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A FAMILY OF INNOVATIVE FASTENERS FOR DRILL STRINGS USED IN ROTARY DRILLING IN THE COPPER MINING INDUSTRY

This paper presents the development of new rotary drilling fasteners intended for copper ore mining applications. The study addresses durability and reliability issues of drill string connections subjected to high mechanical loads and fatigue. Improved thread geometries were designed to reduce stress concentrations and facilitate assembly and disassembly. Numerical analyses based on von Mises stress criteria were performed to compare the proposed designs with standard fasteners. Prototype components were manufactured using additive techniques for preliminary functional evaluation. The results show a more uniform stress distribution, with up to 28.4% reduction in surface stresses for the C17 fastener relative to the reference design. Prototype testing confirmed proper thread engagement and stable contact between the drill tip and fastener collar. The redesigned fasteners provide increased durability, easier handling, and improved operational reliability, supporting safer drilling under difficult geological conditions. The solution has been successfully implemented in industrial practice.

1. INTRODUCTION

The pursuit of innovations by mining companies is key for the sustainable development of this sector. Technological transformations require those companies to cooperate with research and development institutions in order to effectively implement innovative solutions. Business investments in such technologies may contribute to higher energy efficiency, reduced impact on the environment and improved working conditions in mining industry (Kowalski and Nowak 2015). Financing innovations in mining is crucial, as it allows more efficient ex-traction of minerals and thus translates into lower operating costs and greater competitiveness. Advanced technologies also improve the safety of mining operations, minimize the risk of accidents and the negative influence on the environment. Innovations also allow more sustained management of human resources, which is of importance in the context of ecological and social requirements (Tkocz and Heder 2012). Current trends in

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mining focus on implementing innovative technologies which increase work safety and process automation, as well as minimize the impact of the mining industry on the environment. An increasing stress is placed in the development of intelligent monitoring and management systems which improve the efficiency and reliability of mining operations (Klich and Pieczora 2013).

Exploration, including core drilling, is key in finding and evaluating mineral deposits which meet the global demand for raw materials (Tusa, et al. 2020). This paper addresses problems related to research into developing a manufacturing technology of a new family of drill string fasteners for rotary drilling used in the copper ore mining industry. The new fasteners are expected to allow higher reliability and to facilitate both the assembly and the disassembly of the drill string. They represent an important component of the drill string used in the drilling of holes for protective bolts installed in extraction galleries in order to increase the safety of ore mining operations. The current commercially available solutions have a number of disadvantages, which these research and development works intend to mitigate or solve.

Polish mines frequently have difficult geological conditions which hinder the preparation of drillholes, particularly for water drainage. Such problems are encountered for example in lignite, copper ore and basalt mines, in which water is drained with the use of large-diameter dewatering wells. This process may not be effective due to the presence of loose Quaternary and Tertiary sediments as well as to a significant dewatering of the rock mass in the area of the excavations. In such conditions, the drilling process is longer and more prone to complications, such as roof collapse or equipment failure. A more effective drilling can be achieved owing to novel designs of drilling tools and to more research into rock properties, which will allow optimized technological parameters of the drilling process (Macuda 2012).

Drilling in deposits is a complex task due to the non-uniform and complicated geological structure of the rocks, which include sands, gravels, clays, sandstones and other materials having diverse properties (Boiger, et al. 2024). Even with advantageous physical and mechanical properties, the drilling process is obstructed by the rock anisotropy, texture and strength. The rock destruction process is complicated, as the drilling tool encounters irregular, cratered surfaces. Regardless of the applied method, the effectiveness of the process is mainly affect-ed by the shape of the tool and by the rock resistance to penetration (Maziarz, et al. 2007).

The key aspect for mining companies is to properly analyze the elements prone to damage due to material fatigue. This type of damage significantly reduces service life and affect the safety of the tools or of the structure (Labutin, Mattis and Zaitseva 2005). The phenomena observed in the case of standard elements include subsurface and surface fractures as well as other types of damage. Fractures are not the only type of damage found in drilling tools, which importantly may be due to a variety of reasons and may translate into reduced efficiency and durability. In the case of drill strings, any type of damage may lead to excessive clearances on the threaded joints, which may in turn affect their functionality and thus translate into reduced work efficiency (Romanowicz and Zielinski 2007).

