Study of the influence of technological, structural and operational parameters on the efficiency of the water-ice jet cleaning process

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Abstract. Nowadays, waterjet technologies find their use in various fields of manufacturing. Many areas of application of these technologies are well studied, documented and implemented. However, there are still applications of using a high-pressure water-ice jet that have not been studied yet. One of these applications would be the water-ice jet cleaning of the surfaces of machine parts with jets utilizing prepared in advance ice particles.

Water jet methods are considered to be the most environmentally friendly, universal and cost effective. When moving at high speeds, ice particles possess the properties of solid particles and make it possible to remove many contaminants without affecting the surface being cleaned. The use of water mixed with ice particles for cleaning reduces the cost of restoring the cleaning medium [1].

At present this technology has not been sufficiently studied neither theoretically nor empirically. For the widespread implementation of water-ice jet cleaning technology, it is necessary to investigate the properties and parameters of the water-ice jet.

The design of the water-ice jet cleaning instrument is fundamentally similar to the design of the abrasive waterjet cutting or cleaning instrument (Figure 1) [2,3].

High pressure water is being supplied through the pipe 4 and follows through the nozzle 3 and jet forming nozzle 2 located in the instrument housing 1.

In order to study the structure of the water-ice jet, as well as the process of water-ice jet cleaning, experimental studies were conducted on a special test bench consisting of the following main units: high-pressure pump of multiplier type 1, waterjet instrument 2, sliding table with brackets for holding the test samples 3 (figure 2). Pump 1 allows to provide water pressure up to 100 MPa and regulates its flow rate to 30 l/min. Test samples with different physical and mechanical properties were attached to the sliding table 3 by means of special brackets. Sliding table was driven by an electric motor with a thyristor converter and a screw drive. The supply of prepared ice particles was delivered to the waterjet tool via flexible tubing 4. To record the pressure, the first-class precision indicating pressure gauges installed at the outlet of the pumping unit were used.
The most significant factor determining the efficiency of the water-ice jet cleaning process is the mechanical properties of the material being removed. The analysis of the relevant literature sources
indicates it would be beneficial to use the Shore indicator as per AUSS 263-75 (ST SEV 1198-78) [4] to characterize materials exposed to the water-ice jet.

In order to conduct research on the effect of various parameters on the efficiency of the water-ice jet cleaning process, the materials presented in Table 1 were used.

The average strip width of the material to be removed at a thickness of 100 $\mu$m (0.1·10⁻³ m) was taken as a criterion for the efficiency of the water-ice jet cleaning. The studies were conducted while varying water pressure $P_0$ from 25 to 60 MPa, with a sample velocity $V_n = 0.1$ m/sec, the distance from the slice of the collimating device $l_0$ to the surface to be processed $l_0 = 0.05$ m, with a tool with a jet-forming nozzle diameter $= 0.0006$ m, the ratio $d_k/d_0 = 3$ and the discharge coefficient of the jet-forming nozzle $\mu = 0.7$ [5,6].

Table 1. Properties of the studied materials

| №  | Material name                        | Shore hardness |
|----|--------------------------------------|----------------|
| 1  | Polyurethane coatings AUSS 34376.1—2017 (ISO 16365-1:2014) |                |
|    | - test sample 1                      | 62             |
|    | - test sample 2                      | 65             |
|    | - test sample 3                      | 74             |
| 2  | Automotive enamel ML-12 AUSS 9754-76 |                |
|    | - test sample 4                      | 82             |
|    | - test sample 5                      | 89             |


The results are presented in Figure 3.

Figure 3. Effect of the water pressure and hardness of materials on the efficiency of the water-ice jet cleaning process: 1 - $D=62$; 2 - $D=65$; 3 - $D=74$; 4 - $D=82$; 5 - $D=89$. 
The analysis of the experimental data presented in Figure 3 showed an increase in water pressure leads to an increase in the strip width of the material being removed for all the test samples taken for investigation. Thus, for the test sample 1 with an increase in pressure from 25 to 100 MPa, the width of the strip to be removed increases from 0.0093 m to 0.0122 m, i.e. by 20%. For the test sample 2 with an increase in pressure from 25 to 100 MPa, the width of the strip to be removed increases from 0.0085 m to 0.0104 m, i.e. by 18%. For the test sample 3 with an increase in pressure from 25 to 100 MPa, the width of the strip to be removed increases from 0.0069 m to 0.0088 m, i.e. by 21.5%. For the test sample 4 with an increase in pressure from 25 to 100 MPa, the width of the strip to be removed increases from 0.0051 m to 0.0064 m, i.e. by 20%; for the test sample 5 with an increase in pressure from 25 to 100 MPa, the width of the strip to be removed increases from 0.0038 m to 0.0049 m, i.e. by 22%. This can be explained by the fact that the pressure increases simultaneously with the length of the active section of the water-ice jet and, as a result, with the width of the strip of material to be removed [7].

In addition, it was observed that with increasing hardness of the material being removed, the width of the strip decreases for all test samples. With an increase in the Shore hardness from 62 (test sample 1) to 65 (test sample 2), the width decreases on average by 9.5%; from 65 (test sample 2) to 74 (test sample 3), the width decreases on average by 17.5%; from 74 (test sample 3) to 82 (test sample 4), the width decreases on average by 25%; from 82 (test sample 4) to 89 (test sample 5), the width decreases on average by 26%. This is due to the fact that within the active section of the jet, the time of jet interaction with the material surface is higher in the region of the jet axis and decreases towards the periphery, which leads to a decrease in cleaning efficiency and a decrease in the width of the material to be removed.

The results were processed using a multiple regression method and the following final equation was obtained, which determines the effect of the pressure of high-pressure water \( P_0 \) and the Shore hardness of the material being removed \( D \) on the efficiency of the water-ice jet cleaning process:

\[
b = 0.22428 - 0.22 \times 10^{-3} D + 0.2152 \times 10^{-4} P_0.
\]  

(1)

The resulting equation allows with a high accuracy to make a forecast of the efficiency of the water-ice jet cleaning process for specified values of the Shore hardness and water pressure (see Figure 3., dashed lines), thus ensuring a reasonable choice of cleaning parameters [8].

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