IOP Conference Series: Earth and Environmental Science

Defining Parameters of Thermal Exposure Equipment for Buckets of Mine Excavators

Defining Parameters of Thermal Exposure Equipment for Buckets of Mine Excavators

S A Zenkov[1]

[1]Bratsk State University, 40, Makarenko St., Bratsk, 665709, Russia

E-mail: mf@brstu.ru

Abstract. The paper enlists experimental materials of research on effect of thermal exposure on mined rock exploiting by mine excavators. When extracting thawed mine rock under subzero air temperature, intensive freezing of cohesive ground to contacting bucket surfaces, pickup apparatus elements, conveyor belts, treating facilities and links takes place. Freezing intensity depends on humidity, grain size composition, physical properties and temperature of mined rock. Material properties of working bodies which contact mined ground also have significant impact on adhesion of freezing of mined rock. Clay rocks are the most prone to freezing on. Experimental research was carried on thermal exposure on adhesion of cohesive overburden rocks to mine excavator buckets under subzero temperatures. Two elastic heating units, ENGL-1 (ЭНГЛ-1) and ENGLU-400 (ЭНГЛУ-400) were considered as possible options for using directly on excavator bucket. As a result of aforementioned experiments shearing force between ground and surface of thermally exposed working body simulator device was calculated for each of the heating units. The experiments proved that shearing force with thermal exposure decreases sevenfold for ENGL-1 heating element and eightfold – for ENGLU-400 heating element (compared to shearing force without any exposure), which can improve performance of mechanization of stripping operations when overburden rocks exploiting. Results of experimental research are presented and optimal equipment parameters are defined. An engineering solution for excavator bucket with integrated heating unit is proposed.

1. Introduction

Mine excavators operating trial shows that when exploiting wet cohesive overburden rocks (especially under subzero temperature) freezing over and adhesion of ground on working bodies vaguely reduces machinery performance.

This performance decrease is caused by reduced useful capability of a bucket because of incomplete unloading, increase of cutting (digging) drag force resulted by wet ground adhesion to working tool, growth of ram drag of a bucket, longer machine downtime for working tools cleaning. Moreover, energy losses increase because of more friction forces and overall quality of work falls down. Friction force when digging and grading equals to 30...70 % of overall digging resistance, and performance drops by 1.2...2 times and more [1-3]. One of efficient waus to reduce overburden rocks adhesion is known to be thermal exposure [4-11].

2. Formulation of the problem and method of solution

The research is focused on estimating an opportunity to apply thermal exposure to reduce rock mass adhesion to working bodies of mine excavators using elastic strip heating units (ENGL). Laboratory bench was constructed and patented for carrying out experiments (Figure 1 and 2) [12]. The bench is made of metalware 1 with levelling screws 3 and vertical rails 4 fixed with bolt fixtures 5, carriage 6 with excavator bucket imitator and integrated heating unit, which is equipped with rollers 2 and movable fixture to rails 4, plane 10 (steel 3) rigidly fixed to the carriage 6, bottomless tubular yoke 12 with internal concentric extractor ring 11 and stamp 9 with cap 7. The stamp 9 is rigidly connected to bar 20, which has y-axis movable fixture to pilot bush 22, rigidly fixed to metalware 1, and has a knuckle joint to load lever 18. Free end of the lever has a hung-up rack 14 with swappable loads 13. Bottomless yoke 12 is fixed to metalware 1 by pins 16 and adjustable nuts 17 and is equipped with insulating jacket 8 with two bolts 15 for extractor ring 11 fixing. The ring 11 produced from impact-resistant high-pressure polyethylene has inner diameter that equals to stamp 9 outer diameter. The stamp is coreless and fit with perforations 23 and 19 and airtight cap 7 made of material (copper, λ=384 W/(m*K)) that has thermal conductivity higher than thermal conductivity of stamp 9 material (steel 45, λ=47 W/(m*K)). The carriage 6 is connected to actuating mechanism 26 via tensometric ring 25. The bench is equipped with a kit of strain-gauge instrumentation 24 (electronic dynamometer DOR-3-5I (ДОР-3-5И)).

Figure 1. Experimental shear bench for research of thermal effect on soil freezing to metal.