Being used in various surface and underground mining conditions, drilling tools need constant development and improvement. Different extraction locations and deposit characteristics require the technology to dynamically adapt to such challenges as difficult geological conditions or varying depth of mining operations (Sobko, et al. 2019). Improved drilling tools increase work effective-ness, while limiting downtimes and failures of the machinery. Such improved technology also allows more effective management of the turbulent work environment and has an impact on the safety and efficiency of the operations. Modernized tools facilitate the continuity of mining processes, reducing the costs and extending the service life of machines operated in difficult conditions (Jasinski and Janik 2017) (Feld 2000).

Predictive maintenance (PdM), understood as the proactive use of condition monitoring and data analysis to anticipate equipment failures before they occur, can be effectively implemented through methodologies similar to those explored in the present article. The topic addressed in this study aligns with predictive maintenance principles by focusing on systematic monitoring, quantitative evaluation of key parameters, and data-driven decision-making to improve operational reliability and prevent unexpected equipment downtime (Chambi, 2025).

This paper discusses components of equipment involved in the so-called rotary drilling which is one of the basic drilling methods, along the percussion drilling (top hammer or down-the-hole hammer) rotary-percussion drilling (Wisniowski, Wojcik and Toczek 2006). Drilling in rock with the use of rotary cutting tools consists in pressing the tool against the rock with a de-fined axial force, which breaks the rock by cutting. The speed and pressure force are of key importance, and their critical values define the limits of the drilling parameters (Sciezka and Filipowicz 2001).

2. MOTIVATION FOR THE RESEARCH

The development of a new series of fasteners was aimed at solving the above-presented problems and at providing a product that meets market demand. The new fasteners were designed for increased durability owing to the use of anticorrosive coatings and improved sliding properties. The quality and tightness are also improved by using a new thread geometry and by eliminating the clog-ging due to the drill cuttings, which significantly improved the effectiveness of the drilling operation. The research works allowed the introduction of dimension standards in order to facilitate the engagement between the individual elements of the system. The project has contributed to the development of new solutions which optimize mining processes by increasing work efficiency and safety.

The time required for the replacement of mining tools and equipment is critical for maintaining operational continuity, as it directly affects technical availability, utilization rate, and overall productivity of the mining system. An improperly determined replacement moment may lead to increased life-cycle costs, reduced reliability, and unplanned downtime; therefore, replacement decisions should be based on systematic analysis of technical and operational parameters (Castanon, 2024). Effective monitoring of operational times constitutes a fundamental element of performance assessment in drilling systems, as it directly reflects equipment availability, efficiency, and the quality of process control. Precise identification and analysis of time-related parameters enable early detection of performance deterioration, reduction of unplanned downtime, and more informed decision-making regarding maintenance, optimization, and operational planning (Xu et. al., 2026).

Two types of rotary drilling tools are used in Polish copper ore mining plants to bore bolt-holes: those which employ drilling fluid and those which employ dust extraction. The choice of either of the above types is dictated by the particular geological conditions.

The new generation of fasteners for drill strings is the result of a complex research and development pro-cess which included both theoretical analyses and experimental functional tests. The main problem was to identify the existing technological obstacles and to develop solutions which improve the durability, reliability and effectiveness of threaded fasteners. The process is shown in Fig. 1.

