wear amount (W/m^2)	1,19E+04	**1,94E+05**	**1,80E+06**	1,43E+04	1,10E +05
Model X teeth	T5	**T6**	T7	T8	
Maximum wear amount (W/m^2)	3,98E+04	**4,03E+05**	3,62E+04	3,11E+04	



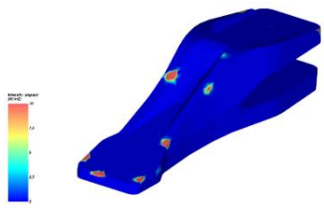
T2

Wear regions associated with T2 tooth



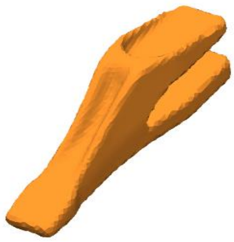
T6

Wear regions associated with T6 tooth

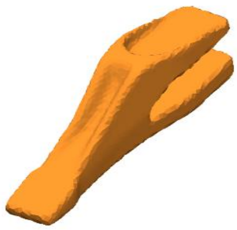


T1

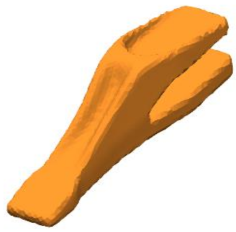
Wear regions associated with T1 tooth



Worn regions of the T2 tooth



Worn regions of the T6 tooth



Worn regions of the T1 tooth

Figure 11. Wear Regions observed on T2, T6 and T1 teeth during the moments of highest stress.

Table 7. Mass loss observed on these teeth at the end of the analysis period

Mass losses in T2, T6 and T1 threads	Teeth with the most severe wear	T1	T5	T4
	Pre-experimental tooth volume (mm^3)	325.460,45		
	Pre-experimental tooth mass (kg)	2,5548		
	Post-experimental tooth volume (mm^3)	323.105,49	323.098,27	322.896,82
	Post-experimental tooth mass (kg)	2,24606	2,53632	2,53474
	Wear amount in one hour (kg)	~ 2,4699. 10^{-3}	~ 2,4613. 10^{-3}	~ 2,4539. 10^{-3}

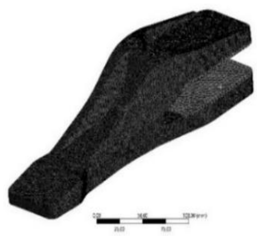
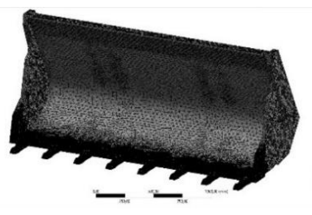
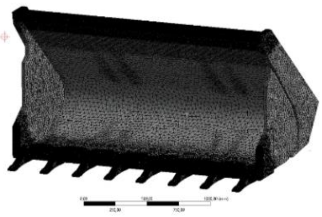
3.3 *Fatigue and working life analysis*

In our study, wear analyses were conducted on two different models of teeth under dynamic loads to determine the fatigue and working life durations resulting from wear effects. The stress and deformation values were determined on the three most worn teeth.

The node and element numbers for each model of tooth, selected for analysis using ANSYS Workbench 2020 R2 software, are presented in Table 8. Mesh quality standards for the teeth were adjusted to acceptable limits according to Skewness, Orthogonal, and Aspect Ratio criteria. Finite element analyses were then performed to determine the fatigue and working life analyses of the teeth.

According to the Gerber approach used in fatigue analysis of ductile materials (Ovalı, 2018 [16]), fatigue and working life analyses were performed on the top 3 most worn teeth for both models. The analysis determined the fatigue strength and working life values for these teeth. (Figure 12)

Table 8. Mesh quality values for two different models of teeth

Model X		Model Y	
			
			
Number of nodes	Number of elements	Number of nodes	Number of elements
2.807.784	1.964.873	4.080.532	2.820.981
Skewness Quality values (max.)			
0,87125		0,87282	
Orthogonal Quality values (min.)			
0,18875		0,18718	
Aspect Ratio Quality values (max.)			
9,887		9,71142	