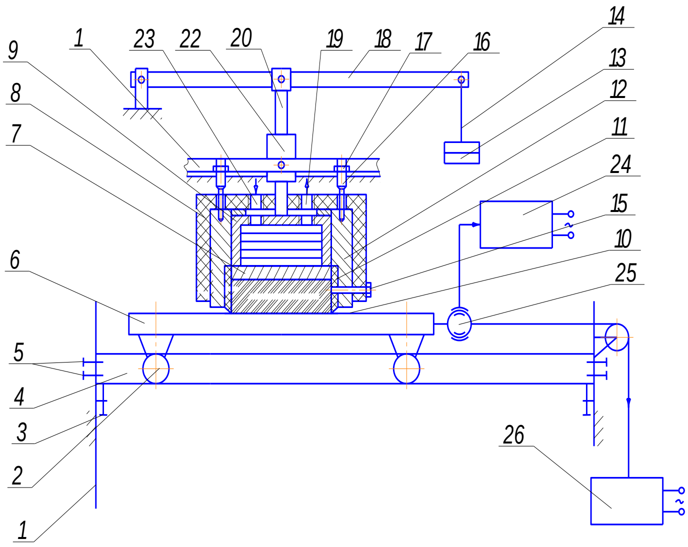


Figure 2. Line diagram of experimental shear bench for research of thermal effect on adfreezing strength between metal and soil.

Experimental research of processes of intensifiable exposure on adhesion to excavator buckets surfaces under subzero temperatures is carried out using methods of system physical modelling and mathematical experimental design theory. The experiments focused on varying over wide range exposure parameters and modes and basic factors affecting adfreezing of ground to metal sliding surface.

Parameters range for thermal exposure equipment (optimal values) was selected based on previously held experiments and results of research on target function (shearing stress) dependency on thermal exposure parameters.

The laboratory bench was used to test two heating units of the same type (elastic heating unit): ENGL-1 (Table 1) and ENGLU-400 (Table 2). Using ENGL-1 (Table 1) led to significant reduction of shearing stress and, therefore, of ground adhesion to working body surface. Another heating unit, ENGLU-400, enabled us to reach higher temperature of working body imitator surface, but shearing stress decrease is not proportional to temperature difference and varies around 13% of shearing stress when using ENGL-1 (Table 3).

Table 1. ENGL-1 technical specifications.

Maximum belt surface temperature	180°C (250°C if ordered)
Minimum assembling temperature	50°C
Minimum curve radius	10 mm
Active part width	24 mm
Active part thickness	3.3 mm

Table 2. ENGLU-400 technical specifications.

Maximum temperature	400°C
Minimum curve radius	15 mm
Low-temperature lead length	700 mm
Power supply	220 V

In order to organize an active experiment and obtain data for mathematical model, the plan was chosen according to recommendations [13] and specifics of this type of experimental research. The optimal design for the given amount of factors is as follows: second-order orthogonal design for two-factor model with $N = 3^2$. The factors to observe are normal ground pressure P and heating duration t_p (Table 3).

Shearing stress was measured with the following constant parameters: ground dispersability $D_э=7*10^{-3}$ mm; ground moisture content W=12.5%; environment temperature $T = -15^0C$; duration of contact between ground and metal t = 10.5 min.

Mathematical processing of results obtained was carried out on PC with MODEL software package for multifactor relations using least squares method. The following regression equations were obtained after processing of experimental data:

for ENGL-1

$$Y_{men} = 5{,}467 + 0{,}25 \cdot x_1 - 0{,}588 \cdot x_2 - 0{,}05 \cdot x_1^2 + 0{,}05 \cdot x_2^2 + 0{,}15 \cdot x_1 \cdot x_2 \quad (1)$$

for ENGLU-400

$$Y_{men} = 5{,}06 + 0{,}217 \cdot x_1 - 0{,}583 \cdot x_2 + 0{,}017 \cdot x_1^2 - 0{,}2835 \cdot x_2^2 + 0{,}1 \cdot x_1 \cdot x_2 \quad (2)$$

Regression equations were checked for adequacy by comparing two dispersions with a five-percent level of significance (α=0.05 and 95% probability belief). Check results prove the given equations to be adequate, as Fisher design ratio for ENGL-1 equals 0.6767186 and for ENGLU-400 equals 0.6645362 when table Fisher coefficient is 5.99.

Table 3. Varied parameters and measured values of shearing stress.

Elastic heating unit type	X_1 – normal ground pressure P, kPa	X_2 – heating duration t_p, min	Shearing stress $Y_{\text{теп}}$, kPa
	10	3	5.8
	10	5	5.3
	10	7	4.3
	20	3	6.0
ENGL-1	20	5	5.4
	20	7	4.9
	30	3	6.1
	30	5	5.6
	30	7	5.2
	10	3	5.2
	10	5	4.9
	10	7	3.9
	20	3	5.4
ENGLU-400	20	5	5.1
	20	7	4.1
	30	3	5.5
	30	5	5.2
	30	7	4.6

After that, using STATISTICA software package yield surfaces were built for two changing factors when applying ENGL-1 (Figure 3) and ENGLU-400 (Figure 4) heating units.