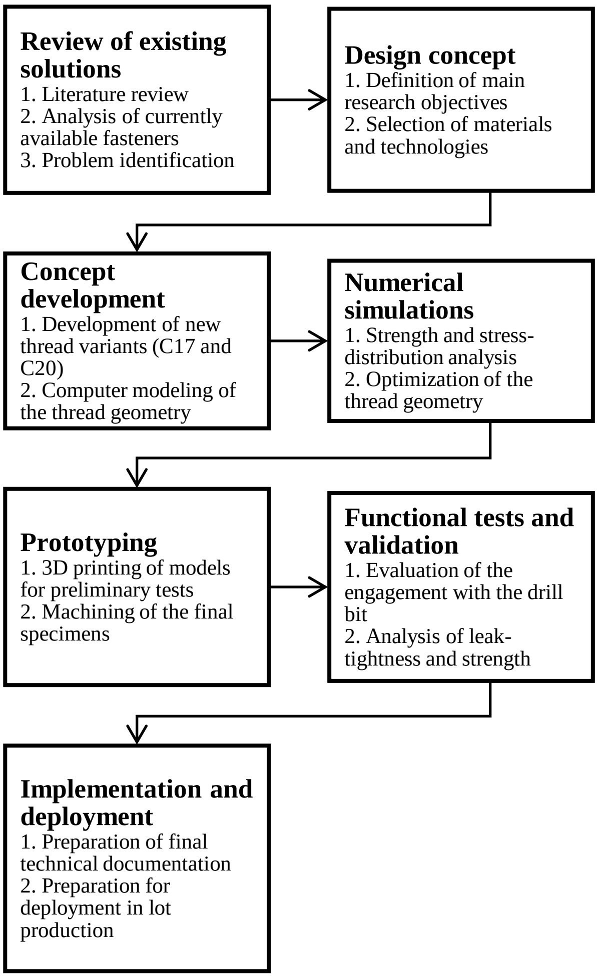

Fig. 1. The research process

The industry research and experimental development works were aimed at developing a new generation of fasteners for drill strings. The process started with the analysis of state-of-the-art solutions and with the identification of main technical problems. In the next step, the design concept was defined, and the models and numerical simulations were performed. The successive step consisted in 3D printing the prototypes and in performing functional tests. The test results allowed further improvements to the structure and the preparation of the final technical documentation for lot production. The project involved detailed industry tests and experimental development works which resulted in a new generation of fasteners for drill strings used in rotary drilling operations performed in copper ore mines. The first step consisted in the careful analysis of the Client's many-year experience which included delivering such products to the mining companies, as well as handling product complaints and customer needs.

The research allowed the identification of the main problems, such as lack of standards, low manufacturing quality, insufficient reliability and limited effectiveness. Based on their many-year cooperation with the mining industry, the Client identified a number of problems which affect the effectiveness and reliability of the currently used fasteners. These challenges included inter alia high surface porosity and corrodibility, problems with disconnecting the elements of the drill string, lack of dimension standards, insufficient manufacturing quality consistency, and long processing times offered by external suppliers. Moreover, the previous solutions had problems with clog-ging cuttings, which negatively influenced the effectiveness of the drilling process, and with complex structure, which increased the production and assembly costs. The implementation of improvements was also problematic due to the absence of manufacturing standards.

3. DESIGNS OF THE C17 AND C20 THREAD PROFILE

The fasteners developed in this project are classified from the functional perspective as connecting either two drill rods or the drill rod and the drill bit. In the case of fasteners between the drill rod and the drill bit used in the presence of the drilling fluid, the fasteners on the side of the bit are provided with a thread having a circular pro-file and being a modification of the classic circular thread. Having fewer notches, this thread reduces stress concentrations at the thread root, which – as demonstrated by the numerical analyses in Section 5 – results in a more uniform stress distribution and thus contributes to a longer service life of the fastener.

However, the commercially available B17 and B20 (Fig. 2) threaded fasteners have discontinuous structures. The available documentation on these threads is inconsistent and the transitions between individual threads are discontinued, resulting in the formation of a notch. This discontinuity additionally leads to the blocking of the drill tip on the thread, compromises the leak-tightness of the connection and causes other technological problems.

The B17 and B20 threads are geometrically identical. The only difference lies in their major diameters, which are Ø 17 mm and Ø 20 mm, respectively.

The proposed modification consists in the deepening of the thread profile by approximately 0.07 mm. It ensures a continuous transition between the individual threads, and thus it eliminates the main manufacturing and operating problem. At the same time, the diameter of the flushing hole was reduced from approx. Ø 8 mm to approx. Ø 6 mm in order to increase the strength of the fastener with the C17 (Fig. 3) thread. The diameter values are approximate because the exact dimensions will be selected in the next phase of the project, during technological tests with the use of CNC machine. In the case of the fasteners with the proposed C20 thread, the diameter of the flushing hole was assumed at 8 mm.

The design of the wet drill tips used with the HEX 22 rods includes two flushing holes having a diameter of 4 mm, which translate into their total surface area $S1$ = 25.13 mm^2. In order not to disturb the flow of the drilling fluid during the drilling operation, the diameter of the central hole in the fastener provided with the new C17 thread should not be smaller than d = 5.66 mm. Therefore the above assumption is structurally correct. On the other hand, in the case of the HEX 28 drill rod, the drill tip engaged with the drill string has a single hole 6 mm in diameter. Therefore, in order to avoid its negative impact, the flushing hole of the fastener cannot have a smaller diameter.

