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Quality of Short-Link Chains as an Element of Innovation in Mining Industry

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Abstract

In the context of innovation in craning equipment, chains play a key role not only as working elements but also as factors influencing the safety and efficiency of production processes. High-quality raw materials and the selection of a qualified supplier are fundamental to increasing innovation in this field.
From an occupational safety perspective, the chain quality used in lifting equipment is crucial. A particularly important operating element in hoists and chain pullers is the chain with short links, which largely determines the safety of the crane employees. The article discusses the basic elements affecting the quality and safety of the chain, pointing out that users of these products should be guided primarily by the certificates and approvals provided by the manufacturers and not just by price when choosing a supplier. Investing in the appropriate materials and technology allows for innovations that can significantly increase operational efficiency and ensure a high level of safety. The use of chains that meet stringent quality standards translates not only into a lower risk of failure but also into longer equipment life, resulting in lower operating costs. Changing the approach to selecting suppliers and raw materials can, therefore, be a crucial step in management innovation.

Keywords

innovation, chain, hoist/ winch, quality, mining industry

Introduction

Coal mining is an industry belonging to the traditional industry sector, whose peak development period in Poland occurred during the centrally controlled economy. However, hard coal remains an important energy resource in many of the world's developing economies, such as China and India. The World Energy Agency estimates that 7 billion tonnes of coal and lignite will be needed for electricity generation in 2030. However, the European Union has a different view of the role of hard coal in the energy sector, ordering Poland to limit electricity production based on this particular raw material (Bołoz, 2021; Tkocz and Heder, 2012). In the context of these figures, the question arises as to what measures the mining ministry is taking to meet these tasks, to become an innovative (i.e. efficient) industry, safe for employees and the environment while still ensuring energy security in Poland (Midor, Biały, Ruzbarsky, 2018; Bartos, 2007).

Modern Europe, in particular the EU, has been focusing for many years on smart development consisting of investing in an economy based on knowledge and innovation, which forms the basis of technological progress and covers the social, economic, political, spiritual, health, consumption and knowledge spheres. Innovative activities should lead to the modernisation of industry both in the manufacturing phase, through increasingly efficient production aiming at minimising production costs, increasing the quality of the final product, and increasing the company's income, but also in the organisational sphere, occupational safety, and in protecting and shaping the environment (Midor and Biały, 2018).

In Poland, the need for innovative action should also be directed at companies in the mining industry, as hard coal mining is still a strategic branch of the Polish industry. In terms of coal mining, Poland ranks 10th in the world rankings and 1st in the European Union. For Poland, coal guarantees energy security, which is currently the primary source of electricity generation (Midor, Biały, and Ruzbarsky, 2018; Midor and Michalski, 2015).

On 6 July 2023, the European Commission published the European Innovation Ranking 2022. It provides a comparative analysis of research and innovation indicators in EU Member States, other European countries and immediate neighbouring countries. Based on these results, European countries were divided into four groups (Kuric et al., 2021): Innovation Leaders, Strong Innovators, Moderate Innovators and Emerging Innovators (Paolicelli, 2023). The innovation ranking was based on 32 indicators grouped into 12 dimensions, such as attractive research systems, investment by companies in research and development and the use of information technology.

According to this ranking, Denmark is the new top innovator with the best performance in the EU, overtaking Sweden after several years of leadership. Other innovation leaders include Sweden, Finland, the Netherlands and Belgium. Austria, Germany, Luxembourg, Ireland, Cyprus and France are strong innovators, performing above the EU average. Estonia, Slovenia, the Czech Republic, Italy, Spain, Malta, Portugal, Lithuania, Greece and Hungary are moderate innovators. Croatia, Slovakia, Poland, Latvia, Bulgaria, and Romania are emerging innovators.

The figure (Figure 1) presents the innovation performance of the EU Member States in 2022. The figure shows the country symbols on the abscissa axis and the innovation index on the ordinate axis.

