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Research Article

EXPERIMENTAL RESULTS ON THE EFFECTIVENESS OF AN IMPROVED EXCAVATOR BUCKET TOOTH DESIGN

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ABSTRACT

From analysis of the performance of hydraulic excavators, it has been found that many hydraulic excavators used in mining operations operate at lower capacities than indicated in the technical description. This can be caused by unexpected work interruptions, rapid failure of parts, and unreliability of the excavator's working parts.

In this article developments on improvement of cutting elements with increased service life for increase of productivity of open-pit excavators are resulted. Also, results of experimental tests of the improved teeth of an excavator bucket are submitted.

KEYWORDS

Quarry, excavator, bucket, tooth, protective element, efficiency, office hours, credibility, rock, abrasive wear.

INTRODUCTION

The efficiency of hydraulic mining shovels depends on a number of factors, including the climatic conditions at the location where the hydraulic shovels are operated, the serviceability of the excavator

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components, the reliability of the working parts and the resistance to abrasion.

Deepening of deposits of minerals in the world, a fact that mining is carried out in difficult mining-geological conditions and demands to reliability and economic efficiency of the existing mining equipment have led to perfection of a design of working elements of hydraulic open-cast excavators. The acceleration of open-pit mining requires the use of modern hydraulic open-pit excavators and an increase in their capacity. Modern hydraulic excavators are high-tech, expensive machines that require important maintenance during operation. A hydraulic excavator involves a complex structural system. The rate of wear of the bucket teeth of quarry excavators today reaches a high level and remains one of the most urgent problems. The issues related to the reduction of operating costs during the operation of quarry excavators, increase of their reliability, are not solved and urgent now [4].

As mentioned above, an increase in the cost of operating hydraulic excavators leads to a decrease in their efficiency.

The analysis of productivity of hydraulic excavators operated in mineral deposits has shown that the increase of efficiency of the open-pit hydraulic excavators is possible on the basis of improvement of design of their working bodies.

Currently, manufacturers of excavator buckets produce a wide range of their products, which are distinguished by improved design of the bucket itself and its individual elements. Manufacturers offer several types of bucket protections, depending on the application, environment, type and size. But the main factors are simplicity, reliability, durability and relative cheapness of its construction which is characterized by competitiveness.

Defects of the cutting elements of hydraulic mining shovels depend on a number of factors, mainly the skills of the excavator operator during operation, failure to comply with operating rules, variability of rock properties, well blasted large rocks and many other technical factors.

MATERIALS AND METHODS

Faults in the part of the cutting element of the bucket of the mining excavator that connects to the adapter are due to the fact that the adapter and the pin, which serve to connect the cutting element, are badly tightened by fitters, special fasteners do not fit, the fastening pin widens the hole for the adapter.

Failures of HITACHI EX-1200 hydraulic mining excavators related to bucket cutting elements and adapter are shown in Fig.1.

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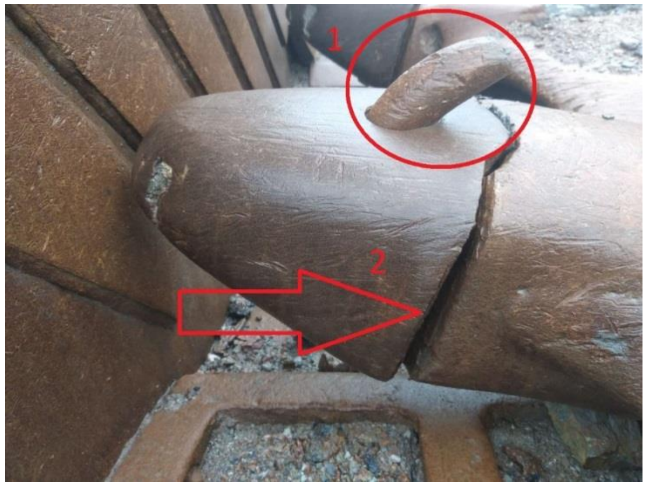

Figure 1: Defective part of the HITACHI EX-1200 excavator, connected to the cutting unit and transition part of the bucket

Failure 1, shown in figure 1, results in additional resistance during cutting and unloading because the tines are not fixed to the required standard in the attachment part of the cutting element and the adapter part of the bucket. 2 - When the quality of the cutting element and adapter part fails to harden, causing the tooth to be in a poor condition and, consequently, to sink poorly into the rock.

