

STUDY ON THE RELIABILITY OF THE BWE TEETH USED IN OLTENIA BASIN

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Abstract: The paper deals with the calculation of the operational reliability for the cutting-teeth mounted on bucket wheel excavators used in lignite extraction in the Oltenia Basin. Based on the data recorded for three types of cutting-teeth used in production, a reliability study has been carried out which determines the main reliability indicators of the quality level of these cutting-teeth. The study compares the constructive and functional characteristics of the three types of cutting-teeth, which is the basic criterion for purchasing a certain type of cutting-tooth, as well as for the supply of spare parts.

Keywords: reliability, cutting-teeth, BWE, lignite, open pit mining.

1. INTRODUCTION

Four types of bucket wheel excavators (BWE), EsRc-470-15 / 3,5-400, SRS-1300-26 / 3,5-500, SRS-2000-30 / 7-2 × 500, and EsRc-1400-30 / 7-630, are used in lignite open pit mines in the Oltenia Coal Basin.

There are three types of cutting teeth on the market that can fit the buckets of these BWEs. For the study, the supply company A, supplies cutting teeth of types 1400-MII and 1400-3GX, and another company, called B, delivers tooth type 1300-AOM.

In figure 1 a chisel type tooth is presented, and the representative geometric parameters defining the shape of the tooth are specified. The teeth that equip the BWE bucket are designed to displace the material from the face and guide it towards the inside of the bucket. The teeth are mounted on the buckets with bolts or by wedging in cassettes.

Since the working conditions of the teeth are very different, it is necessary to use statistical calculations of their actual operating time. This is done by performing a reliability study that best shows the behavior of the teeth. The study is conducted by real-life testing of three representative samples of each of the three types of teeth.

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When testing under the actual operating conditions of the three types of teeth, the admissible wear limits must be considered. The maximum permissible wear limits (maximum wear of tooth), depending on the construction variant, are:

Type 1300-AOM = 50 mm;

Type 1400-MII = 115 mm;

Type 1400-3GX, = 125 mm.

Replacing of the teeth when they reach this level of wear is strictly necessary for at least three reasons. The first is to avoid increasing the energy consumption for the bucket-wheel drive. The second is to avoid damaging the buckets and the bucket-wheel. An finally, the maintenance of the used tooth in the allowances for reconstruction and hardening.

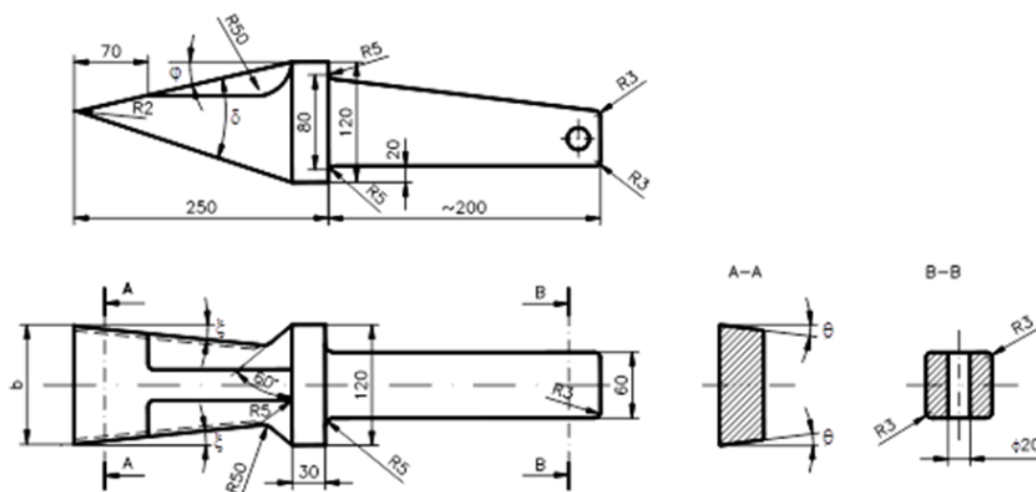


Fig. 1. Dimensions and parameters of a chisel type BWE cutting teeth

2. ESTIMATION OF THE AVERAGE USAGE TIME OF 1400-MII TYPE CUTTING TOOTH

During excavation, the cutting teeth are subjected to composed bending stresses in two perpendicular directions and to compression along the longitudinal axis direction. There are also crushing stresses in the area where they are attached to the bucket and shocks due to the unevenness of excavated rocks.

Very important is the high and aggressive mechanical abrasion that occurs in the area of the active part (the tip of the teeth), which is decisive in determining the level of tooth reliability.

