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Tribological studies of monolithic drawing dies for the production of reinforcing wires used in construction

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Abstract: Cold drawn products are widely used in the construction industry. Drawn products are obtained by a drawing process in which the most important tool is the drawing tool. Drawn products include wire, bar and pipe. The material used in this study was a drawing die mesh made of sintered carbide, grade H10S. The abrasive wear analysis of prepared samples was carried out using the ball on disc method with a ZrO_2 ceramic ball. Hardness measurements were carried out using the Vickers method in accordance with the PN-EN 23878:1996 standard. The resistance to brittle fracture was determined based on the length of the measurement of cracks formed at the corners of the impression.

Keywords: rebar wires, drawing dies, abrasive wear

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Introduction

There are mainly two types of steel used in construction. Reinforcing steel is used to make reinforced concrete elements and structural steel is used to build load-bearing structures for floors, roofs and columns. The reinforcement works with the concrete to transfer internal forces that occur during operation of the structure. Since concrete is a material with high compressive strength and low tensile

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strength, the main task of reinforcement is usually to transfer tensile forces (Zapolski, 2021).

Reinforcing steel is produced as straight reinforcing bars or wire supplied in coils. Steel grades A-0 and A-I produce smooth round bars and wire, used mainly as auxiliary elements of reinforcement, such as stirrups and lacings (Zapolski, 2021). Class A-III ribbed bars of 34GS grade steel with a diameter of 8-20 mm are primarily used for the main reinforcement. Classes A-III and A-IIIN produce circular double ribbed bars have two longitudinal ribs and transverse ribs situated in a herringbone pattern (Piekarczyk, 2021). Bars 20G2Y of steel grade A-IIIN, in order to distinguish them from bars 34GS of grade A-III, have longitudinal ribs rolled on both sides of the length equal to three intervals of the transverse ribs. On the construction site, the connection of bars to stirrups and each other is made using soft tie wire by creating cross knots at the connections (Piekarczyk, 2021).

The wire properties can be shaped to a large extent by drawing processes using different grades of steel and non-ferrous metals and alloys. Depending on the type of wire and the required properties, the material is subjected to suitable thermal treatments before the drawing process e.g. softening annealing, quenching and tempering, supersaturation (Knap et al., 2004). In addition, it is possible to apply complex drawing technologies, e.g. modification of drawing dies, administration of lubricating mediums, thanks to which the phenomenon of material hardening is minimised, allowing the application of many successive drawing operations without the need for intermediate annealing to soften the material (Knap et al., 2004).

The drawing industry places very high demands on forming tools. The drawing process and product quality depend to a large extent on the quality of the tool. The material for drawing dies should be characterised by high abrasion resistance, good water resistance, thermal fatigue resistance, ease of polishing, corrosion resistance and low susceptibility to bonding with the drawing material (Knap et al., 2004).

Drawing dies are manufactured using powder metallurgy. Sintered components open up new possibilities for creative and cost-effective design solutions. The production of structural parts from powders has proven to be in many cases more competitive than other manufacturing technologies, especially for parts with complex geometric shapes. The manufacturing process involves densification of the powder material and a subsequent sintering process (Dembiczak et al., 2021; Náprstková et al., 2017; Náprstková et al., 2018; Wachowicz et al., 2021).

In industrial practice, sintered carbide drawing dies are still a common tool material. Sintered carbides are characterised by high hardness, high resistance to abrasive wear, good thermal and electrical conductivity and thermal stability at elevated temperatures (Nowacki, 2004). Cobalt, most often used as a matrix, is characterised by very good wettability with carbides, very good thermal conductivity and has a high melting point of 1494°C. Carbides are hard and wear-resistant materials, although not as hard as superhard materials and ceramics, and they have quite good strength properties, although not as good as those of high-speed steels. They therefore represent an intermediate material between two groups of materials with extreme properties (Cichosz, 2006). Carbides are obtained by powder metallurgy through free sintering (Arato et al., 1998), hot pressing (HP) (Jia, 2007), isostatic hot pressing (HIP) (Wei, 2010), microwave sintering (Bao, 2012), high-frequency induction sintering (Bao, 2013) or spark-plasma sintering (SPS) (Kim & Oh, 2004; Kim et al., 2004).

Preliminary research is also being carried out to develop $W_xTM_{1-x}B_y$ type multicomponent coatings, i.e. WB_4 ceramic coatings doped with transition metals, in the working part of the tractor.