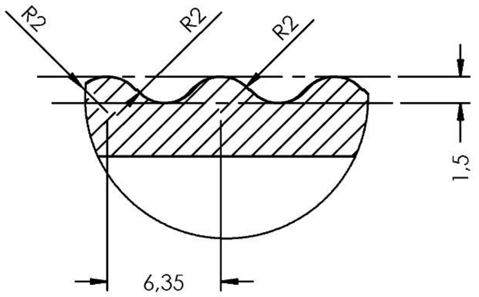

Fig. 2. Profiles of the current B17 and B20 threads

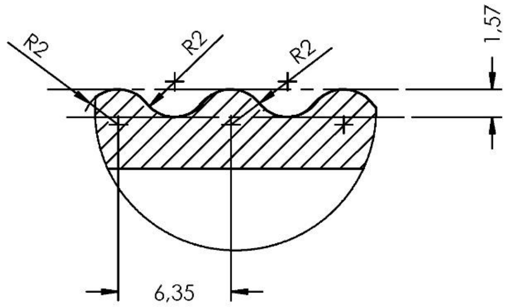

Fig. 3. Profiles of the proposed C17 and C20 threads

Importantly, except an optimal profile, the thread should also have a proper runout. On the one hand, it should be possibly gentle and have a possibly rounded shape in order to avoid the formation of a notch which concentrates stresses. On the other hand, it should be ensured that when the drill tip, regardless of its manufacturer, is screwed on the fastener, the face of the tip rests against the collar of the fastener. If the female thread on the tip is not chamfered (which is a solution used by some manufacturers), and if the radius of the runout is equal to the radius of the thread, the tip may stop on the rounded runout of the thread. In such case, the tip will not be completely blocked on the screw line of the thread, compromising the leak-tightness of the connection and in effect leading to accelerated wear.

Figures 4 and 5 a proper engagement between the drill tip and the fastener with the proposed C17 thread and with the runout of Fig. 3. The red circles indicate are-as of engagement between the threads on both elements. The green circle indicates the area with no engagement between the tip thread and the thread runout on the fastener. As the tip rests against the collar of the fastener, the elements are locked along the screw line. Such a solution ensures that the connection is leak-tight and stable.

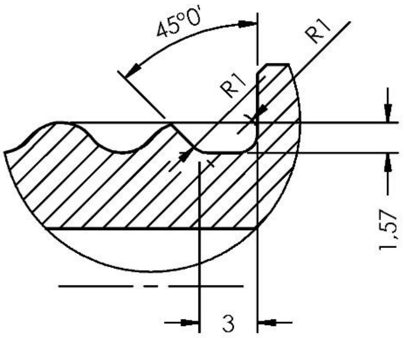

Fig. 4. Runout profiles for the proposed C17 and C20 threads

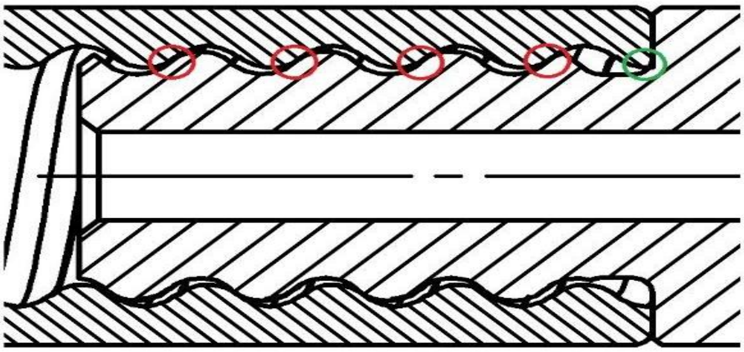

Fig. 5. Profile of the element engaged with the fastener (proper engagement with the runout edge of the thread)

4. ADJUSTMENT OF THREAD TOLERANCES

The manufacturing technology and the engagement between the fastener and the drill tips provided by different manufacturers necessarily rely on the properly selected manufacturing tolerances. Numerical machines ensure manufacturing tolerances on the level of 0.02 mm. However, such precision seems unnecessary in relatively inexpensive elements subjected to wear, particularly as the Client desires possibly short manufacturing times in order to limit the time needed to respond to the demand from the customer. Therefore, the fastener manufacturing tolerances, and thread tolerances in particular, are expected to be higher than workshop tolerances, but lower than those offered by numerically controlled lathes. In order to ensure high and uniform quality of the manufactured fasteners, the tolerances for their key elements are set at 0.1 mm. As the drill tips engaging with the fastener are cast, their manufacturing tolerance may be up to 0.4 mm. Considering the need on the one hand to limit the risk of excessive clearance on the fastener and on the other hand to allow the fastener to engage properly with drill bits offered by various manufacturers, these values were found sufficient.