Table 1. Values of the operating time until failure for the cutting teeth type 1400-MII

No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs
1	95	9	165	17	198	25	261	33	300	41	382	49	463	57	552	65	597
2	97	10	170	18	200	26	265	34	300	42	387	50	465	58	580	66	600
3	97	11	172	19	200	27	273	35	300	43	392	51	489	59	580	67	600
4	98	12	180	20	200	28	279	36	300	44	395	52	493	60	590	68	600
5	99	13	180	21	200	29	283	37	352	45	398	53	495	61	591	69	688
6	100	14	185	22	200	30	286	38	359	46	400	54	500	62	592	70	693
7	100	15	185	23	245	31	291	39	362	47	400	55	500	63	594		
8	100	16	189	24	259	32	295	40	378	48	400	56	500	64	595		

The field studies for the 1400-MII type cutting teeth were performed on EsRc-1400 excavators in the Berbești and Roșia open pit mines on a sample of 70 teeth.

Effective operating times to failure (change due to wear above the permissible limit), in hours, form the statistical series of type (S1) shown in table 1.

Table 2 shows that the exponential distribution is not validated, the difference between the empirical and theoretical distribution being higher than the critical value of the test. The normal distribution (Gauss-Laplace) and Weibull 2-parameter and 3-parameter distributions, with parameters calculated by different analytical methods, are validated.

The normalized 2-parameter Weibull distribution, for which the parameters are calculated with the least squares method, respectively with the maximum likelihood estimation, approximates the theoretical distribution best.

However, it can be stated with certainty that any of the validated distributions can characterize the functionality of the bucket wheel cutting teeth.

It is also noted the validation of the normal distribution. This is indicated by the literature for the characterization of the phenomenon of mechanical, electrical and thermal aging phenomena, which also happens in the studied case.

For the value of the shape parameter $\beta = 2$, ($\beta_1 = 2,085$; $\beta_2 = 2,124$; $\beta_3 = 2,009$) resulting from the calculations, Rayleigh distribution law criteria is met. This distribution law is a particular form of the Weibull distribution law and is characterized by the linear variation of the failure intensity.

Table 2. Comparative analysis of the theoretical distributions that characterize the 1400-MII type teeth

Theoretical distribution	Equation of the reliability function, $R(t)$	Maximum deviation, D_{max}	Risk, α (%)	Critical value, $D_{\alpha,76}$	Validation
Exponential, ep	$e^{-0,003266t}$	0,307194	0,5	0,203855	No
Normal (Gauss – Laplace), nv	$\frac{1}{2} - \Phi\left(\frac{t-347,271}{171,997}\right)$ or $1 - \frac{1}{171,997} \frac{1}{\sqrt{2\pi}} \int_0^t e^{-\frac{1}{2}\left(\frac{x-347,271}{171,997}\right)^2} dx$	0,115382	20	0,125858	Yes
Normalised 2-parameter Weibull, Wbp	$e^{-\left(\frac{t}{393,987}\right)^{2,085}}$	0,088134	20	0,125858	Yes
3-parameter Weibull, Wtm	$e^{-\left(\frac{t-3,429 \cdot 10^{-8}}{392,114}\right)^{2,124}}$	0,095357	20	0,125858	Yes
2-parameter Weibull, Wbv	$e^{-\left(\frac{t}{395,848}\right)^{2,009}}$	0,084148	20	0,125858	Yes

Figures 2 and 3 show the main reliability indicators that characterize the functionality of the teeth analyzed.