Figure 2: Perforations in the bucket teeth of the HITACHI EX-1200 excavator as a result of erosion: a - front and side perforation; б - front perforation; в - side perforation

In many cases, the permissible dimensions of the bucket cutters are not taken into account in the operation of quarry excavators. As a result, the teeth wear out beyond the allowable level and, over time, holes appear in the teeth (Fig. 2 a, б, в).

Failures caused by untimely maintenance behind the teeth can lead to even more serious failures in other systems. Tooth bore research and analysis in production also leads to rapid wear of the adapter part, and these processes reduce the efficiency of quarry excavators and increase operating costs.

In addition, the brittleness of the materials of the cutting bodies of quarry excavators, the quality of the preparation process technology and the occurrence of badly blasted rock during excavation cause tooth failure due to high stresses in the teeth (fig. 3).

Figure 3: Fracture of the teeth of the backhoe bucket

The analysis of results of the above researches shows, that most of defects of teeth of quarry hydraulic excavators, used at surface mining works, do not possess necessary durability and longevity of bucket teeth, i.e. they quickly lose their properties, under influence of various minerals quickly become impassable, that leads to failure of other parts of quarry excavators and to drop of operational characteristics [3].

Taking into account above-stated, at carrying out the development of technical solutions on increase of durability, service life and efficiency of cutting elements of buckets of mine excavators is the actual problem.

Teeth are the main wearing parts of bucket and they can be replaced when they are worn out, that extends the life time of bucket. Modern tines consist of an adapter welded to the bucket and the tines are easier to replace with a pin if needed.

Studies have shown that as excavator and loader cutters wear out, their productivity decreases significantly, changes in cutting edge geometry adversely affect their efficiency and increase the duration of excavation work [1]. It has been proved that power consumption in excavation works with blunted cutting edges is 1.5-2 times higher than with new cutting edges. Practice of using of excavator buckets has shown that allowable for wear of teeth increases specific shift load by 50-100 % in comparison with cutting conditions with teeth of nominal shape

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and size. Failure of cutting elements of excavator and loading machines significantly affects their working capacity. In some cases, due to wear of the working part, machine productivity is reduced by up to 40 % and fuel consumption increases by up to 30 % [2].

THE MAIN PART

There are several types of bucket teeth of hydraulic open-pit excavators, which are used as a base teeth of hydraulic open-pit excavators operating in all open pits of JSC "Navoi Mining and Metallurgical Plant" of the Republic of Uzbekistan, pictures of these teeth below are shown in Fig. 4 и 5.