The proper functioning of the new C17 and C20 threads was verified by rapid-prototyping their models in accordance with the following tolerance tables. The aim was to test what actual value of the major diameter of the fasten-er thread ensures proper engagement with the commercially available drill tips. The range of the tested diameters was decided to be from -0.2 mm to +0.15 mm with respect to the nominal thread dimensions. Practice teaches that in the case of most manufacturers minor diameters for drill tips with female thread are greater than the nominal values. Tolerances for the key dimensions of drill bits are not standardized or otherwise regulated, and therefore, in order to precisely verify the engagement quality of the proposed threads, a wide range of tolerances was accept-ed, as shown in the Table 1.

Table 1. Range of tolerances [mm]

	Major diameter of the thread prototype [mm]							
Thread C17	16.80	16.85	16.90	16.95	17.00	17.05	17.10	17.15
Thread C20	19.80	19.85	19.90	19.95	20.00	20.05	20.10	20.15

5. NUMERICAL CALCULATIONS FOR THE NEW C17 AND C20 THREADS

One of the assumptions in the project was that the boreholes for the protective bolts are drilled with use of the proposed fasteners and a bolter having the maxi-mum torque of 450 Nm. It is the highest theoretical load possible during the drilling process. It may occur if the drill rig is blocked in the borehole, but is practically a very rare case. Typically, in such a situation first the car-bide plates of the drill tip would break and splinter, and then the tip body would become damaged due to friction, as it has a lower hardness than the rocks. Therefore, the torque of 450 Nm was assumed to be the limit value in the numerical calculations. This value corresponds to the maximum rated torque of the bolters used at the mining sites, as confirmed by the equipment specifications provided by the customer. It was also assumed that in the case of such a load the fastener body cannot be destroyed, i.e. that the fastener cannot be permanently deformed due to exceeded yield point *R*e for the material used in the fastener.

The numerical calculations were also based on an assumption that the fasteners are made of the HGS 35 heat treatment steel. Its properties required in strength calculations are presented in the table below. The properties to apply to heat-treated steel are shown in the Table 2.

Table 2 The properties to apply to heat-treated steel

Name	Value	Unit
Tensile strength *R*m	1620	MPa
Yield point *R*e	1280	MPa
Reduction in area Z	40	%
Elongation *A*	9	%

The treaded fasteners are loaded with a torque of 450 Nm. The character of the threaded fastener causes the torque to be transformed into an axial tensile force acting on the threaded part of the fastener. With the efficiency of the threaded fastener assumed at approx. 18%, during its operation the fastener is subjected to a maximum tensile force of 80.148 [N].

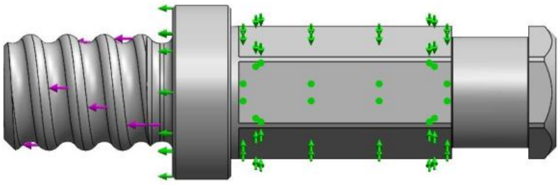

Fig. 6. Schematic diagram showing the load and fastening of the tested element – violet arrows indicate load, and green arrows indicate the restraint

As the contact between the drill rig and the tested fastener is linear along the screw line, the tested element was loaded with an axial force of 80.148 N applied to the screw line at half the thread height. The fastener was restrained with the use of the so-called sliding fixture which accepts only the translation perpendicular to the restrained surface. All the surfaces of the hexagon and the face of the fastener were restrained as shown in the figure above. All tests were performed with the use of tetrahedal elements having the characteristic mesh dimension of 1.5 mm.

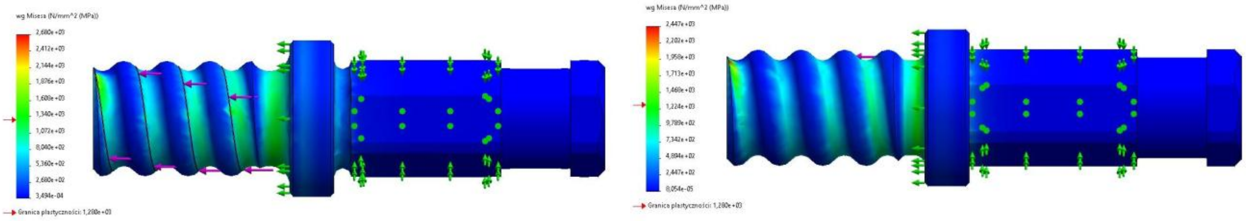

Fig. 7. Stress distributions for the fasteners with the B17 (left) and C17 threads (right)

The numerical simulations indicate that the modified thread profile and the reduced size of the flushing hole allowed a decrease of the maximum stresses at the thread root from approx. 1386 MPa to approx. 992 MPa. Owing to the elimination of the notch in the new C17 thread, the stress distribution on the surface of the thread is more uniform than in the case of the fastener with the B17 thread. In the figures above, the C17 thread does not show a clear cut-off between the colors of the stresses at the root and at the crest.

