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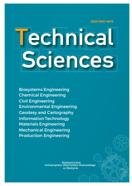

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WEAR ANALYSIS OF A GUN BARREL DRILL BLADE IN 1.0503 STEEL DRILLING PROCESS IN MILPRO HG12 OIL ENVIRONMENT WITH THE ADDITION OF ULTRA-DISPERSIVE COPPER PARTICLES AND COPPER OXIDES

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A b s t r a c t

This paper presents structural solutions for guiding a single-sharp barrel drill blade during deep hole drilling, and it analyzes the structural and technological problems associated with two modes of inserting the drill into the processed material in the first stage of drilling – with the use of a pilot hole or a guide sleeve.

The kinematics of the object-tool system (P-N) and other technological parameters affecting the execution of pilot holes under strictly defined conditions were analyzed during deep drilling with barrel drills in the FNE 40NC AVIA vertical numerical milling machine.

Performance tests involving two types of cooling-lubricating agents, Milpro HG12 oil with and without the addition of ultra-dispersive copper particles and copper oxides (0.05 ÷ 0.6 μm) and Panther GP-1 additive (PWPH PantherOil Poland), applied in a 1:100 ratio, were described.

The wear of the barrel drill blade along the entire drilling path (Lw = 8,000 mm) for 112 holes, and the geometric wear coefficient K_w of the drill bit were determined in 1.0503 steel with the use of EB80 drills made of K15 cemented carbide (WC 94%, Co 6%) with a diameter Dc = 8 mm.

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The results of wear tests were compared with the results of tribological tests involving cooling lubricants and 1.0503 steel with the chemical composition of K15 tungsten carbide. The abrasive wear of friction pair and the performance of the barrel drill blade during deep hole drilling were analyzed under identical conditions.

Introduction

Deep hole drilling in machining operations is influenced by the method of drilling holes whose depth (length) exceeds hole diameter five-fold (GÓRSKI 1961, STREUBEL 1993, RYCHLIK 2010). The following characteristics of the deep hole drilling technology have to be analyzed:

– cutting tool design,

– working parameters of the tool, in particular the type and parameters of the applied coolants (cooling and lubricating agents),

– the configuration of specialist machinery for implementing the deep hole drilling technology.

Deep hole drilling operations can be divided into two main groups based on the manner in which the material is processed into chips (GÓRSKI 1961, GÓRSKI 1990) – Figure 1.

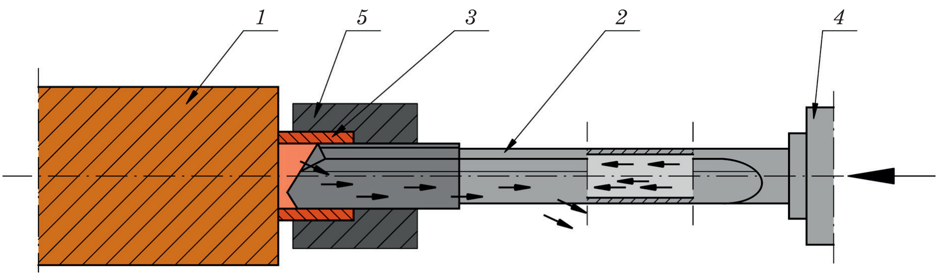

Fig. 1. Guiding a barrel drill with a pilot sleeve: *1* – workpiece, *2* – drill, *3* – drill guide (pilot sleeve), *4* – tool holder, *5* – steady rest

The guide sleeve of a barrel drill works in harsh conditions because each time it enters and exits the workpiece, it comes into contact with the tool blade and chips. For this reason, sleeve material should be highly resistant to wear. Most guide bushes are made of K15 sintered carbide which is characterized by sufficient durability. However, sintered carbide guide bushes are expensive due to a difficult machining process. The authors' experience indicates that only several holes can be drilled with the use of high-speed steel sleeves because the guide sleeve hole has to be calibrated. Guide sleeves made of H10 carbide have superior mechanical properties. Drill guide bushings should be manufactured with high accuracy because they significantly influence drilling precision (not only at the point of the tool's entry into the material, but also along the entire drilling path). Drill guide bushing also acts as a sealing lubricant and a base in the axial direction of the workpiece. The axial homing of the workpiece is particularly important when drilling depth is strictly determined by technological requirements.