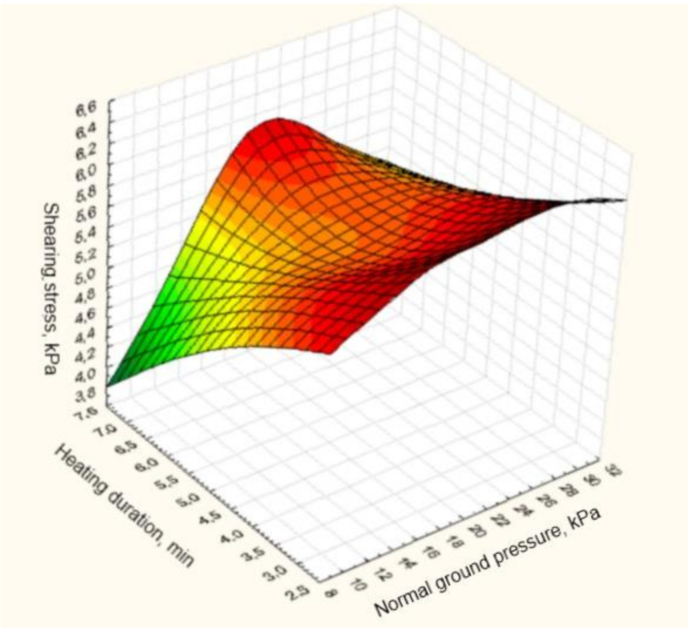


Figure 3. Yield surface with two factors combined using ENGL-1 heating unit.

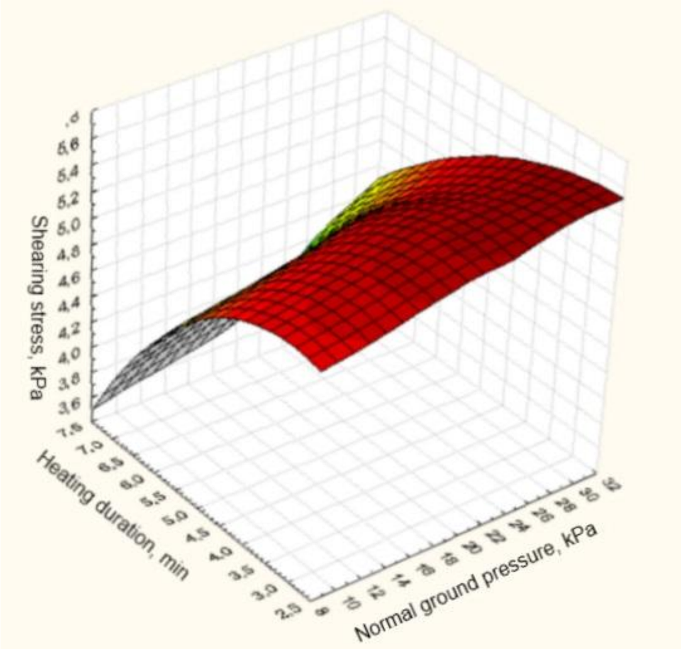


Figure 4. Yield surface with two factors combined using ENGLU-400 heating unit.

3. Resultsanddiscussion

The extremums for multivariable functions of equations (1, 2) were found by Newton method using WolframAlpha software. The extreme point is located in negative response area. Within the examined range of factor variation increase of normal ground pressure results in 5…21% increase of shearing stress, while longer heating duration results in 17…35% decrease of shearing stress. The minimum value of shearing stress was observed when normal ground pressure equaled 10 kPa and heating duration was 7 minutes (within examined variation range).