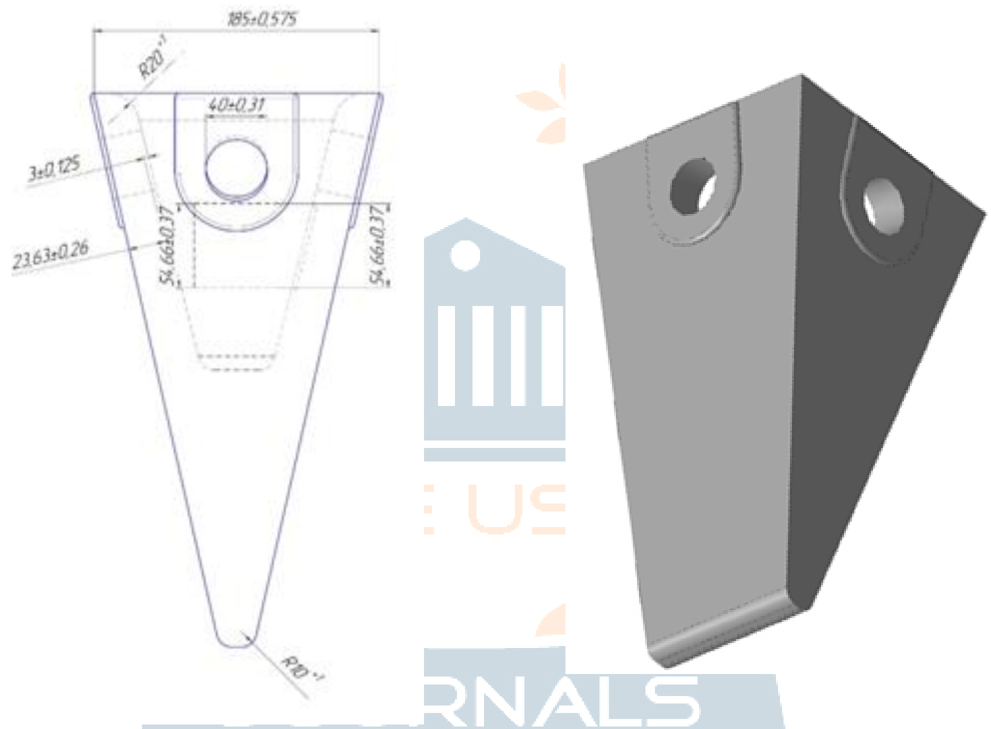

Figure 4: Schematic drawing and three-dimensional view of a standard bucket tooth

The average service life of this type of bucket teeth currently averages between 12 and 14 days. The time required for each replacement reduces the efficiency of the excavator, and prolonged failure of the teeth leads to higher operating costs.

Thus, in order to increase productivity of hydraulic excavators, it is important to create anti-slip tine shapes and develop and select effective technological methods to improve their durability.

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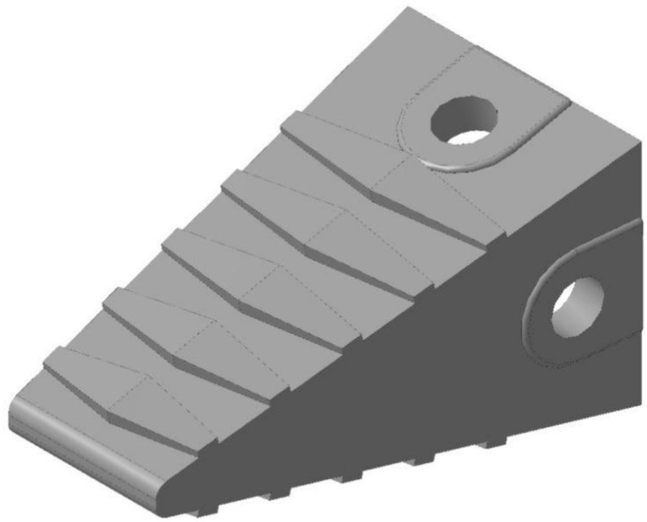

Figure 5. Three-dimensional view of the improved excavator bucket teeth

Theoretical researches and observations of the cutting elements usage in the production process showed the necessity to increase the strength of the upper and lower surfaces of the bucket teeth that are in the most contact with the rock. For this purpose special notches for standard bucket surfaces, and also some improved types of bucket teeth for increase of efficiency of surface excavators at the expense of increase of resistance of cutting elements to abrasion have been developed.

For the purpose of increase of wear resistance and service life of bucket teeth we have developed the new design of a tooth containing lozenge-like relief pattern on its surfaces, the drawing of which is shown on fig. 5 и 6.