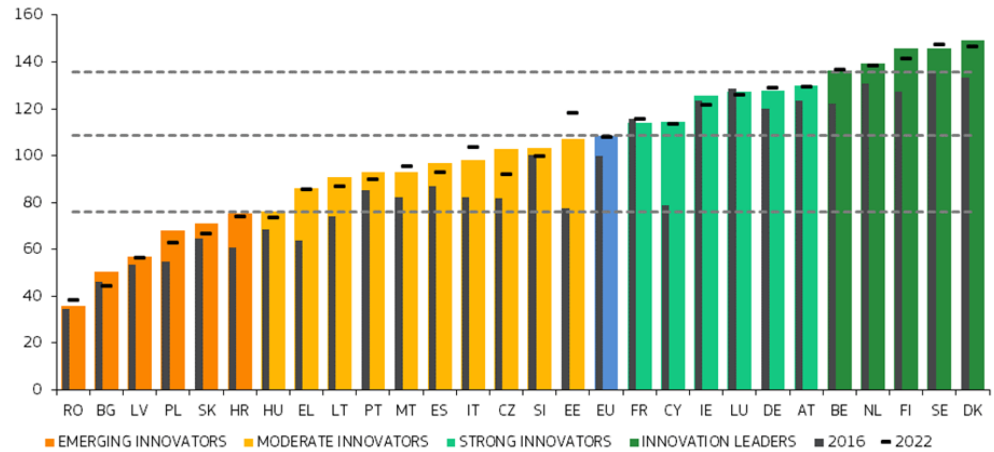

Fig. 1. Performance of EU Member States' innovation systems. Source: (Paolicelli, 2023)

Poland is an Emerging Innovator with a performance of 62.8% of the EU average. The performance of the Polish innovation economy is above the average of Emerging Innovators. Phenomena favouring innovation in Poland are project-based applications, ICT training companies, 'work-to-work' mobility HRST, trademark applications, or the population with higher education. On the other hand, the elements of the Polish economy that hamper innovation are the number of PhD graduates, PCT patent applications, environment-related technologies, business process innovators and the amount of innovation expenditures per employee.

In the Polish industry, the highest share of innovative enterprises is observed in the electricity, gas and water generation and supply industry (26%), and the lowest is in the mining and quarrying industry (18%). This industry stands apart from the others and recorded the lowest percentage of innovative companies in all groups classified by size. The industry suffers from a shortage of resources and long-standing underinvestment not only in new technologies but also in replicating production capacity - as a result, the share of innovative companies in their population is the lowest (Midor, 2015; Taraniuk et al., 2024; Midor, Klimecka-Tatar and Chybowski, 2017).

Innovations implemented in coal mining under market economy conditions can be divided into four groups (Pomykalski, 2001; Tkocz and Heder, 2012; Midor and Biały, 2018):

1. Innovation in the sphere of management, i.e., the implementation of new ways of organising and managing production and service activities, as well as occupational safety.
2. Product innovation, i.e. bringing a product with better properties and higher quality to the market.
3. Process innovation, i.e. the adoption of new or significantly improved methods of production or product delivery.
4. Technological innovation significant technological changes to production processes.

Innovation is not always associated with revolutionary technologies or complex solutions. It can also manifest itself in simple but significant steps to improve the safety of the work and the quality of the components used (Sánchez and Hartlieb, 2020; Stubrin, 2017; Aznar-Sánchez et al., 2019; Kovanič et al., 2021; Urban et al., 2024).

Products such as technical chains are indispensable in many industrial and economic sectors and are designed to carry heavier loads. They are used primarily as transport chains, with the basic division including models with short and long links. Short link chains are used in a number of mechanical equipment applications, mainly as drive chains, working with socket wheels and auxiliary slings in tractors in underground mine workings, in coal dust and methane explosive atmospheres. Long-link chains are general-purpose chains and have particular applications in the mining industry (Piątkiewicz and Sobolski, 1977; Kalita, 2013).

The article will focus on short-link chains, which are primarily used in cranes.