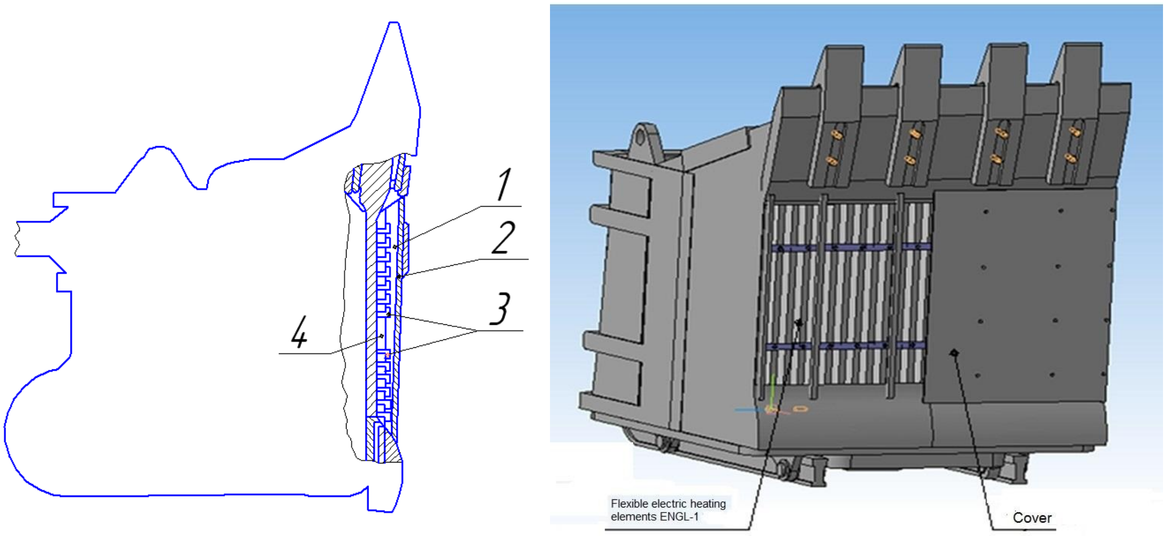
As a result of the experiments shearing stress between ground and surface of working body imitator was calculated for each heating unit. The tests prove that under thermal exposure shearing stress decreases sevenfold with ENGL-1 heating unit and eightfold with ENGLU-400 heating unit. (compared to shearing stress without any exposure), which improves output of stripping mechanization when exploiting cohesive overburden grounds.

4. Conclusion

Using ENGL-1 unit is the most reasonable option as the difference in shearing stress reduction in comparison with ENGLU-400 is less than 13% while power consumption is substantially lower. The optimal operation mode for the heating unit is 3 to 7 minutes because during this amount of time the unit can heat surface of excavator bucket to 11…40 ºC, which is enough to decrease ground adhesion to excavators buckets up to seven times under subzero temperatures.

The concept of using elastic heating units as a source of thermal exposure for decreasing ground adfreezing was implemented on excavator bucket of front shovel type, presented on Figure 5. Belt unit 3 is wound over the beams 4 that are rigidly fixed to outer surface of bucket front wall between enforcement ribs and is covered with another sheet 2. Free space is filled up with dry silica sand 1 which acts both as insulator and thermal energy conductor, providing uniform heating of the front wall. The heating unit is mounted on the outer surface of the front wall because this wall is the most prone to adhesion and the space between teeth void and lower bulge doesn’t contact ground to a great extent when the excavator is operating.

IOP Conf. Series: Earth and Environmental Science **272** (2019) 022147 doi:10.1088/1755-1315/272/2/022147



a b

Figure 5. Excavator buckets: a - with elastic heating unit; b - 3D-model of EKG-8 (ЭКГ-8) excavator bucket with elastic electric heating units ENGL-1.

5. References

[1] Abdrazakov F K 1990 Odnokovshovye ekskavatory mogut rabotat' proizvoditel'nee*Mekhanizatsiya stroitel'stva***6** 16–17

[2] Zadneprovskiy R P2005 *Teoriya treniya skol'zheniya*(Volgograd: Ofset) 51p

[3] Zadneprovsky R P 1992 *Working bodies earthwork and reclamation machines and equipment for soil and high humidity materials* (Moscow: Mashinostroenie) 176

[4] Zenkov S A, Balahonov N A and Ignatyev K A*Vestnik*2014 *MGSU***2** 98-104

[5] Zenkov S A and Kurmashev E V 2009 *The journal Nauchno-tekhnicheskie vedomosti SPbGPU* **89-2** 90-94

[6] Buturovich I and Han Duc Kim 1969 Calculation curved concentrators *Trudy LPI***309**169

[7] Rajaram Gand Erbach DC 1999 *Journal of Terramechanics***36**39-49

[8] Sharma V K, Drew L O, Nelson L 1977 *Transactions of the ASAE* **20**46-51

[9] Tong J 1993 *Study on reducing adhesion and resistance of soil to soil engaging components of machinery for land locomotion by bionics.* A Ph.D. Dissertation, Jilin University of Technology,Changchun, China (in Chinese)

[10] Tong J, Ren L, Yan J, Ma Y and Chen B 1999 *Int. Agricultural Eng. J.***8** 1-22

[11] Wang X L, Ito N, Kito K and Garcia P P 1998 *J. of Terramech.***35**87-101

[12] Zenkov S A 2009 *Systems Methods Technologies* **1**59-64

[13] Ignatyev K A, Filonov A S, Lkhanag D and Battseren I 2013Definitions of time from the surface soil breakout body work in a high impact*Scientific transactions*(Ulaanbaatar: MUST) **3/139**144–146