Another material solution proposed for drawing dies are ceramic composites doped with Si_3N_4 particles. The mechanical properties of ceramic tool materials are strongly dependent on the microstructure development during the sintering process, and in order to obtain very good mechanical properties, a uniform pore-free microstructure is required.

1. Materials and methods

The test material was a sintered carbide drawing die for drawing round wires of ϕ4 mm final cross-section, as such wires of ϕ4 mm diameter are used in the construction industry: from nets and reinforcement materials, screeds to reinforcement of floors, walls, ceilings, and highways. Thanks to their constructional characteristics, they increase the strength of the substrate and the structure, while preventing shrinkage (Blikharskyy & Selejdak, 2021). Steel wire mats with a diameter of ϕ4 mm also protect under-floor heating.

The main tool for shaping this small diameter wire in the drawing process is a drawing die. The drawing tool construction consists of a tungsten carbide mesh with dimensions ϕ25×20 mm set in a steel frame with dimensions ϕ53×35 mm. The draw string was purchased from a Polish manufacturer. Figure 1 shows a cross-section of a classic eye-puller with a conical shape of the working zone.

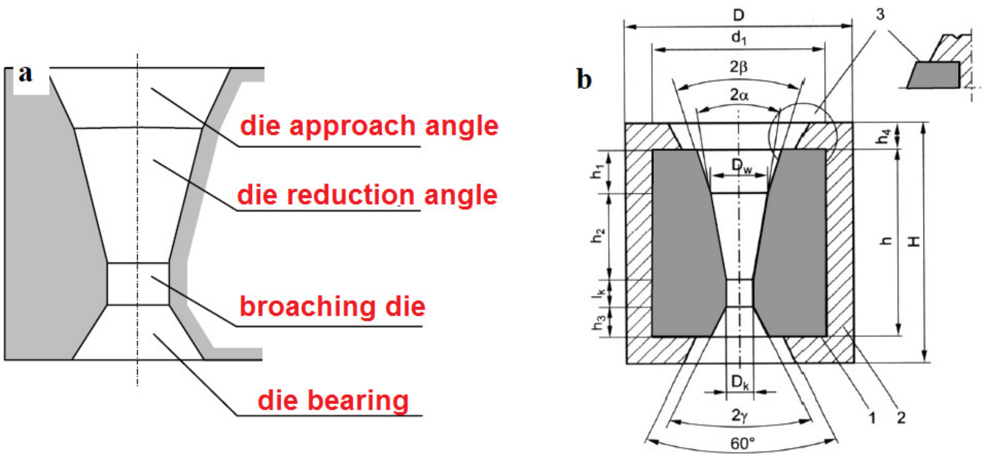

Fig. 1. Profile of the ring drawing die with zoning (a), and cross-section of the conical ring drawing die (b): 1 – drawbar eye, 2 – steel frame, 3 – eyelet protection against pulling out (Łuksza, 2006)

The chemical composition of the cemented carbide mesh was analysed using a TESCAN scanning electron microscope with an EDS analyser from OXFORD Instruments. Figure 2 shows the scanning microscope used in this study.

Fig. 2. Scanning microscope used in the study (*own source*)

The study comprised a Vickers hardness measurement carried out in accordance with PN-EN ISO 6507-1:2018-05 (Metale – Pomiar twardości sposobem Vickersa – Część 1: Metoda badania) using a Future Tech FM-700 hardness tester with a load of 294.2 N and a measurement time of 10 s. In order to estimate the average hardness measurement, 5 measurements were made. In addition, the resistance to brittle fracture was determined from the empirical relation (1). Figure 3 shows the hardness tester used to measure the hardness of the prepared samples.

$$K_{Ic} = 0.15\sqrt{\frac{HV}{\sum l}} \qquad (1)$$

where:
HV – Vickers hardness,
$\sum l$ – sum of length of cracks formed at the corners of the imprint.

Fig. 3. Hardness tester used in the study (*own source*)

Tribological wear tests were conducted using the ball-on-disc method. A ceramic ball ϕ10 mm was used for the tests, and the tests were carried out with a pressing force of 10 N. The duration of one cycle was 5 minutes. After each cycle, the samples were degreased with ethyl alcohol in an ultrasonic cleaner for 5 minutes, then dried and weighed on a balance to five decimal places.

2. Results and discussion

Analysis of the chemical composition of the tested material grade provided information on the mass composition of the elements present in the tested material. Figure 4 presents the results of the chemical composition analysis along with EDS spectra.