Cranes as devices using short-link chains

Cranes are a group of lifting and transport devices used to move loads, animals and people vertically or horizontally over short distances in intermittent traffic. In the classic literature (Piątkiewicz and Sobolski, 1977; Kalita, 2013), we distinguish pulleys, drawbars, trolleys, lifts, gantries, and cranes in the division of cranes. Due to the issues addressed in the article, the author is interested in pulleys, which are divided into devices such as winches and hoists, among others. These two devices - hoists and winches - are adapted to lift a load vertically by means of a rope or chain using a gripping element, usually a hook. The difference between the two is in the attachment of the supporting structure. Depending on how they are constructed, the aforementioned devices can be used in different spaces such as industry, construction, automotive or forestry (Cebula and Kalita, 2014; Midor, Biały and Ruzbarsky, 2018, ; Kovanič et al., 2024).

By type of drive, hoists can be divided into manual, electric and pneumatic. On the other hand, the division, according to the type of tie rod used, divides these devices into chain or rope ones. Examples of such hoists are presented in Figure 2.

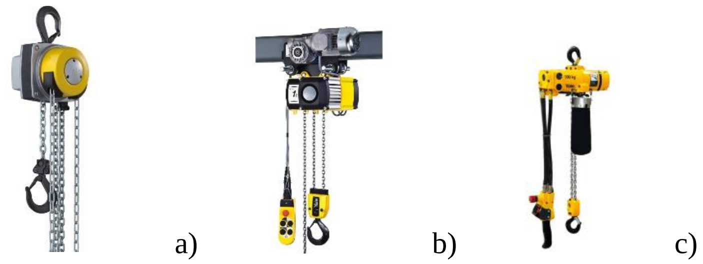

Fig. 2. Examples of hoist types: a) manual chain hoist model Yale lift 360, b) chain hoist model CPV with electric drive, c) chain hoist with pneumatic drive Model CPA 1-13. Source: (Midor, Biały and Ruzbarsky, 2018)

For lifting loads, it is necessary to select the right chain for the hoist/chain winch, depending on the design of the hoist/chain winch, the weight of the load and the environment in which it is used. Depending on the method of driving the hoist/winch, the PN-EN 818-7 standard distinguishes chains of type (PN-EN 818-7:2002+A1:2008):

T — Chain used in manually operated hoists/ winches or low-speed motorised hoists that do not operate in abrasive conditions. The safety factor of the chain should have a ratio of 4: 2.5: x (breaking load/test load/load capacity in accordance with ISO 4301-1 drives). The chain should be calibrated and tested. Temperature limits -40 °C to 200 °C

DAT	Chain for use on motorised hoists/ winches that reach high speeds, in combination with high workloads, where abrasion resistance is required, associated with increased chain life. The safety factor should have a ratio of 4: 2.5: x (breaking force/test force/load capacity in accordance with ISO 4301-1 drives). The chain should be calibrated and tested. Temperature limits of -20°C to 200°C.
DT	Chain used on motorised hoists/ winches in abrasive working conditions. The safety factor should be characterised by a ratio of 4: 2.5: x (breaking load/test force/load capacity in accordance with ISO 4301-1 drives). The chain should be calibrated and tested. Temperature range -10°C to 200°C.

Short link chains for lifting loads can be used in a wide range of industrial and economic sectors, including but not limited to underground mine workings, coal dust and methane explosive atmospheres.

Requirements for short-link chains

Among other things, chain hoists are used in the mining industry for materials handling, enabling the assembly of machine and equipment components and the movement of materials. Due to the difficult operating conditions in limited spaces of excavations and assembly chambers, lifting devices intended for the mining industry, in addition to appropriate lifting capacity, must be characterised by high lifting speed, low unladen weight, small dimensions and work safety (PN-G-46732:1997; Midor and Biały, 2018).