Guide bushing generally does not come into contact with the workpiece when the hole is drilled and the drill is inserted an an angle. The authors' experience indicates that the gap between the workpiece and the sleeve should not exceed 0.1 mm (RYCHLIK 2010). When the gap is too large:

– the drill entry point is displaced, which increases the straightness error of the drill hole at the exit,

– additional oil mist is formed, and it is difficult to remove from the machining chamber,

– the evacuated chip gap is jammed.

In the second drilling method, the drill is inserted into the workpiece using a pilot hole (Fig. 2). In this approach, a pre-drilled hole with diameter $D_c^{+0.03}$ should be made to a depth of approx. 1÷1.5 D_c. This method usually requires a CNC machining center. The main limitation of this approach is the depth of the drilled hole due to the difficulties associated with the use of supports and the reduced distance between the spindle face and the machining chuck (table). These limitations apply mainly to vertical machining centers.

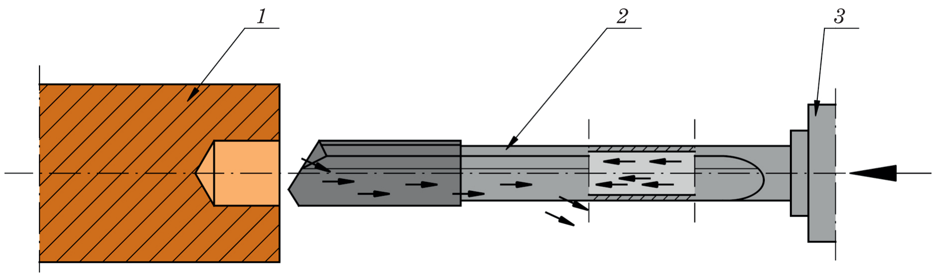

Fig. 2. Guiding a barrel drill through a pilot hole: *1* – workpiece, *2* – drill, *3* – tool holder

The results of wear tests involving H10 sintered carbide and K15 tungsten carbide barrel drills were analyzed in view of the processing requirements for deep hole drilling as well as the structural properties and the behavior of the tested materials. The wear behavior of the examined materials was examined during laboratory tests of H10 sintered carbide and K15 barrel drills. The impact of the applied lubricants on the progression of wear was described, and the friction coefficient and the geometric wear coefficient K_w of the barrel drill blade were determined in accordance with Standard PN-83/M-58350.

Materials and Methods

The study involved tribological and performance tests to determine:
– material resistance to abrasive wear using the pin-on-disc method,
– the wear of single-edge barrel drills during hole drilling.

Material resistance to abrasive wear was tested with the use of the pin-on-disc method on H10 sintered carbide substrate. The physicochemical properties of H10 sintered carbide are presented in Table 1. Sample dimensions are presented in Figure 3.

Table 1

Physicochemical properties of the substrate material for tribological tests and performance tests (barrel drill blades)

Parameter	Manufacturer's specifications (BAILDONIT)
Type of material	Sintered carbide
Type	H10
Chemical composition	WC 94%, Co 6%
Density	14.85 g/cm^3
Grain size	1.0 ÷ 2.0 μm
Hardness HV30	1,600

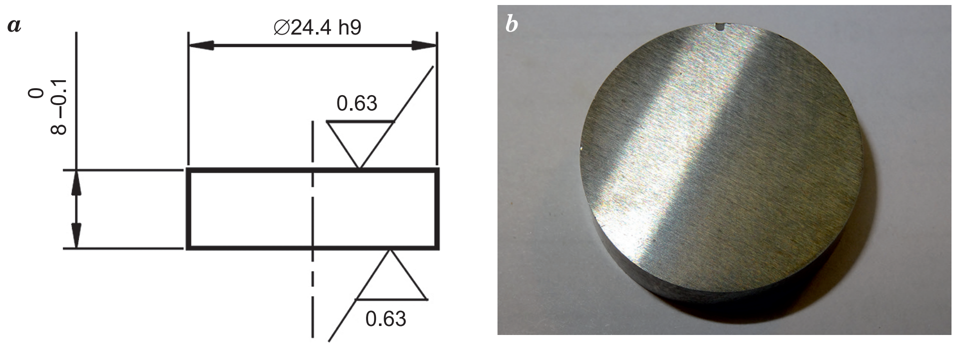

Fig. 3. Substrate material for tribological tests: *a* – schematic diagram, *b* – substrate material (H10 sintered carbide). The properties of the substrate material are presented in Table 1