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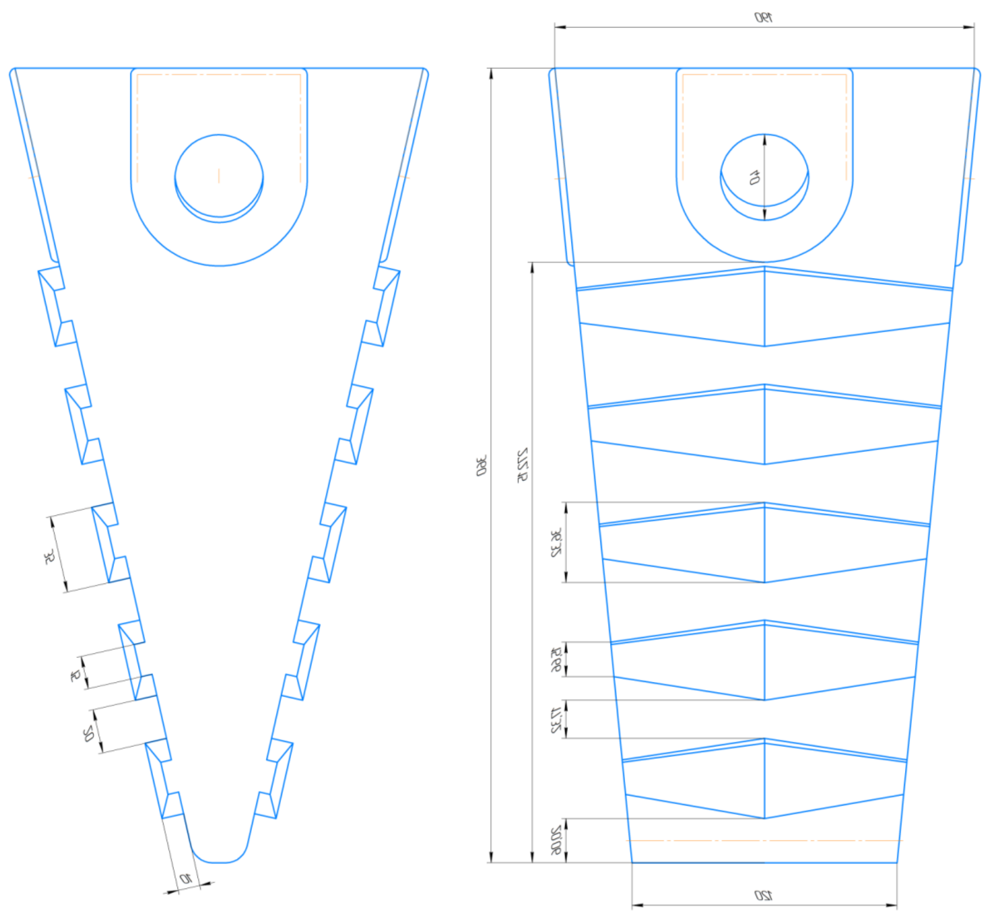

Figure 6. Appearance and dimensions of the bucket tooth design of the improved diamond-shaped relief tooth: a - top view and dimensions; b - side view and resolution

The improved bucket tooth design differs slightly from the basic design in terms of structure and dimensions, while the material remained unchanged.

With the improved tooth design, special relief patterns were formed on the top and bottom of the entire body. The total length of the developed tooth was 36.0 cm and 5 lozenge-shaped relief patterns were formed on the upper and lower surfaces of the tooth along the tooth length of 27.2 cm, forming a strong abrasion due to high loads in contact with the rock.

In order to determine the effectiveness of the new design of teeth of the developed excavator bucket, their experimental tests were conducted.

During the experimental work of the new teeth, their resistance to abrasion, that is, their working life, was investigated.

The experimental tests were conducted on the open-cast hydraulic excavator HITACHI EX-1200 at "Auminzo-Amantaytau" mine of the central mine administration of Navoi mining-metallurgical combine JSC.

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The experimental tests were conducted in the following way, at the first stage of tests with the installation of basic teeth on the excavator bucket the loaded rock and semi-rock with the strength f = 12 ÷ 14 was excavated. During the conducted experimental tests, the length of the bucket teeth and the average thickness 5 of the detachable parts were determined by wear during their operation for a certain time (Fig. 7).

