IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: S A Zenkov 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 032049

IOP Conf. Series: Materials Science and Engineering **537** (2019) 032049 doi:10.1088/1757-899X/537/3/032049

Using polymer antiadhesive sheets as a method to reduce ground adhesion to working bodies of digging machines

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Abstract. The analysis is carried out for using polymer antiadhesive sheets in order to reduce adhesion of wet cohesive soil to working bodies of digging machines when operating under sub-zero temperatures. 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. An experiment was held using PPL-EI and PPL-UI polymer coatings. After mathematic analysis of experimental results regression equations were obtained, which were applied to engineering solution of excavator bucket.

1. Introduction

Excavation of wet cohesive soil involves intensive ground adhesion to working bodies of digging machines [1-10]. Currently applied methods of preventing adhesion and freezing are very laborious and ineffective and dramatically reduce performance of working equipment of digging machines [2-8]. One of the approaches to reduce the adhesion is creating an intermediate layer out of liner polymer coatings on the contact boundary between soil and working body (preventive treatment) [2,3].

Liner coatings manufacturing is based on ultra-high molecular polymers. The expertise of operating various engineering equipment in fields of industry dealing with mining and processing mineral resources proves that the most efficient way to reduce adhesion and freezing of wet mined rock and mineral materials to working equipment units contacting them is protecting (lining) with polymer coatings that have hydrophobic and antiadhesive properties [2,3]. These are polymer antiadhesive liner plates (PALP) manufactured by LLC “As-Tik KP” and polymer antiadhesive sheets (PAS) recommended by “Technotex” group of companies.

Polymer material graphite-reinforced plastic, designed in Research institute of efficiency and safety of mining operations, has been successfully implemented on assets of RF Ministry of Energy as preventive solution. However, further implementation of this material is limited by insufficient shock resistance and lack of preventive effect under sub-zero temperatures. After the research it was concluded that the most suitable material according to technical specifications is modified polyurethane, fluoroplastic F-3M [2].

Depending on the working mode, the most efficient polymer antiadhesive sheets are PAS liner sheets of different grades. Polymer antiadhesive sheets (PAS) grades are as following: PPL-EI: abrasion resistance – 400 units; shock resistance – 9 u; operating temperature range - -45 to +90°C; application – contacting materials with f coefficient up to 5 u [2]; PPL-UI (high-modulus): abrasion resistance – 200 units; shock resistance – 25 u; operating temperature range - -80 to +100°C;

application – contacting materials with f coefficient up to 8 u. Application of ultra-high molecular polymers allows to improve performance due to the following properties: low wear, low friction coefficient, high impact resistance, chemical resistance to acids, alkalies, salts and other aggressive environments, wide operating temperature range from -50 to +90°C, high durability within this range, sound absorption, crack resistance and hydrophobic properties that prevent wet materials from sticking to and freezing over the surface of polymer coating.

2. Formulation of the problem and the method of solution

In order to examine accuracy of represented data an experiment was conducted on a special shift bench [3].

Methods of multi-factor planning were applied for chosen objectives of experimental research, which enabled one to obtain maximum volume of valuable data about the processes under research with minimal amount of experiments. The effect was evaluated based on the magnitude ratio of specific adfreezing factor, which is considered to be shearing stress for start of ground sample shifting along the operating surface. This parameter is defined by the following formula:

$$\tau = \frac{P_s}{S}$$

where P_s – force required to shift ground sample along various surfaces, N; S – applied part are of frozen ground sample, m^2.

In order to conduct active experiment and build a mathematical model, rotatable central composite design is chosen according to recommendations [3] and specifics of experimental research being carried out. Levels of factors and variability intervals when conducting the experiment are enlisted in table 1.

Table 1. Levels of factors and variability intervals for the experiment.

Factors	Levels of factors					Variability intervals
	-2	-1	0	1	2	
X_1 –soil dispersity, D_e , mm	$9\cdot10^{-3}$	$7\cdot10^{-3}$	$5\cdot10^{-3}$	$3\cdot10^{-3}$	$1\cdot10^{-3}$	$2\cdot10^{-3}$
X_2 – normal pressure on the ground P, kPa	0	10	20	30	40	10
X_3 – gravimetric moisture of soil, W, %	7.5	12.5	17.5	22.5	27.5	5.0
X_4 – environment temperature, T, ℃	5	-5	-15	-25	-35	10
X_5 – soil to metal contact time, t, min	0.5	10.5	20.5	30.5	40.5	10

In order to define necessary amount of replicated experiments in the research a series of trial experiments was set. It included experiments on shifting all ground types used in the research. Experiments were conducted with and without preventive treatment with environment temperature T = -15 °C, soil to metal contact time t_c = 20.5 min., gravimetric moisture of soil W = 17.5 %, normal pressure on the ground P = 20 kPa.

The experiments were being carried out on a shift bench (figure 1), with two polymer antiadhesive sheets being used. Polymer antiadhesive sheets (PAS) are squeezed with clamps which prevents them from moving along the carriage. PAS types used in the experiment were the two most suitable in terms of parameters and recommended by “Technotex” group of companies: PPL-UI (10 mm) and PPL-EI (6 mm).