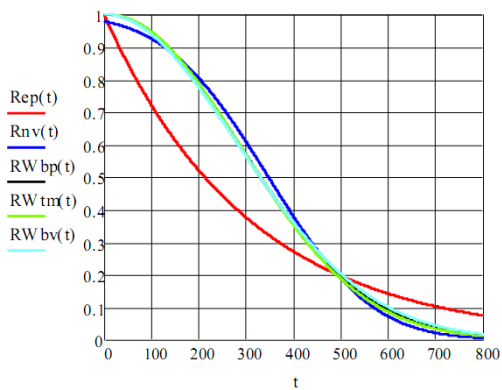


Fig. 2. Variation of the reliability function for the 1400 MII type teeth

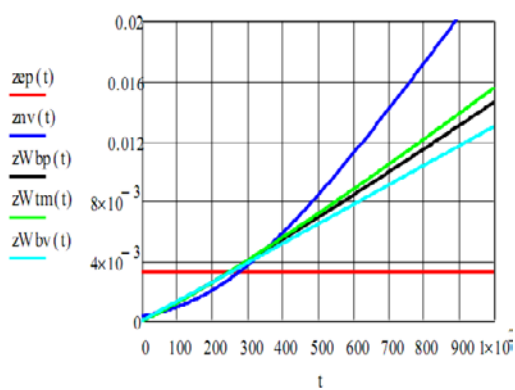


Fig. 3. Variation of the failure rate for the 1400 MII type teeth

Analyzing the variations of the reliability and non-reliability functions, for an effective running time of the BWE of 200 hours, the reliability is 80%. This means that after about 13 working days it is not yet necessary to replace the teeth. The amount of time in working days is calculated on the assumption that the BWE actually works on average 15 hours a day. The value of reliability for 200 hours, in the case of type 1400 MII cutting teeth is very good.

For the up to 100 hours of operating time, there is a fall in reliability to about 93%. This decrease is absolutely normal due to the wear phenomenon. The period is characterized by a small value of the slope of the reliability curve, which suggests a low wear speed. After 100 hours, the slope of the curve increases, which indicates the increase in tooth wear. This behavior in operation also results from the failure rate variation curves, for which this same interval is characterized by low failure intensity.

For the average 348 hours of use time of the cutting teeth, it corresponds a 50% reliability. If an average operating time of 500 hours is imposed, the tooth reliability is only 20%. This means that out of 100 new teeth mounted at the same time, after 500 hours of operation, only 20 will be in operation. The other 80 teeth are changed due to reaching the admissible wear limit. The rapid decrease in reliability from 80 to 20%, with an increase in the time from 200 to 500 hours, shows the increase in wear speed. This increase is indicated by the steepness of the reliability curve slope and the increase in the intensity of wear.

3. ESTIMATION OF THE AVERAGE USAGE TIME OF 1400-3GX TYPE CUTTING TOOTH

The field studies for the 1400-3GX type cutting teeth were performed on EsRc-1400 BWEs in the Berbești and Roșia open pit mines on a sample of 40 teeth.

Effective operating times-to-failure (change due to wear above the permissible limit), in hours, form the statistical series of type (S1) shown in table 3.

Table 3. Values of the operating time until failure for the cutting teeth type 1400-3GX

No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs
1	80	7	185	13	198	19	283	25	365	31	400	37	495
2	95	8	186	14	200	20	283	26	383	32	477	38	500
3	95	9	190	15	200	21	298	27	389	33	481	39	582
4	175	10	192	16	275	22	300	28	390	34	483	40	591
5	175	11	195	17	279	23	357	29	399	35	490		
6	180	12	195	18	281	24	359	30	400	36	493		

Table 4 shows the comparative analysis of the theoretical distributions that characterize the 1400-3GX type teeth.

Table 4. Comparative analysis of the theoretical distributions that characterize the 1400-3GX type teeth

Theoretical distribution	Equation of the reliability function, $R(t)$	Maximum deviation, D_{max}	Risk, α (%)	Critical value, $D_{\alpha;76}$	Validation
Exponential, ep	$e^{-0,03590 \cdot t}$	0,399666	0,5	0,268027	No
Normal (Gauss – Laplace), nv	$\frac{1}{2} - \Phi\left(\frac{t-314,350}{138,780}\right)$ or $1 - \frac{1}{138,780} \frac{1}{\sqrt{2\pi}} \int_0^t e^{-\frac{1}{2}\left(\frac{x-314,350}{138,780}\right)^2} dx$	0,158882	20	0,165472	Yes
Normalised 2-parameter Weibull, Wbp	$e^{-\left(\frac{t}{356,750}\right)^{2,346}}$	0,137006	20	0,165472	Yes
3-parameter Weibull, Wtm	$e^{-\left(\frac{t-1,363 \cdot 10^{-8}}{354,564}\right)^{2,414}}$	0,141894	20	0,165472	Yes
2-parameter Weibull, Wbv	$e^{-\left(\frac{t}{349,708}\right)^{2,314}}$	0,123908	20	0,165472	Yes

Figures 4 and 5 show the variation of the main reliability indicators that characterize the functionality of the cutting teeth..