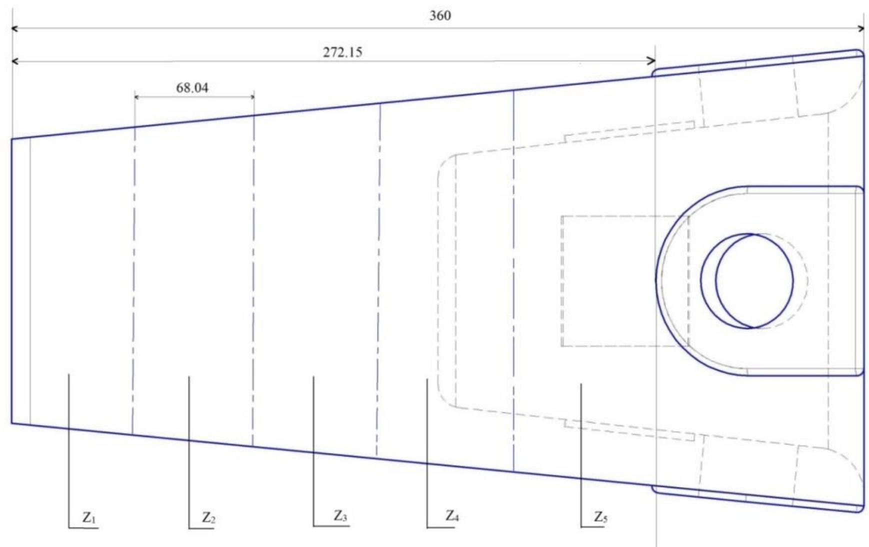

Figure 7: Arrangement of the cuts for which the wear value of the base tooth is measured: z_1, z_2, z_3, z_4, z_5 are the ordinal numbers of the cuts on the flat surfaces

In experimental tests, one of the most effective differential methods was used to determine the change in bucket teeth dimensions due to friction along its length and disconnected parts within a certain time interval, using a caliper of Shtz-400 type with a measurement error tolerance of Δl = 0.1 mm and the results are shown in Table 1.

Table 1

Wear rates of the bucket's base tooth as a function of operating time

T, moto-hours	L, mm	Δl, mm	Z_1, mm	Z_2, mm	Z_3, mm	Z_4, mm	Z_5, mm
0	360	0	40	81	103	143	174
30	332	28	33	79	102	142	173
60	308	52	-	76	100	140	171
90	286	74		70	98	137	168
120	264	96		64	95	134	165
150	249	111		-	91	131	162
180	235	125			85	128	159
210	221	139			78	124	156
240	210	150			72	119	153
270	196	164			65	114	150
300	180	180			-	108	147

where, T - operating time, moto-hours;

L - tooth length, mm;

Δl - wear value, mm.

The following experimental tests were carried out on five teeth in a lozenge-shaped relief pattern, which have been refined. (Figure 8).

The diamond-shaped relief patterns and flat wear rates over time were measured in the five areas shown in Figure 8 and the results are shown in Table 2.

Table 2

Wear rates of the improved bucket tooth as a function of operating time

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T, moto-hours	L, mm	Δl, mm	Sections 1		Sections 2		Sections 3		Sections 4		Sections 5	
			Z_1 mm	Z_{16} Mm	Z_2 mm	Z_{26} mm	Z_3 mm	Z_{36} mm	Z_4 mm	Z_{46} mm	Z_5 mm	Z_{56} mm
0	360	0	35	45	76	86	98	108	138	148	169	179
30	346	14	32	38	75	85	97	107	138	147	169	179
60	329	31	28	30	74	84	96	102	137	146	168	178
90	318	42	-	-	72	82	95	98	137	146	167	177
120	306	54			70	80	94	96	135	145	166	175
150	293	67			68	78	92	94	135	142	164	173
180	286	74			65	73	90	92	132	140	162	171
210	273	93			63	65	87	89	130	138	161	169
240	248	112			-	-	84	87	128	136	159	167
270	237	123					80	82	125	134	157	165
300	226	134					76	78	121	131	156	163
330	214	146					72	74	117	126	154	160
345	203	157					68	70	114	122	152	157
360	191	169					64	66	111	111	150	151
375	180	180					-	-	108	108	147	147