Commercial H10 carbide for the experiment was manufactured by Baildonit, and its chemical composition was identical to that of the K15 carbide barrel drill. H10 sintered carbide containing 6% Co (% wt.) is widely used in the production of cutting materials and plastic deformation tools due to high resistance to abrasive wear, very high hardness and mechanical strength, and superior cutting properties, in particular high resistance of the cutting edge to micro spalling and adhesive bonding at high temperatures. The functional properties of WC-Co carbides are influenced by the size of WC grains and the admixture of Co, where the hardness of the material increases with a rise in the size of WC grains. In WC-Co carbides, fracture toughness increases with a rise in Co content, and hardness is maintained by the ductile Co matrix.

The counter specimens were 1.0503 hypereutectoid steel pins which are presented in Figure 4.

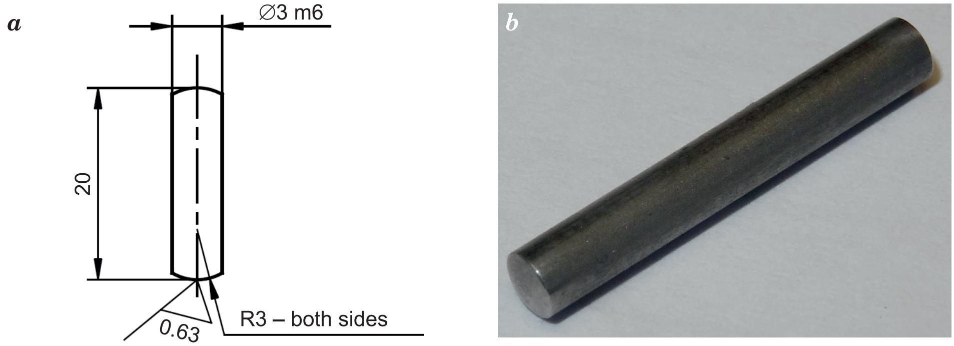

Fig. 4. Counter specimen – 1.0503 steel pin for pin-on-disc wear tests:
a – schematic diagram, *b* – steel pin

The friction coefficient and the wear of the friction pair were determined in abrasion resistance tests based on Standards ISO 20808: 2016; DIN 50324: 1992; PN-ISO 5725: 2002; ASTM G99 - 95.

The tests were carried out in the T-11 tribotester (Fig. 5) which assesses the tribological properties of sliding machine components such as lubricants and materials intended for operation at high temperatures.