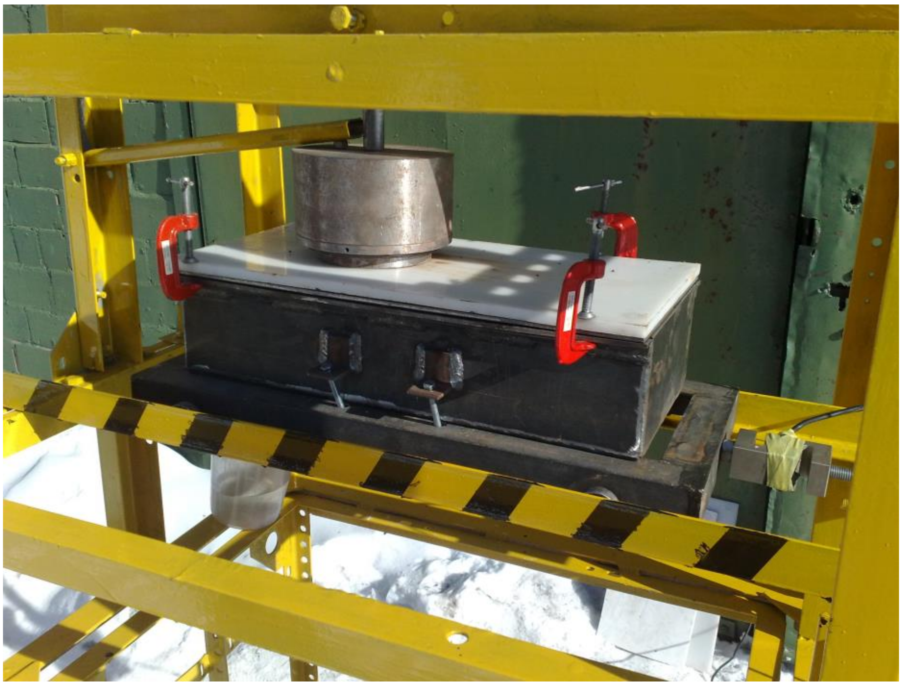

Figure 1. Shift bench.

Experimental data processing resulted into the following regression equations that define quantitative and qualitative character of response function alteration depending on the factors in the field of research when implementing the matrix of experiment.

Soil shearing stress without antiadhesive sheets being applied:

$$R_{w.e.} = 20.28 + 0.74x_1 + 1.69x_2 - 1.91x_3 - 1.24x_4 - 1.01x_5 - 0.88x_1^2 - 1.49x_2^2 - 0.31x_3^2 - 0.163x_4^2 - 0.51x_5^2 + 1.42x_1x_2 - 0.283x_1x_3 - 0.046x_1x_4 - 1.058x_1x_5 - 0.092x_2x_3 + 1.47x_2x_4 - 4.167x_2x_5 + 0.02x_3x_4 + 2.183x_3x_5 - 3.254x_4x_5$$

Soil shearing stress for PPL-EI:

$$R_{EI} = 2.596 + 0.06x_1 + 0.225x_2 - 0.627x_3 - 0.152x_4 + 0.007x_5 - 0.158x_1^2 + 0.203x_2^2 + 0.053x_3^2 - 0.171x_4^2 - 0.103x_5^2 + 0.025x_1x_2 - 0.679x_1x_3 + 0.058x_1x_4 - 0.225x_1x_5 - 0.236x_2x_3 - 0.09x_2x_4 - 0.333x_2x_5 - 0.679x_3x_4 + 0.08x_3x_5 - 0.225x_4x_5$$

Soil shearing stress for PPL-UI:

$$R_{UI} = 3.028 + 0.506x_1 + 0.127x_2 - 0.247x_3 - 0.522x_4 + 0.289x_5 - 0.103x_1^2 + 0.308x_2^2 + 0.058x_3^2 - 0.203x_4^2 - 0.241x_5^2 + 0.334x_1x_2 - 0.203x_1x_3 + 0.178x_1x_4 - 0.290x_1x_5 - 0.159x_2x_3 - 0.090x_2x_4 - 0.771x_2x_5 - 0.128x_3x_4 + 0.359x_3x_5 - 0.334x_4x_5$$

The regression equations mentioned above were used to build floor-quasifactorial shearing stress dependencies on external factors with the rest of variable factors being fixed.

3. Results and discussion

Analysis of obtained results proves that the surfaces under research have different stress values. Shearing stress variations for PPL-EI and for 3-grade steel are similar to each other, but differ 17 kPa on average in thrust, while the highest stress being observed with 17.5 % humidity.

Shearing stress reduces when temperature drops for all types of coating. 10 degrees temperature fall results into 1 kPa average increase of shearing stress for all types of coating. Average difference in shearing stress between polymer coatings and steel equals 18 kPa. The difference between PPL-EI and PPL-UI equals 0.5 kPa which is insignificant. When temperature reaches -25 degrees, shearing stress for PPL-EI surface stops increasing and stays almost constant.

Shearing stress on contact time dependency varies for all types of coating. For steel shearing stress increases with contact time increase up to 20.5 minutes and stays almost constant with the further increase in contact time. In case of polymer coatings shearing stress does not vary significantly within all contact time interval.

4. Conclusion

Polymer antiadhesive sheets differ in chemical composition and structure, therefore, performance for each of them has been tested by experiment. The most suitable type of polymer coating in terms of shearing characteristics is PPL-EI. Analysis of obtained data proves that the difference in shearing stress between polymer antiadhesive sheets and steel is evident and equals 17-18 kPa, which was proven by experiment.

As a practical application of the research's conclusion, PPL-EI antiadhesive sheets were mounted inside EK-18 excavator bucket that is operated by "Direction of urban infrastructure" municipal enterprise in the city of Bratsk (figures 2). Using PPL-EI polymer antiadhesive sheets with the bucket of EK-18 excavator within 2 years of operation has led to reduction of cycle duration for excavation of wet adhesive soil due to 17% less adhesion and freezing over the working body of the excavator; to lower power consumption during operation due to better cleaning of the bucket from soil.

Figure 2. EK-18 excavator's bucket before operation.

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