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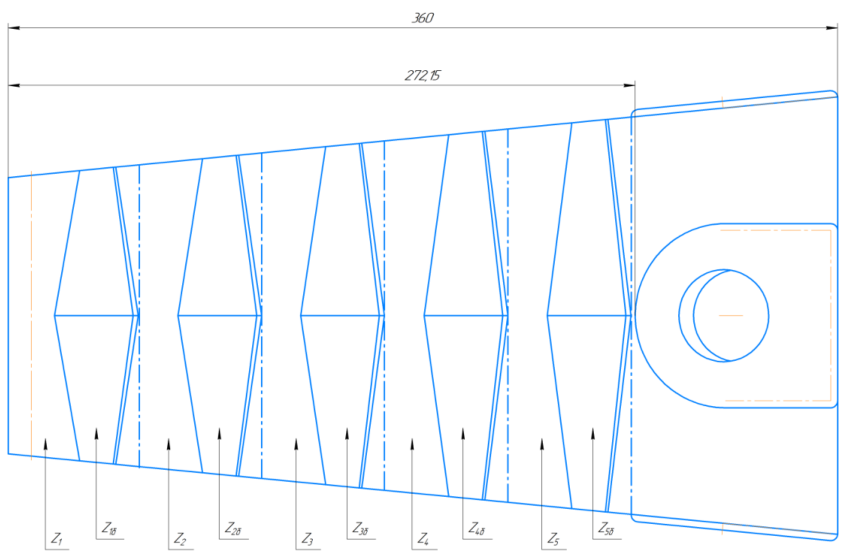

Figure 8. Location of sections for which the wear value of improved teeth is measured: z_1, z_2, z_3, z_4, z_5 - ordinal number of flat surfaces of sections; z_{1b}, z_{2b}, z_{3b}, z_{4b}, z_{5b} - ordinal number in the arrangement of diamond-shaped relief patterns on sections

EXPERIMENTAL RESULTS

Based on the analysis of the results of the experimental tests conducted to determine the effectiveness of the improved design of excavator bucket teeth, it is found that the service life of the bucket teeth depends on the wear value.

Based on the results of the above experiments, the dependence of the service life of the excavator bucket tooth of the basic design on the wear value is shown graphically in Figure 9 below.

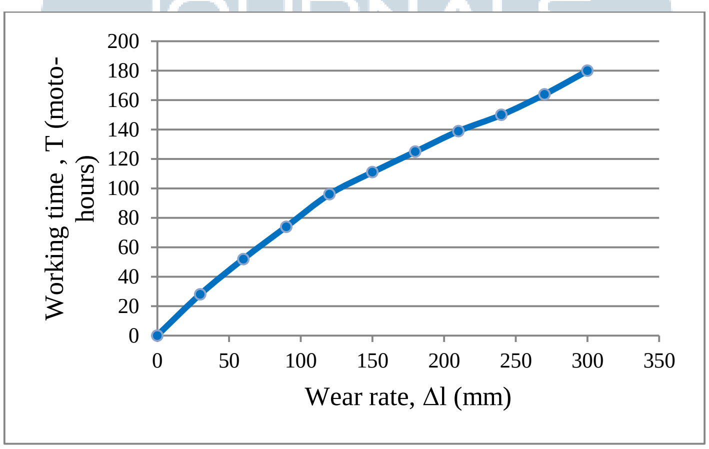

Figure 9. graph of the wear rate of the bucket's base tooth as a function of operating time

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As it can be seen from the graph of the base bucket tooth's operating time versus the wear value in Figure 9 above, there is an increase in the wear value of the tooth as the excavator's operating time increases. Thus, as a result of increase of operating time every 30 hours the value of wear on the length of the bucket's basic tooth was 22-28 mm in the initial hours of work of the tooth, i.e. up to 150 hours of moto-hours. During the next 150-300 moto-hours of operation every 30 moto-hours, the amount of wear on the tooth length was 11-16 mm.

The excavator's operating time for the permissible length of the bucket's basic tooth was 300 engine hours.

The results of the performance of the new excavator bucket tooth designs developed during the experimental and test work were also recorded, and based on these results the dependence of the operating time of the 5-rhombic excavator bucket tooth shape on the wear size was established, and this dependence is shown in Figure 10 below.