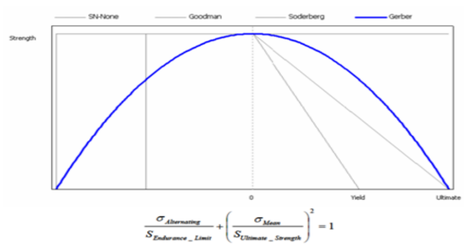
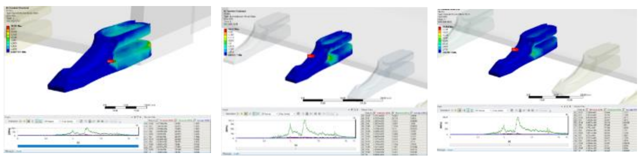


Figure 12. Gerber approach (bader Q. and kadum E., 2014 [17])

The determination of the working life of model X tooth: The stresses and working lives of the T1, T5, and T4 teeth at the time of maximum wear, where wear is most pronounced, have been observed (Table 9).

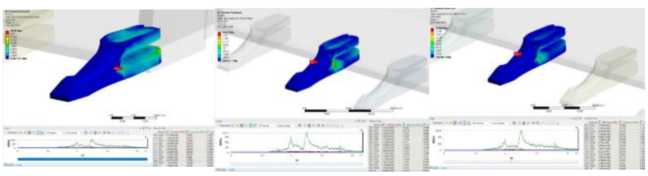
Table 9. Stresses and working lives of T1, T5 and T4 teeth at the time of maximum wear.



T1	T5	T4
Maximum equivalent stress at 6.35 seconds, where wear is highest	Maximum equivalent stress at 4.95 seconds, where wear is highest	Maximum equivalent stress at 9.05 seconds, where wear is highest
396.4 MPa	206.12 MPa	219.31 MPa
Working life (cycle) at 6.35 seconds, where wear is highest	Working life (cycle) at 4.95 seconds, where wear is highest	Working life (cycle) at 9.05 seconds, where wear is highest
2780.6	18389	22951

The determination of the working life of model Y tooth: The stresses and working lives of the T2, T6, and T1 teeth at the time of maximum wear, where wear is most pronounced, have been observed. (Table 10)

Table 10. Stresses and working lives of T2, T6 and T1 teeth at the time of maximum wear.



T1	T5	T4
Maximum equivalent stress at 6.3 seconds, where wear is highest	Maximum equivalent stress at 5.05 seconds, where wear is highest	Maximum equivalent stress at 5.95 seconds, where wear is highest
474.22 MPa	96.042 MPa	203.54 MPa
Working life (cycle) at 6.3 seconds, where wear is highest	Working life (cycle) at 4.95 seconds, where wear is highest	Working life (cycle) at 9.05 seconds, where wear is highest
5241.1	1.10^6	$2.87.10^5$

4 Conclusions

In this study, the results regarding the wear condition of the teeth were obtained using the Rocky DEM software, while the determination of fatigue and working life was performed using the ANSYS software.

During the wear analysis, as can be observed from the figures, the predominant result applicable to all teeth is that the majority of wear occurs around sharp edges and small contact areas, Figure 13.

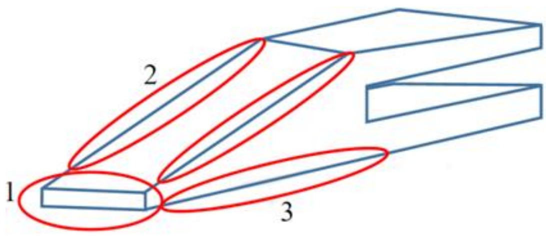


Figure 13. Total wear zones

The sides of the X-model tooth were thin compared to the other model tooth, so the wear effect was seen more on the side parts. In the Y-model tooth group, although the side walls are strong, it has been observed that the middle and upper parts wear out more quickly.

According to market conditions, the tooth model with the most ideal wear life among the two most commonly used types of tooth models is the Y-model teeth.

The discrete element method provides a significant advantage in determining wear data, thus providing insights into the ideal geometric structure and material for teeth used in backhoe loaders. This method will serve as a guide for future studies.