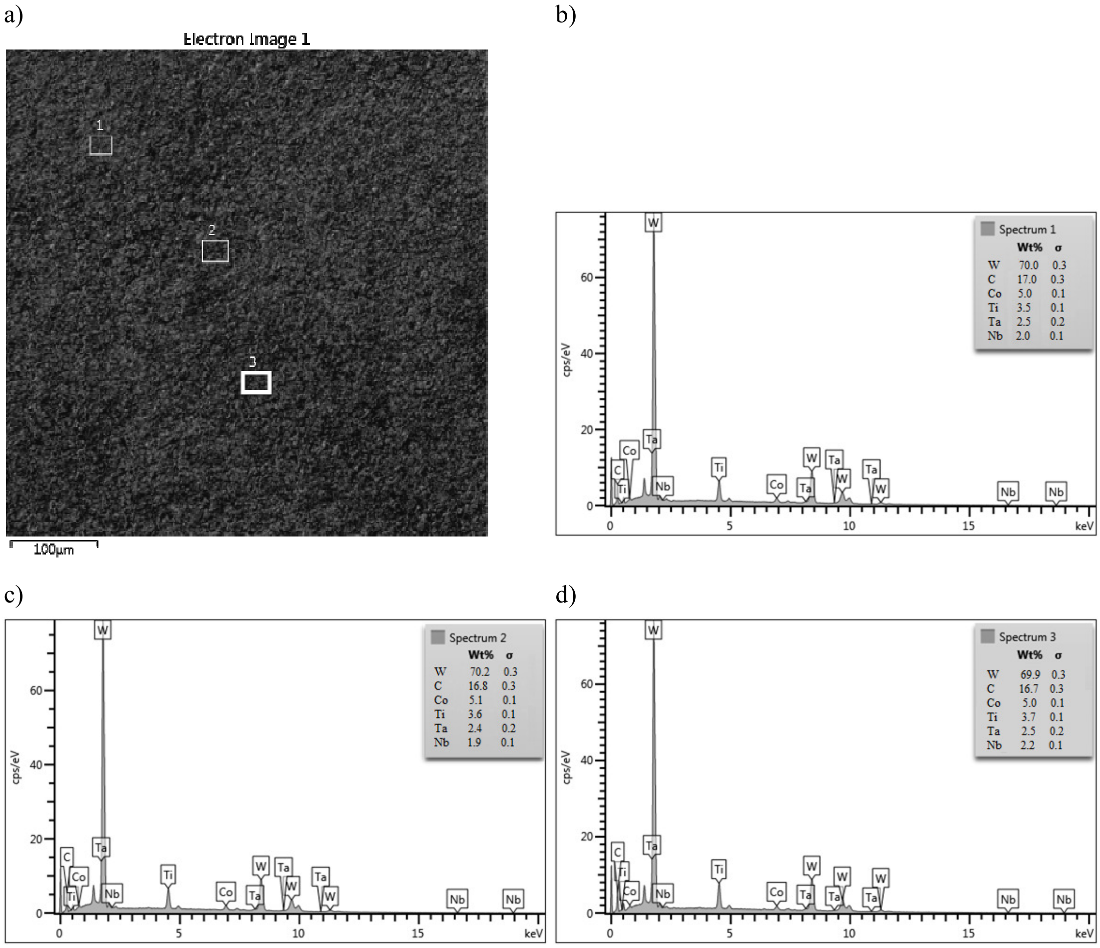

Fig. 4. Analysis of the chemical composition of the draw bar mesh used in this study (*own source*)

The EDS spectra showed the existence in the chemical composition of tungsten at 70 wt.%, carbon at 16.8 wt.%, cobalt at 5 wt.%, titanium at 3.6 wt.%, tantalum at 2.46 wt.% and niobium at 2 wt.%. The intensity of the peaks is not a quantitative measure of elemental concentration, although relatively the amount can be inferred from the height of the peaks. Table 1 shows the results of the chemical composition, hardness measurements and fracture toughness.

Table 1. Test results for WC-Co tungsten carbide drawing die insert (*own source*)

Chemical composition			Hardness	Resistance to brittle fracture
WC	Ti+TaC+NbC	Co	[HV30]	[MPa·m$^{1/2}$]
86.9	8.1	5.0	1780±10	9.47

On the basis of the scanning analysis (SEM), the chemical composition of the mesh of a drawing die of the U 10S grade produced by conventional sintering technology was revealed. The percentage content of the revealed pier-elements differs from the chemical composition given in the specification by the manufacturer, who showed only an approximate chemical composition. The average hardness of the drawing die mesh was 1780 HV30 while the average value of fracture toughness was 9.47 MPa · m$^{1/2}$. The measurements obtained in preliminary studies show very good results of drawing die mesh produced by conventional sintering technology in the light of the literature. It can be assumed that fine-grained powder particles were used in the sintering process, which did not grow to large sizes during the sintering time. The mass loss of tribological wear is shown in Figure 5.