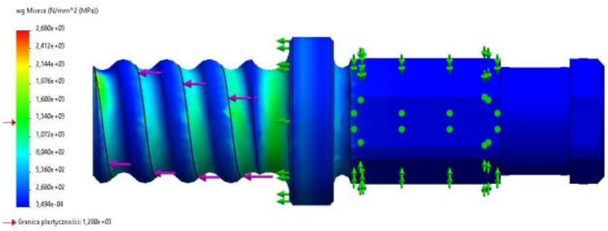

Fig. 8. Stress distribution for thread C17

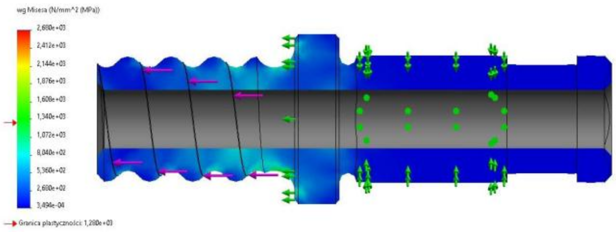

Fig. 9. Stress distribution for the runout of thread C17

The stress distribution in the proposed runout profile of thread C17 is very similar to the distribution in thread B17. The stresses for the C17 thread were observed to decrease from 1415 MPa to 1382 MPa.

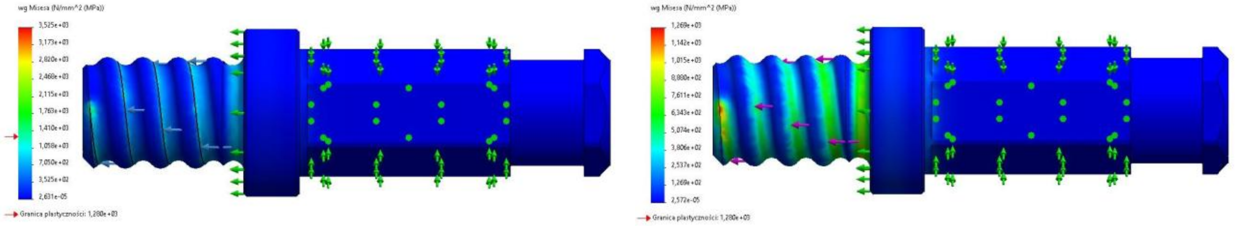

Fig. 10. Stress distributions for the fasteners with the B20 and C20 threads

The numerical simulations indicate that the stress values for thread B20 and C20 are similar. The proposed thread C20 shows a slight reduction of maximum stress values from 698 MPa to 684 MPa. Owing to the elimination of the notch in the new C20 thread, the stress distribution on the surface of the thread is more uniform than in the case of the fastener with the B20 thread. In the figures above, the C20 thread exhibits a more gradual transition in the stress colour gradient between the thread root and crest, indicating a more uniform stress distribution compared to the B20 thread.

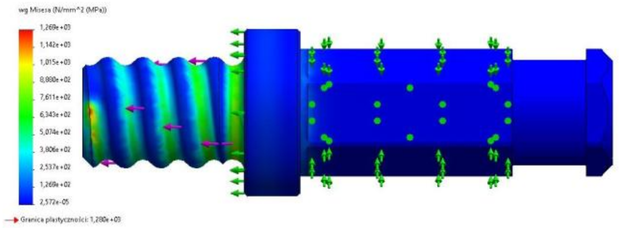

Fig. 11. Stress distribution for thread C20

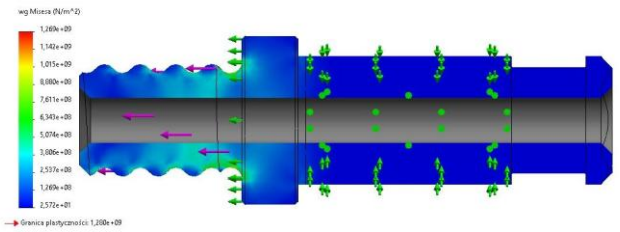

Fig. 12. Stress distribution for the runout of thread C20

The stress distribution in the proposed runout profile of thread C20 is similar to the distribution in thread B20. The stresses for the C20 thread were observed to decrease from 1035 MPa to 1007 MPa.