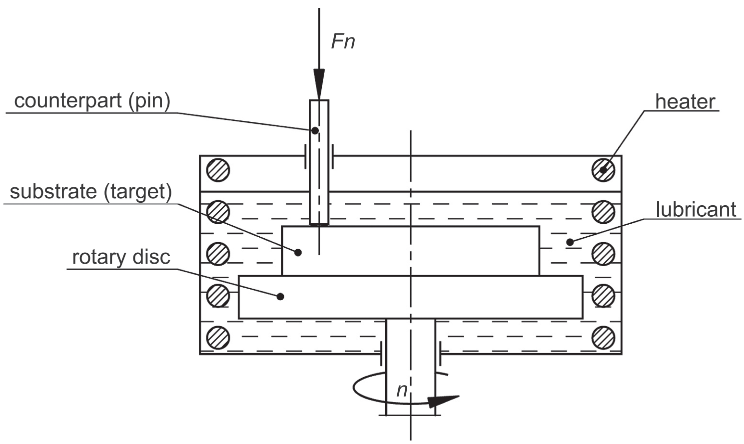

Fig. 5. Diagram of the T-11 tribotester chamber

In abrasion resistance tests, the friction pair comprised a stationary mandrel pressed with force F_n to a disk rotating with rotational speed n. The friction node was placed in an insulated thermal chamber with a heating element which heats the chamber and maintains a constant temperature of up to 300°C. Materials can also be tested in the chamber in a gas atmosphere. Changes in the friction force, linear wear and temperature at the point of contact between the elements at a given constant rotational speed of the disc were registered continuously by a digital control system to determine the time and path of friction in the test chamber. Abrasion resistance tests were carried out without and with Milpro HG12 oil, with and without the addition of Panther GP-1. Milpro HG12 oil is intended for grinding and machining under harsh conditions. It consists of deeply refined mineral oils, lubricants and EP/AW anti-wear and anti-seize additives. The properties of the applied oil are presented in Table 2.

Table 2

Specification of Milpro HG12 oil based on the product safety data sheet

Parameter	Value
Appearance	transparent
Color	yellow
Density at 15°C	859 kg/m^3
Viscosity at 40°C	12 mm^2/s
Ignition temperature	155°C
Copper corrosion	4B
Chlorine content	0%
Anti-fog properties	yes

Panther GP-1 concentrate (PWPH PantherOil Poland) formulated based on Valona MS 7023 oil and containing 10% of ultra-dispersive Cu and CuO particles (0.05 ÷ 0.6 mm) was used as an additive to decrease the friction coefficient. The concentrate was added to Milpro HG12 oil (1:100) in abrasive wear tests. Panther GP-1 concentrate forms microlayers with unique properties which improve the durability of the oil film during barrel drill cutting at high temperature and high unit load when the viscosity of the lubricating-cooling oil decreases.

Before the test, each sample was washed in acetone and dried in air. The parameters of abrasive wear tests in the T-11 tribotester are presented in Table 3.

Performance tests involved single-acting barrel drills (Fig. 6) manufactured by GÜHRING with cutting blades made of uncoated K15 material with identical properties to the H10 carbide substrate in tribological tests (Tab. 1).

The structural parameters of the drills are presented in Table 4.

Table 3

Parameters of tribological tests analyzing the wear resistance of H10 sintered carbide and 1.0503 steel friction pair in the T-11 tribotester

Parameter	Value
Type of motion	sliding motion
Contact geometry	pin-on-disc
Counterpart diameter (pin)	φ 3 mm with rounded face and radius of R3
Substrate diameter (target)	φ 25.4 mm
Rotational speed of the disc	95.5 rpm
Sliding velocity	0.1 m/s
Friction path	1,000 m
Number of cycles	15,923
Load	10 N
Fraction radius	10 mm
Temperature in the test chamber	23°C
Relative air humidity	52%
Reading recorded results	every 100 mm of the friction path

Table 4

Structural parameters of barrel drills with sintered K15 carbide blades used in performance tests

Parameter	Description
Drill type	EB80
Number of cutting edge	2 edges located asymmetrically relative to the tool rotation axis
Blade type	monolithic K15 carbide (uncoated)
Arrangement of work support blade	G-type
Convergence of work support blade	1:800
Drill shank	WHISTLE NOTCH (E – STANDARD)

Fig. 6. Single-blade barrel drill used in performance tests

The base unit of the test stand was the FNE 40NC AVIA vertical numerical milling machine with stepless adjustment of spindle speed in the range of 0÷4,000 rpm. The milling machine was equipped with a 5.5 kW vertical spindle and an ISO40 socket for hydraulic clamping of the tool holder. A horizontal table enabled pivoting movements in *X*/*Y*/*Z* directions to 620/420/400 mm, respectively. The cooling system comprised a 100 L oil tank and a hydraulic pump which supplied oil to the machining zone through the tool holder and the drill (pressure – 3 MPa, flow rate – 10 L/min).

The components of the tool kit used in field tests are presented in Table 5.

Table 5

Tool kit components used in performance tests

Component	Description
Working tool	EB80 barrel drill
Specialized modular holder with external coolant supply:	–
– holder	DIN2080 A40 OTT MHD63.60
– rotary joint	ACR63/63
– tool holder	AW63/20

To implement the deep hole drilling technology with the use of barrel drills, pilot holes for guiding the drill had to be made in the first phase of drilling. The pilot hole was drilled in four stages, as shown in Figure 7.