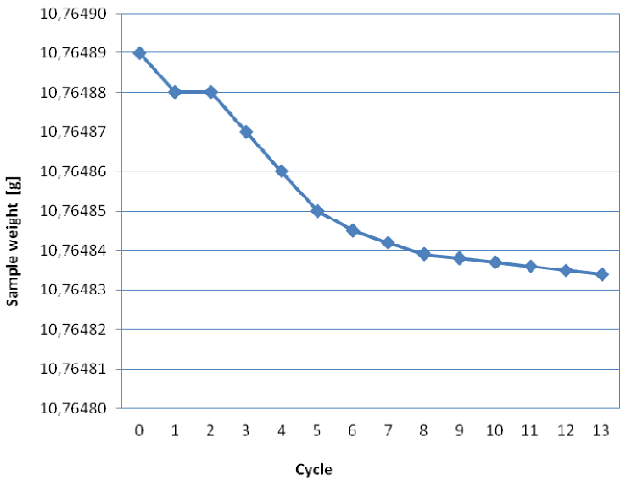

Fig. 5. Loss of mass during tribological tests after 13 cycles (*own source*)

No tribological wear was found on the basis of an analysis of tribological wear loss carried out for thirteen cycles; the wear value was within the measurement error range.

The recorded friction forces allowed the friction coefficient to be determined for the carbide drawing die mesh. Figure 6 shows the average friction coefficient.

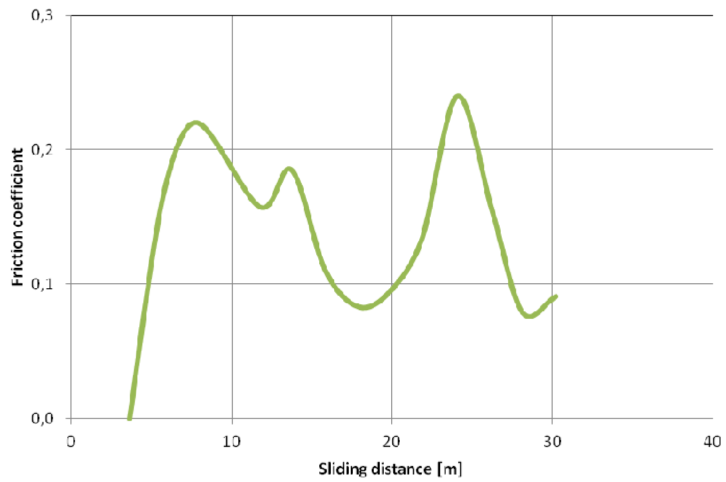

Fig. 6. Average coefficient of friction (*own source*)

The average coefficient of friction $\mu_{śr}$ of the tested sample at 22±1°C was unstable and varied in time in the range of 0.079-0.220.

Tests of the friction coefficient and the wear index have shown that the material studied has a favourable effect on tribological properties. A decrease in friction forces and thus a decrease in energy dissipated in frictional contact resulted in a decrease in the wear rate of the tested material. From a practical point of view, a lower friction coefficient leads to a decrease in the temperature of the working surface of the drawing tool, and thus to a slower rate of its wear.

In the construction industry, drawn bars are used which should be round along their entire length. However, the mesh of the drawing dies wears out over time and the drawn wires can take on a new oval cross-section, which is not desirable in the building industry because of the calculated design for round bars.

Conclusion

In the construction industry, drawn bars are used which should be round along their entire length. However, the mesh of the drawing dies wears out over time and the drawn wires can take on a new oval cross-section, which is not desirable in the building industry because of the calculated design for round bars.

It is only natural that drawbars wear over time and do not retain their cross sectional area over their entire length. Therefore, there is a lot of research on new composites for drawing dies, which will increase the life of drawing dies. The authors of this article are also carrying out preliminary research into the development of a new material for drawing tools.

On the basis of tribological tests carried out for a commercial tractor, it was concluded that thirteen test cycles are insufficient to accurately estimate the total tribological wear. It is expected that the number of cycles should be increased at least eight times. Carbides are characterised by a hardness close to diamond and high wear resistance.

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