6. TESTS OF ENGAGEMENT BETWEEN THE PROPOSED C17 AND C20 THREADS AND THE DRILL TIPS

The following criteria were taken into consideration in tests of engagement between the thread prototypes with selected commercially available drill tips used in the mines:

- Thread engagement smoothness,
- Clearance level at incomplete drill tip engagement,
- Evaluation whether the drill tip resting against the collar,
- Connection stability at fully tightened fastener.

Each of the eight printed specimens (Fig. 13–16) corresponds to a distinct major diameter variant listed in Table 1; the diameter value is engraved on the flange of each specimen and additionally indicated in the figure caption.

Due to the thread engagement character, the tests of the 3D-printed threads C17 showed that the connection between the drill tip and the thread of the prototype fastener is stable for all the considered clearance values. In addition, the tip firmly rested against the fastener collar for each of the tested major thread diameters. Criteria for the evaluation of the engagement between the tip and the new fastener thread were subjective and served only for preliminary evaluation. All drill tips used in the engagement tests were new, commercially available specimens sourced directly from the mine's stock, ensuring that any thread deformation observed during testing could be attributed solely to the plastic prototype material rather than to prior wear of the metal tips.

Fig. 13. Images of 3D-printed C17 threads

Fig. 14. Images of 3D-printed C17 threads

Fig. 15. Images of 3D-printed C20 threads

Fig. 16. Images of 3D-printed C20 threads

Table 3. Results of engagement tests between thread C17 and the drill tips

Thread diameter	Drill tip symbol	
	Drill tip KNW ⌀26 B17	Drill tip CX ⌀26 B17
16.80 mm	Excessive clearance while screwing	Excessive clearance while screwing
16.85 mm	Excessive clearance while screwing	Excessive clearance while screwing
16.90 mm	Excessive clearance while screwing	Excessive clearance while screwing
16.95 mm	Excessive clearance while screwing	Moderate clearance while screwing
17.00 mm	Moderate clearance while screwing	Moderate clearance while screwing
17.05 mm	Moderate clearance while screwing	Moderate clearance while screwing
17.10 mm	Moderate clearance while screwing	Small clearance while screwing
17.15 mm	Small clearance while screwing	Small clearance while screwing

Table 4. Results of engagement tests between thread C20 and the drill tips

Thread diameter	Drill tip symbol	
	Drill tip KNW ⌀38 B20	Drill tip CX ⌀38 B20
19.80 mm	Excessive clearance while screwing	Excessive clearance while screwing
19.85 mm	Excessive clearance while screwing	Excessive clearance while screwing
19.90 mm	Excessive clearance while screwing	Excessive clearance while screwing
19.95 mm	Excessive clearance while screwing	Moderate clearance while screwing
20.00 mm	Moderate clearance while screwing	Moderate clearance while screwing
20.05 mm	Moderate clearance while screwing	Moderate clearance while screwing
20.10 mm	Moderate clearance while screwing	Small clearance while screwing
20.15 mm	Small clearance while screwing	Small clearance while screwing

Due to the thread engagement character, the tests of the 3D-printed threads C20 showed that the connection between the drill tip and the thread of the prototype fastener is stable for all the considered clearance values. In addition, the tip firmly rested against the fastener collar for each of the tested major thread diameters. Criteria for the evaluation of the engagement between the tip and the new fastener thread were subjective and served only for preliminary evaluation.

Further in the research, the major diameter for thread C17 was assumed to be 17 mm, and for thread C20–20 mm. It was also decided that the final major thread diameters will be provided with an increased precision as the prototypes are manufactured with the use of the target technology, i.e. on a lathe.

7. CONCLUSIONS

This article addressed the optimization and improvement of the mining process, which can be considered a form of predictive maintenance strategy. The literature emphasizes that implementing predictive maintenance strategies is essential for effective management of mining equipment, as it enables early detection of anomalies and reduces unplanned downtime. Moreover, integrating data analytics and machine learning into maintenance systems improves scheduling efficiency, enhances equipment reliability, and supports cost-effective operation in demanding mining environments (Dayo-Olupona, 2023).