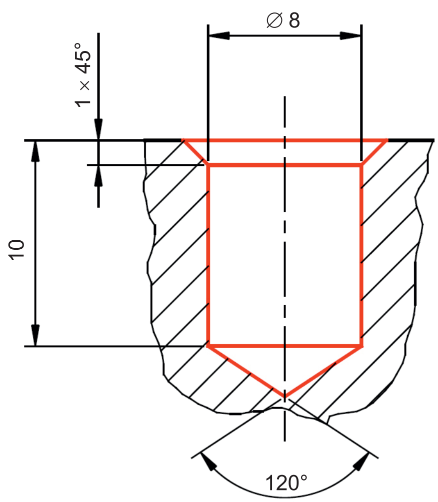

Fig. 7. Basic dimensions of the pilot hole

The following assumptions were made to determine the work cycle of the barrel drill in performance tests:

– the drill is inserted into the workpiece (PO) through a pilot hole,

– holes are drilled through,

– the accumulated chips have to be removed when drilling successive holes,

The technical parameters of drilling tests are presented in Table 6, and the operation of the barrel drill in performance tests is illustrated graphically in Figure 8.

Table 6

Technical parameters of deep hole drilling with barrel drills in performance tests

Parameter	Value
Rotational speed of drill, n	2,500 rpm
Drill feed rate, f_m	50 mm/min
Feed rate per drill tooth, f_z	0.02 mm
Cutting speed, V_c	62.8 m/min
Cooling lubricant	Milpro HG12 oil Panther GP-1 supplement
Oil pressure, P	3 MPa
Oil flow, Q	10 l/min

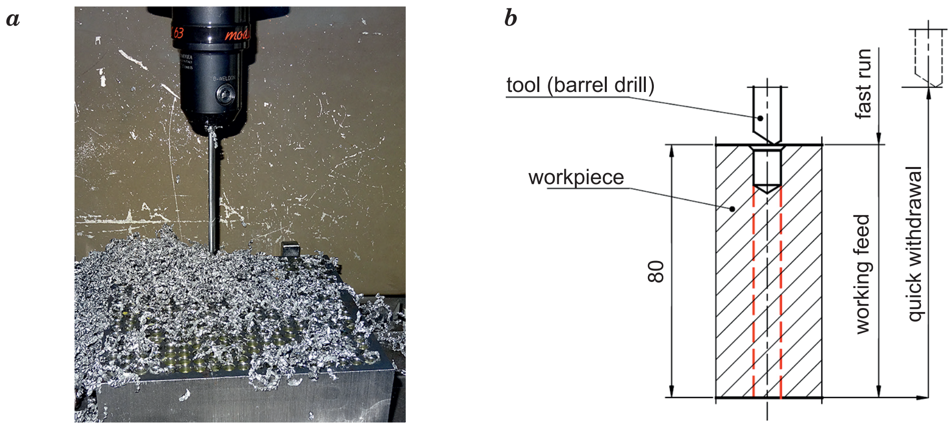

Fig. 8. The operation a single-blade barrel drill in the test stand:
a – deep hole drilling, *b* – work cycle of the barrel drill

Plates made of 1.0503 steel, measuring 200 × 200 × 80 mm, were used in wear tests of barrel drill blades.

The wear of barrel drill bits at 14-hole intervals (LWO), which were equivalent to the drilling path L_w = 1,000 mm, was determined under OPTA-TECH MN800P and Levenhuk DTX 90 microscopes equipped with a measuring and image recording system. The first measurement was made after drilling 28 holes (L_w = 2,000 mm). The total length of the drilling path for the analyzed tool-coolant-lubricant configuration was L_w = 8,000 mm, and it corresponded to 112 through holes. The measurements were used to determine the geometric wear coefficient K_W of the barrel drill according to Standard PN-83/M-58350.

Results and Discussion

Friction pair measurements (1.0503 steel and H10 cemented carbide) are presented in Tables 7 and 8 and are illustrated graphically in Figures 9 and 10.