Acknowledgement

We owe a debt of gratitude to the Metalon Steel company for the information about the mechanical and chemical properties of teeth and the valuable information they provided about the bucket teeth of construction machinery.

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): .15%

References

[1] S.K. Gencer, Investigation of the effect of hardening heat treatment methods on the mechanical and wear properties of aisi 4140 quality steel. Master 's Thesis, Gebze Technical University Graduate School of Natural and Applied Sciences, Turkey, 2020.

[2] J.M. Boac, R.P.K. Ambrose, M. E. Casada, R.G. Maghirang, D.E. Maier, Applications of discrete element method in modeling of grain postharvest operations. Food Engineering Reviews, 6(4), 128–149. https://doi.org/10.1007/s12393-014-9090-y 2014

[3] F. Yılmaz, Analysis of wear effect, fatigue, and working life of backhoe loader bucket teeth with 1 m3 capacity under dynamic loads. Master 's Thesis, Niğde

Omer Halisdemir University Graduate School of Natural and Applied Sciences, Turkey, 2023

[4] P. Wang, D. Si, S. Wang and Q. Yi, Study on gage widening methods for small-radius curves. China Academy of Railway Sciences Corporation Limited, Beijing 100081, China, Applied Sciences. 2021.

[5] M. Bahadır, M.A. Tekeli, New backhoe loader tooth model design, analysis and manufacturing. International Congress of Climate Change: Sustainability on Health, Agriculture, Food and Livestock Policies ICSAFL 2018 Amsterdam, Holland.

[6] S. Oz, Dynamic analysis of backhoe loader bucket teeth. Master 's Thesis, Niğde Omer Halisdemir University Graduate School of Natural and Applied Sciences, Turkey, 2022.

[7] M. Ozdoğan, Bucket penetration mechanism and bucket penetration force of dragline excavators. 42, (1), 17-26. 2003

[8] S. Kalpak, R. Dagwar, G. Telrandhe, Excavator bucket tooth failure analysis. International Journal of Research in Mechanical Engineering and Technology, 5 (2) issn: 2249-5762 (online) 2015.

[9] S. Khan, M. Sheikh, Comparative analysis of wear for excavator bucket tooth using different materials. International Journal of Science and Research (IJSR), 5(5), 2016.

[10] S.H. Suryo, W.M. Fawwaz, Y.A. Wijaya, E.W. Saputro, H. Harto, Analysis and topology optimization structural design excavator bucket tooth using finite element method. The 5th International Conference on Industrial, Mechanical, Electrical, And Chemical Engineering (ICIMECE 2019), 2020. https://doi.org/10.1063/5.0000531 2020.

[11] V.A. Polovinko, A.I. Fedulov, Abrasive wear of excavator teeth. Journal of Mining Science, 29, 48–51. 1993. https://doi.org/10.1007/BF00734332.

[12] V. Moni, P. Klouda, T. Miletič, F. Helebrant, L. Donát, J. Blata, M. Řehoř, Evaluation of tooth no. 2674 and esco tooth 3d models. Multidisciplinary Aspects of Production Engineering – MAPE, 2 (1) 2019.

[13] Z. Virag & S. Sandor, Examination of an optimized replaceable cutting tooth of excavator. Geosciences and Engineering, 1 (2), 337–342 .2012.

[14] M. Popović, I. Milićević, G. Marković, M. Marjanović, V. Vujičić, Load analysis for the design of cutting teeth for bucket chain excavators. 8th International Scientific Conference Technics and Informatics in Education Faculty of Technical Sciences, Čačak, Serbia, 18 - 20th September. 2020

[15] Z. Ren, H. Sun, Y. Liang, Y. He, M. Feng, Strength analysis of excavator bucket based on normal digging trajectory and limiting digging force. Journal of Vibroengineering, 23(1), 2021

[16] İ. Ovalı, C. Esen, ANSYS Workbench.3 rd edition. 2018

[17] Q. Bader, E. Kadum, Mean stress correction effects on the fatigue life behavior of steel alloys by using stress life approach theories. International Journal of Engineering & Technology IJET-IJENS, 14 (4), 50-58. https://doi.org/10.12691/ajme-4-7-15 2014.