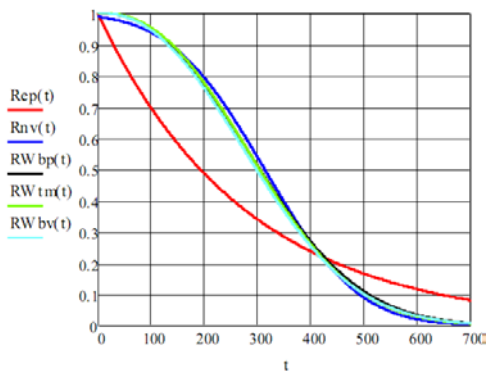


Fig. 4. Variation of the reliability function for the 1400-3GX type teeth

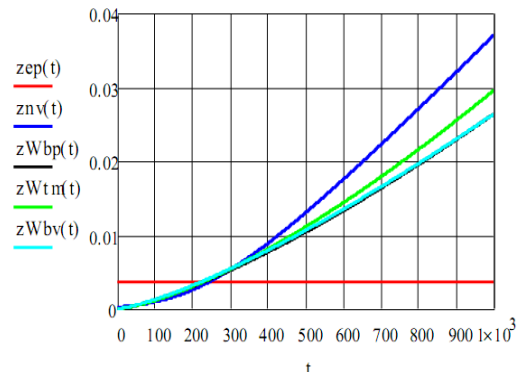


Fig. 5. Variation of the failure rate for the 1400-3GX type teeth

Analyzing the variations of the reliability and non-reliability functions, for an effective running time of the BWE of 200 hours, the reliability is 80%. This means that after about 13 working days it is not yet necessary to replace the teeth. The amount of time in working days is calculated on the assumption that the BWE actually works on average 15 hours a day. The value of reliability for 200 hours, in the case of type 1400 MII cutting teeth is very good.

For the up to 100 hours of operating time, there is a fall in reliability to about 95%. This decrease is absolutely normal due to the wear phenomenon. The period is characterized by a small value of the slope of the reliability curve, which suggests a low wear speed. After this time, the slope of the curve increases abruptly, which indicates a pronounced increase of the tooth wear speed. This behavior in operation also results from the failure rate variation curves, for which this same interval is characterized by low failure intensity.

For the average 314 hours of use time of the cutting teeth, it corresponds a 50% reliability. If an average operating time of 500 hours is imposed, the tooth reliability is only 10%. This means that out of 100 new teeth mounted at the same time, after 500 hours of operation, only 10 will be in operation. The difference of 90 teeth are changed due to reaching the admissible wear limit

The rapid decrease in reliability from 80 to 10%, with an increase in the time from 200 to 500 hours, shows the increase in wear speed. This increase is indicated by the steepness of the reliability curve slope and the increase in the intensity of wear.

4. ESTIMATION OF THE AVERAGE USAGE TIME OF 1300-A0M TYPE CUTTING TOOTH

The field studies for the 1300-A0M type cutting teeth were performed on EsRc-1400 BWEs in the Berbești open pit mines and on a E-470 BWE in the Olteț open pit mine, on a sample of 41 teeth.

Effective operating times-to-failure (t_i) in hours, form the statistical series of type (S1) shown in table 5.

Table 5. Values of the operating time untill failure for rhe cutting teeth type 1300-A0M

No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs	No.	T_i , hrs
1	95	7	193	13	269	19	299	25	398	31	585	37	789
2	98	8	195	14	283	20	300	26	425	32	597	38	823
3	100	9	196	15	290	21	351	27	489	33	600	39	861
4	183	10	200	16	293	22	385	28	490	34	642	40	887
5	188	11	250	17	296	23	385	29	500	35	659	41	950
6	189	12	265	18	298	24	393	30	542	36	725		

Table 6 shows the comparative analysis of the theoretical distributions that characterize the 1300-A0M type teeth and figures 6 and 7 show the variation of the main reliability indicators that characterize the functionality of this type of teeth. These are the main indicators that allow differentiation of the functional characteristics of the teeth, viewed from the point of view of actual operating times.

Table 6. Comparative analysis of the theoretical distributions that characterize the 1300-A0M type teeth

Theoretical distribution	Equation of the reliability function, $R(t)$	Maximum deviation, D_{max}	Risk, α (%)	Critical value, $D_{a,76}$	Validation
Exponential, ep	$e^{-0,002711t}$	0,325905	0,5	0,264824	No
Normal (Gauss – Laplace), nv	$\frac{1}{2} - \Phi\left(\frac{t-413,561}{233,599}\right)$ or $1 - \frac{1}{233,599} \frac{1}{\sqrt{2\pi}} \int_0^t e^{-\frac{1}{2}\left(\frac{x-413,561}{233,599}\right)^2} dx$	0,162410	20	0,163492	Yes
Normalised 2-parameter Weibull, Wbp	$e^{-\left(\frac{t}{465,906}\right)^{1,954}}$	0,130895	20	0,163492	Yes
3-parameter Weibull, Wtm	$e^{-\left(\frac{t+2,413 \cdot 10^{-8}}{465,458}\right)^{1,835}}$	0,115663	20	0,163492	Yes
2-parameter Weibull, Wbv	$e^{-\left(\frac{t}{448,708}\right)^{1,902}}$	0,103994	20	0,163492	Yes