Table 7

Friction measurements of the 1.0503 / H10 friction pair

Test	Coefficient of friction, μ	Average coefficient of friction, μ	Standard deviation
Dry run			
1	0.71209	0.63932	0.06602
2	0.61949		
3	0.54473		
4	0.69123		
5	0.62909		
Friction in Milpro HG12 oil environment			
1	0.12337	0.11744	0.00551
2	0.11646		
3	0.11249		
Friction in Milpro HG12 oil environment with Panther GP-1 additive			
1	0.10699	0.11281	0.00535
2	0.11392		
3	0.11751		

The results of 1.0503/H10 friction pair tests revealed that the average value of the friction coefficient (around m = 0.64) was highest in the dry run. When the friction pair was tested in the presence of Milpro HG12 oil (without the addition of Panther GP-1), the friction coefficient decreased by 81.6% to approximately M = 0.12. When both Milpro HG12 oil environment and Panther GP-1 lubricant were added to the test chamber, the friction coefficient increased by approximately 82.4% relative to the dry run. The application of Panther GP-1 lubricant with ultra-dispersive Cu and CuO particles with a diameter of 0.05 ÷ 0.6 μm decreased the viscous friction coefficient by around 4% (relative to pure Milpro HG12 oil) in the gap between the surfaces of co-acting elements.

Table 8

Cumulative results of wear tests involving the 1.0503/H10 friction pair

Test	Wear [μm/m]	Average wear [μm/m]	Standard deviation [μm]
Dry run			
1	0.96812	1.23463	0.20650
2	1.10251		
3	1.35549		
4	1.37352		
5	1.24195		
Friction in Milpro HG12 oil environment			
1	0.13737	0.13737	0.01593
2	0.10555		
3	0.12289		
Friction in Milpro HG12 oil environment with Panther GP-1 additive			
1	0.09108	0.09195	0.00123
2	0.09282		
3	0.10882		

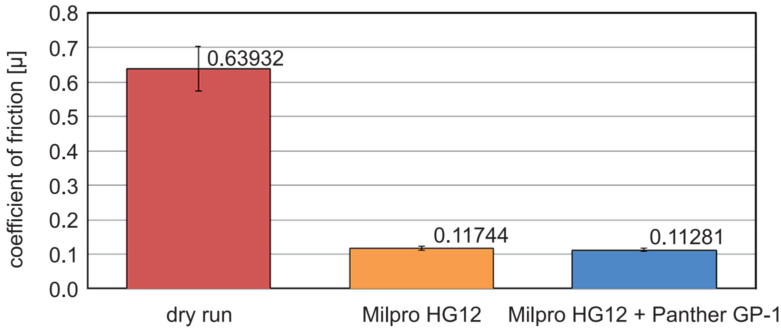

Fig. 9. Average values of the friction coefficient in the 1.0503/H10 friction pair

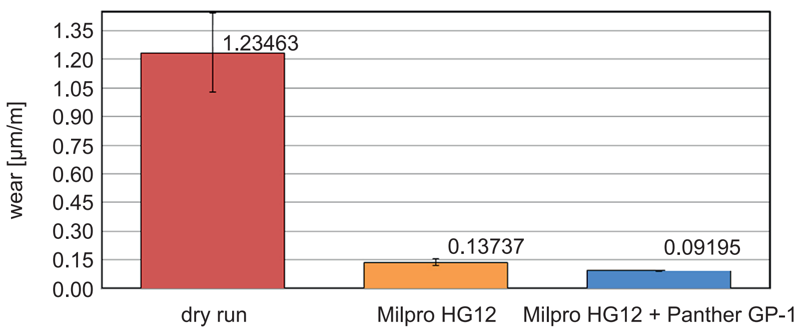

Fig. 10. The results of wear tests involving the 1.0503/H10 friction pair

Similarly to the friction coefficient μ, the highest wear (around 1.23 μm/m on average) of the 1.0503/H10 friction pair was noted in the dry run. Wear decreased by 88.8% to approximately 0.14 μm/m when Milpro HG12 oil was used without the addition of Panther GP-1. Wear decreased by approximately 92.6% when Milpro HG12 oil and Panther GP-1 lubricant were added to the test chamber. The friction coefficient decreased by around 4% because the friction surface was protected by a sublayer formed by Milpro HG12 lubricating oil with ultra-dispersion Cu and CuO particles (relative to Milpro HG12 lubricating oil applied alone), which decreased the wear of the tested friction pair by approximately 33%. The above can probably be attributed to the fact that ultra-dispersion Cu and CuO particles were able to rebuild the protective lubricating layer of Milpro HG12 oil under abrasive wear conditions.