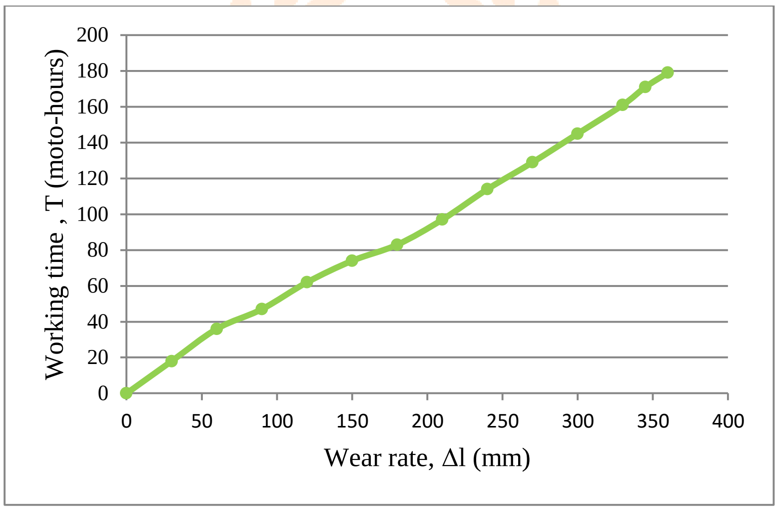

Figure 10. Flowchart of the wear rate of the improved diamond shaped bucket teeth versus operating time

As can be seen from the graph of the working time of the improved bucket tooth and the wear value, shown in Figure 10 above, there is an increase in the wear value of the tooth as the operating time of the excavator increases. Thus as a result of increase of operating time every 30 hours the value of wear on length of the bucket's improved tooth was 11-18 mm during the initial working hours of the tooth, i.e. up to 150 hours. During the next 150-360 hours of work every 30 hours the amount of the wear was 11-16 mm on the length of the tooth.

The operating time of the excavator for the permissible length of the improved five diamond-shaped relief teeth of the excavator bucket was 360 moto-hours.

CONCLUSION

Based on the results of experimental studies, graphs of wear length from operating time of basic bucket tooth and the improved five lozenge-shaped relief bucket teeth have been established and their mutual correlation has been developed (Fig. 11).

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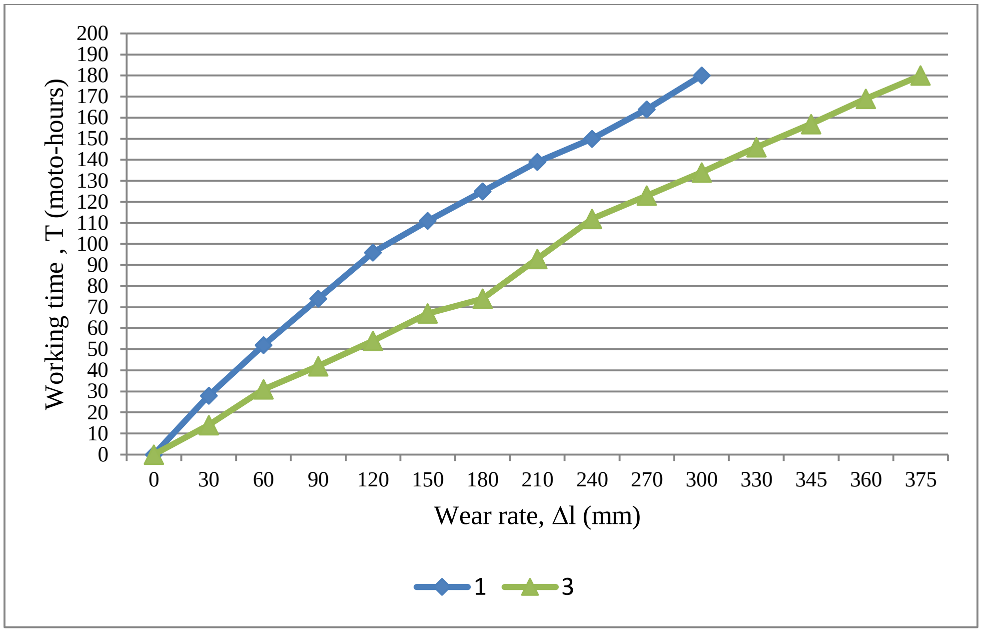

Figure 11. Lifetime relationship graph for basic and advanced five rhombic relief teeth: 1 - basic tooth; 3 - five rhombic relief teeth

Basis shown in Fig. 11 from the above graph of the dependence of the value of longitudinal slippage on the operating life of the 5 diamond-shaped relief teeth of the bucket, it can be seen that the improved operating life of the 5 diamond-shaped relief teeth in comparison to the basic bucket tooth is 60 hours, i.e. 20% more time of performance detection.

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