An important operational element in these machines is the chain, which is largely responsible for the safety of the workers operating the crane. To be safe for the user, the chain must meet a number of technical requirements contained in standards such as:

- PN-G-46732 Mining chain hoists - Calibrated short link chains,
- EN 818-7:2002+A1:2008 Short link chains for lifting loads - Safety - Part 7 - Fine tolerance hoist chain - Grade T (Types T, DAT and DT),
- Safety requirements taking into account the provisions of the Act of 9 June 2011. "Geological and mining law" (J. of Laws of 2017 pos. 2126, as amended),
- Regulation of the Minister of Economy of 28 June 2002 on occupational health and safety, traffic management and specialised fire protection in underground mines (J. of Laws of 2002; No. 139, item. 1169),
- Act of 12 December 2003 on general product safety (J. of Laws of 31 December 2003),
- EN 10025 Hot-rolled products of structural steels,
- EN ISO 643 Steel - Micrographic determination of grain size,
- EN ISO 6507-1 Metals - Measurement of hardness using the Vickers method - Part 1: Test method,
- Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC

In addition, each manufacturer ensures that its factory technical conditions for the produced chain are met.

The basic concept characterising a chain is the so-called chain size. This quantity is defined as the product of the rod diameter " d" from which the link is made and the largest internal dimension "p" called the pitch of the link or chain. In addition, the link is further characterised by the quantities: "a" - internal length measured at the link lumen, "b" - external width of the link and "L11p" - internal length of the chain with 11 links (Midor, Biały and Ruzbarsky, 2018). These link dimensions are presented in Figure 3.

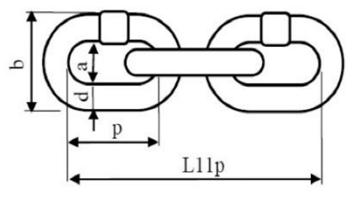

Fig. 3. Link/chain dimensions. Source: (Midor, Biały and Ruzbarsky, 2018)

Standard chain sizes are shown in Table 1. In addition to standard sizes, customised chains can be produced to meet special customer requirements (Midor, Biały and Ruzbarsky, 2018).

Tab. 1. Standard chain sizes

Chain size *d x p*	*d*		*p*	*a* not less than	*b* not more than	Weight 1 m of chain	Nominal length *L = 11 x p*	Tolerance	Max. weld diameter
	[mm]					kg. approx.	[mm]		
4 x 12	4	+/-0.2	12	4.8	13.6	0.35	132	0.6	4.3
5 x 15	5	+/-0.2	15	6.0	17.0	0.54	165	0.8	5.4
6 x 18	6	+/-0.2	18	7.2	20.4	0.8	198	1.0	6.5
7 x 21	7	+/-0.3	21	8.4	23.8	1.1	231	1.1	7.6
8 x 24	8	+/-0.4	24	9.6	27.2	1.4	264	1.3	8.6
9 x 27	9	+/-0.4	27	10.8	30.6	1.8	297	1.4	9.7
10 x 30	10	+/-0.4	30	12.0	34.0	2.2	330	1.6	10.8
11 x 31	11	+/-0.4	31	13.2	37.4	2.7	363	1.7	11.9
12 x 36	12	+/-0.5	36	14.4	47.6	3.1	396	1.9	13.0
13 x 39	13	+/-0.5	39	15.6	44.2	3.7	429	2.1	14.0
14 x 42	14	+/-0.6	42	16.8	47.6	4.3	462	2.2	15.1
16 x 45	16	+/-0.6	45	19.2	54.4	5.6	528	2.5	17.3
18 x 54	18	+/-0.9	54	21.6	61.2	7.0	594	2.9	19.4
20 x 60	20	+/-1.0	60	24.0	68.0	8.7	660	3.2	21.6
22 x 66	22	+/-1.1	66	26.4	74.8	10.5	726	3.5	23.8

Welded chains for T class hoists and chain hoists (in T, DAT, DT design) must be characterised by high quality, excellent performance and long service life. To fulfil this, they must be made with the greatest care so as to ensure safety during their use.

Among other things, parameters that determine the quality and safety of chains are mechanical properties and loads (Barnik et al., 2019). For the production of chains intended for winches/ hoists, steel with mechanical properties in accordance with PN-EN 10025 (PN-EN 10025:2002) is used so that the final product meets all the requirements defined by stringent European standards in accordance with PN-EN 818-7 and PN-G-46732.

The European standard EN8-18-7 +A1:2008, which is also applicable in Poland, sets out clear requirements for the type of steel to be used, the process by which the steel should be produced and its chemical composition. Tables 2 and 3 present the requirements for the elemental content of steel.