In performance tests, the wear of the single-blade barrel drill was analyzed based on the wear of blade tip *W* in plane P_r, and it was expressed by the geometric wear coefficient K_W, as shown in the diagram in Figure 11. The results of performance test conducted under all drilling conditions with the use of specific lubricants (without dry runs) are presented in Table 9 and Figures 12 and 13.

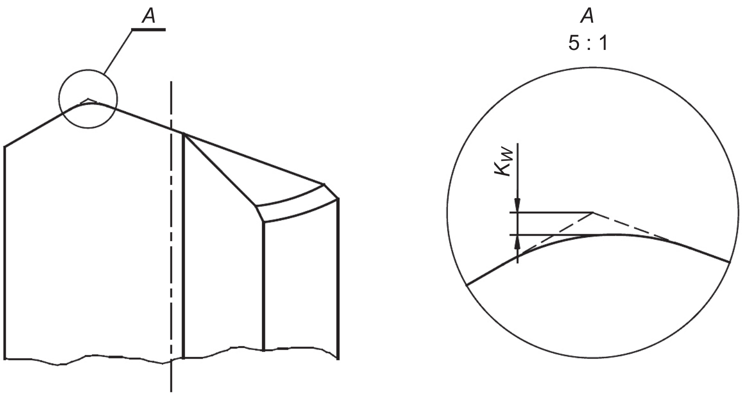

Fig. 11. Wear coefficient K_W of the single-blade barrel drill in plane *Pr*

The results of microscopic tests revealed that the tip *W* of the barrel drill bit was worn in plane P_r under the applied drilling conditions. After drilling (L_w = 8,000 mm; LWO = 112 through holes), tip wear was determined at K_w = 0.132 mm when the barrel drill was operated in the presence of Milpro HG10 oil without the addition of Panther GP-1. When Milpro HG12 oil was used in combination with the Panther GP-1 additive along the same drilling path L_w, the wear coefficient was determined at K_w = 0.087 mm, and it was more than 34% lower relative to the test involving pure Milpro HG12 oil.

The friction coefficient increases when the feed rate is reduced and the remaining machining parameters remain constant (BOGDAN-CHUDY, NIESŁONY 2015, FELDSHTEIN, MARUDA 2010). The obtained results indicate that drilling tests performed at a low feed rate per drill tooth (f_z = 0.02 mm) can significantly affect the friction coefficient. Unfortunately, the feed rate of barrel drills cannot be significantly increased due to design and strength constraints.

Table 9

The wear of the single-blade barrel drill expressed by the wear coefficient K_W

Measurement No.	Number of drilled holes LWO	Drilling path *Lw* [mm]	Wear coefficient K_W	
			Milpro HG12 oil [mm]	Milpro HG12 oil + Panther GP-1 additive [mm]
1.	28	2000	0.053	0.039
2.	42	3000	0.069	0.045
3.	56	4000	0.082	0.056
4.	70	5000	0.089	0.061
5.	84	6000	0.094	0.067
6.	98	7000	0.11	0.072
7.	112	8000	0.132	0.087