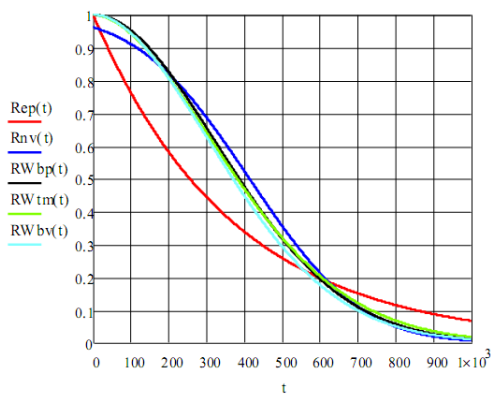


Fig. 6. Variation of the reliability function for the 1300-A0M type teeth

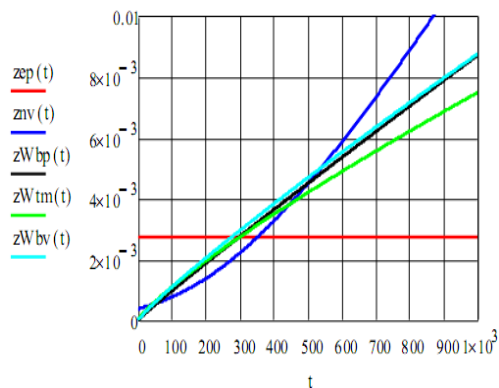


Fig. 7. Variation of the failure rate for the 1300-A0M type teeth

Analyzing the variations of the reliability/non-reliability function graphs, for an effective running time of the BWE of 200 hours, the reliability is 80%. This means that after about 13 working days it is not yet necessary to replace the teeth. The amount of time in working days is calculated on the assumption that the BWE actually works on average 15 hours a day. The value of reliability for 200 hours, in the case of this type of cutting teeth is very good.

For the first 100 hours of operating time ($t=100$, $R(100)=0.95$), there is decrease in reliability to about 95%. This is normal due to the wear. The period is characterized by a gentle slope of the reliability curve, which means a slow wear. After 100 hours, the slope of the curve steepens indicating increase in tooth wear and breakdown. The same results from the failure rate variation curves.

For the average 410 hours of use time of the cutting teeth we have a 50% reliability. If an average operating time of 500 hours is imposed, the tooth reliability is only 50%. This means that out of 100 new teeth mounted at the same time, after 500 hours of operation, only 30 will be in operation while the other teeth are changed due to reaching the admissible wear limit.

The rapid decrease in reliability from 80 to 30%, with an increase in the time from 200 to 500 hours, shows and increased wear speed. This increase is indicated by the steepness of the reliability curve slope and the increase in the intensity of wear.

5. CONCLUSION

Taking into account the operating conditions for the cutting teeth, the determination of the average time-of-use can only be done using statistical calculations. Operating conditions mean excavation in non-homogeneous material, abrasive wear phenomenon, being subjected to various type of stresses, especially shocks. Besides, there are different teeth requirements based on their placement on the buckets and the excavation technology used.

Thus, it was chosen by the mining company, to carry out the reliability study on the three types of teeth used in production. As a result of the study, besides the average use time, other characteristics proving the quality of the teeth resulted.

The reliability study was performed using representative samples of each type of tooth. By tracking the teeth working under actual operating conditions the effective operation of each tooth until replacement was recorded.

A first conclusion is the identical behavior of all the three types of teeth for up to 200 hours of operation. Behavior is characterized by equal wear rates. This demonstrates that the three types of teeth when mounted are characterized by the same cutting characteristics (both geometric and strength).

Differentiation occurs after 200 hours of operation when the wear rate increases, more for the 1400-3GX type and less for the 1300-A0M type. This means that the geometric and strength characteristics of each type of tooth changes. Thus, for a reliability level of 50%, the average running time differs substantially, the best being the 1300-A0M type tooth with an average of 410 hours.

The assessments made on the behavior of the three types of teeth tested lead to their ranking in terms of technical and functional characteristics. The first is the 1300-AOM type tooth, the second is the 1400-MII type tooth, and the third is the 1400-3GX type tooth. Differences between the three types of teeth appear from the different constructive-functional solutions adopted for their assimilation. These are related to geometry and strength characteristics, especially in terms of the thickness of the hardened material on the cutting edges, as well as its strength.

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