Similarly to studies analysing the influence of drilling and installation techniques on the load-bearing capacity of fasteners, precision of execution and control of geometric parameters play a crucial role in determining stress distribution within the contact zone. In the case of the designed C17 and C20 threads, achieving a more uniform stress distribution and reducing stress concentrations along the engagement line were particularly significant, as these factors directly affect the durability and operational reliability of the connection under service conditions (Ortner, 2024).

The design works performed as part of the first stage of the project resulted in the development of the profiles for threads C17 and C20. Their technical docu-mentation is presented in the Fig. 17. Most importantly, the numerical calculations for the newly designed threads C17 and C20 showed a uniform stress distribution on the entire thread surface, an particularly on the engagement line between the fastener and the drill tip. This result is of significance, as stress discontinuities and their concentrations along the engagement line may lead to accelerated wear and damage of the fastener. In addition, the reduced (von Mieses) stresses also decreased on the thread surface and in areas of the proposed relief, i.e. the thread runout. The Table 5 below lists the values of the reduced stresses observed in the reference fasteners with threads B17 and B20, and of the stresses observed in the proposed threads C17 and C20.

The tests of the 3D-printed prototypes of new threads C17 and C20 indicate that they were correctly designed and that they will ensure an appropriate engagement of the fastener. The proposed solution allows the drill tip to be easily screwed on the fastener and to firmly rest against the fastener collar.

Stress reduction in threads is of significance for the mining industry, as it influences the service life, reliability and safety of drilling elements. High stresses may lead to fatigue cracks and thus limit the life of such elements and increase the risk of their failure. With a proper design, the risk of damage can be reduced, the leak-tightness and precision of fasteners can be improved, and the costs of downtime and repair can be minimized. In difficult mining conditions, e.g. in the presence of high loads and in corrosive environments, reduced stresses translate into increased resistance of individual elements to damage. As a result, the safety, effectiveness and efficiency of drilling operations are improved.

This research resulted in a new technology, which effectively solves the above problems with the use of novel technical solutions. The new fasteners show a significantly higher durability owing to the use of anticorrosive coatings and improved sliding properties. The redesigned thread geometry increased the leak-tightness of the fastener, and also facilitated its assembly and disassembly. The research results also include new dimension standards, which increase the manufacturing quality consistency and facilitate the production process. The tests performed in difficult operating conditions confirmed that the new solution shows higher efficiency and reliability.

Owing to the project, the Client was able not only to meet the growing market demand on quality, but also to commercially introduce an innovative product which increases its competitiveness, allowing a better response to customer requirements and the development of a stronger brand.

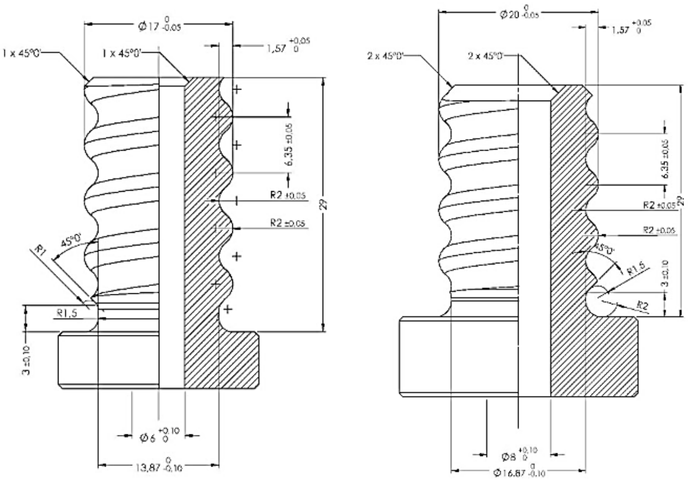

Fig. 17. New C17 and C20 threads

Table 5. The values of the reduced stresses observed in the reference fasteners with threads B17 and B20, and of the stresses observed in the proposed threads C17 and C20

	Values of von Mieses reduced stresses for the thread		Stress reduction [%]
	Thread B17 [MPa]	Thread C17 [MPa]	
Thread surface	1386	992	28.4
Thread runout	1415	1382	2.3
	Values of von Mieses reduced stresses for the thread		Stress reduction [%]
	Thread B20 [MPa]	Thread C20 [MPa]	
Thread surface	698	684	2.0
Thread runout	1035	1007	2.7

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