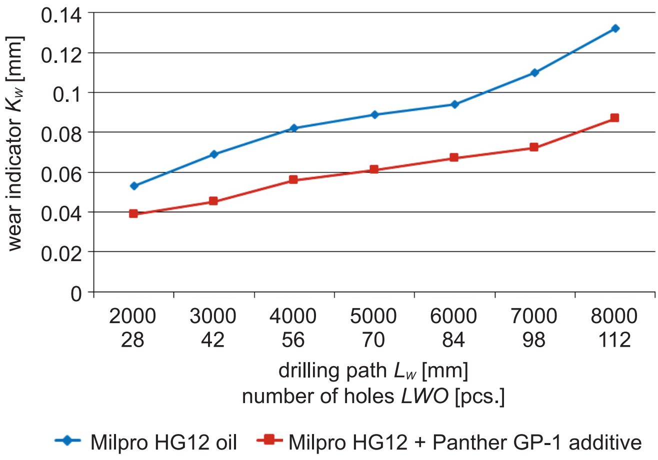

Fig. 12. Changes in the value of the wear coefficient K_W of the single-blade barrel drill as a function of the number of drilled holes, expressed by changes in the drilling path in performance tests conducted under all drilling conditions with the use of specific lubricants

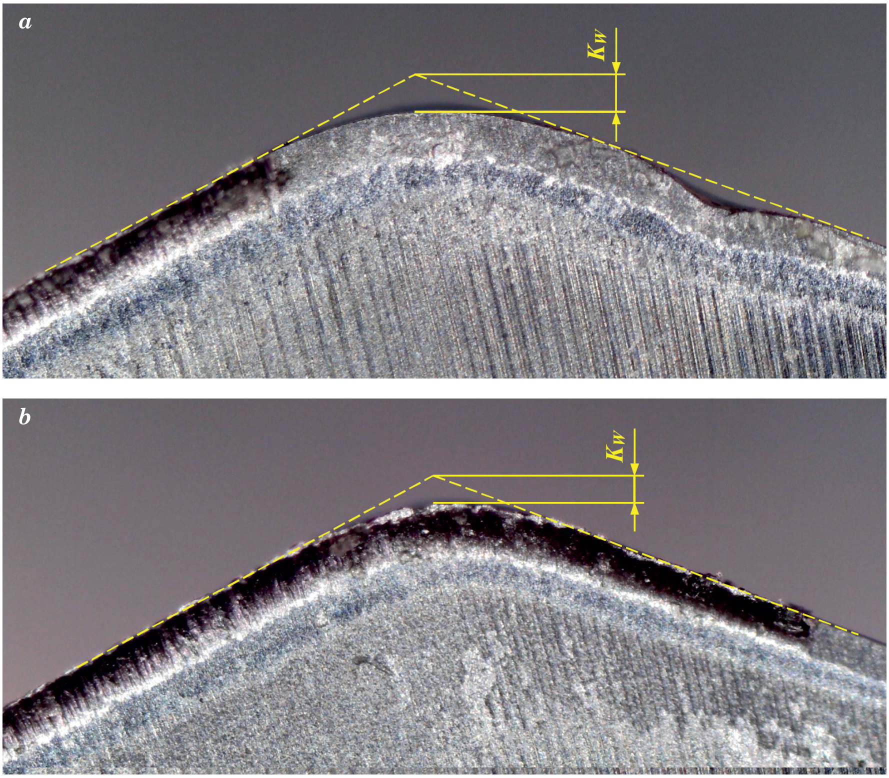

Fig. 13. Corner wear of the single-blade barrel drill at LWO = 112; *Lw* = 8,000 mm with oil: *a* – Milpro HG12, *b* – Milpro HG12 with Panther GP-1 additive

Conclusions

The results of the tribological tests of the C45 / H10 friction pair indicate that a decrease in the friction coefficient μ is accompanied by a decrease in wear during wet abrasion when a lubricant is used. In tests involving Milpro HG12 oil with Panther GP-1 additive, the wear of the tested friction pair decreased by more than 33%, and the friction coefficient μ decreased by approximately 4% relative to the values noted when pure Milpro HG12 oil was used. The performance tests of the barrel drill blade revealed considerable wear of the blade tip based on the calculated values of the geometric wear coefficient K_W. When 112 through holes were drilled along a path of 8000 mm, the application of Milpro HG12 oil with Panther GP-1 additive decreased tip wear by approximately 34%. Tribological and performance tests confirmed that the addition of Panther GP-1 lubricant to Milpro HG12 oil decreases the coefficient of friction μ and the linear wear of the material used in barrel drills.

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