Tab. 2. Chemical composition of steel for crane chains - alloying elements

Element	Minimum mass fraction in % determined by melting analysis		
	Type T	DAT type	DT type
Nickel (Ni)	0.40	0.7	0,9*
Chromium (Cr)	0.40	0.40	0.4
Molybdenum (Mo)	0.15	0.15	0.15

*Increased surface hardness and/or greater depth of hardening require higher nickel content to avoid brittleness.

In order to protect the chain from ageing during its service life, the steel should contain at least 0.025% aluminium (Al.).

Tab. 3. Sulphur and phosphorus content of crane chain steels

Element	The largest mass share in % specified in	
	smelting analysis	Control analysis
Sulphur (Si)	0.020	0.025
Phosphorus (P)	0.020	0.025
Total sulphur and phosphorus	0.035	0.045

The above standards also require the manufacturer to subject the chain to a calibration process. Also, an important element influencing the safety of the chain's use is the quality of its workmanship, with particular regard to deviations from the dimensions included in Table 2. In addition, the EN 818-7 standard requires the manufacturer to use a complex product quality testing programme to ensure safety during chain operation. Particular emphasis is placed on the use of suitable grades of steel as the material of choice for the T-class short-chain components. Each delivery to the customer must be marked with the manufacturer's mark, chain thickness, production batch number, chain length and number of pieces in the batch. The ends of the chain are marked every 1 metre with a mark containing the manufacturer's mark, the year of manufacture, the number indicating the month of manufacture and the chain grade (T, DAT or DT- for standard 818-7); 5,6 or 8 for standard PN-G-46732.

Requirements for suppliers

The requirements to be met by the supplier when supplying the product to the customer are contained in the standard PN-EN ISO/IEC 17050, specifying that the supplier should provide a declaration of conformity together with the product (PPUH "Anima" Krzysztof Śleziak). The provided Declaration of Conformity contains information such as the name of the supplier, the name of the product, assurances of the product's conformity with the requirements of legal acts and standards such as the Geological and Mining Law and standards PN-EN 818-7 and PN-G-46732, an extract from the technical specifications, certificates, instructions for use, test reports supplied with the product and a declaration of assumption of responsibility for the quality and safety of the offered product.

With each chain delivery, the purchaser receives an inspection certificate, which contains data on the manufacturer, product identification data, data on quantities, dimensions and test results.

Summary

The development of mechanisation systems in various industries, including mining, requires the use of auxiliary equipment to support assembly, service or transport work and fault detection (Cheng et al., 2023). The movement of increasing masses requires equipment with ever-increasing technical performance. One such piece of equipment belonging to the so-called 'small mechanisation' are winches and chain hoists (Cebula and Kalita 2014). In addition to the technical and design parameters of these devices, the chain by which the goods are moved influences the operation and safety.

Short-link chains play a key role in ensuring safety and efficiency in crane operations. Their design allows for precise load transfer, which is extremely important in the context of working in harsh environments such as underground mine workings or other places with the risk of explosion. Using short-link chains of the right quality can minimise the risk of damage to mechanisms and increase the stability of transported loads.

In terms of innovation, manufacturers strive to continually improve materials and chain manufacturing processes, which translates into performance and service life. Modern technologies, such as heat treatment and the use of materials with improved wear resistance, allow products that better meet industrial requirements (Sganzerla, Seixas and Conti, 2016; Bołoz and Midor, 2018).

The considerations presented in the article show that innovation in a company is not limited to innovative products or technologies but can also include other aspects of the business, such as management processes, supplier selection, purchasing strategy or newly developed system (Hu et al., 2022). Choosing the right supplier is crucial, as it affects product quality, operational efficiency and work safety.

The article only indicates the basic elements and determinants that affect the quality of the chain. From this analysis, it is clear that when choosing chains, attention should be paid to the mechanical properties of the chain material and the quality of the workmanship. Confirmation of the material quality and the chain's workmanship is provided by the manufacturer's certificate, which is supplied with the product.

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