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## ANALYSIS OF THE INFLUENCE OF LUBRICATION CONDITIONS ON TOOL WEAR USED IN HOT DIE FORGING PROCESSES

### ANALIZA WPŁYWU WARUNKÓW SMAROWANIA NA ZUŻYCIĘ NARZĘDZI W PROCESACH KUCIA MATRYCOWEGO NA GORĄCO

*The study discusses the subject of lubrication in the processes of hot die forging with the consideration of the durability of forging tools and instrumentation. It presents a literature research as well as the authors' own investigations of the effect of the use of cooling and lubrication agents, the amount of the dosage as well as the direction of its application, and also the factors influencing the tribological conditions. The lubrication devices and systems currently applied in the industry have been analyzed as well. On this basis, making use of their knowledge and experience, the authors have developed and constructed a lubricating device. The elaborated system, implemented into the industrial process, makes it possible to select and ensure the optimal tribological conditions of the process by way of controlling the amount and frequency of the applied lubricant dosage. It can constitute an alternative for the manual method of lubricant application, which is dependent on the human factor, or the fully automated, yet expensive, lubrication systems. The obtained test results point to potential possibilities of a permanent introduction of the constructed device also into other forging processes, through its integration with a manipulator. The proposed solution ensures more stability and higher repeatability of the lubrication conditions as well as increases the efficiency of the production process, thus significantly reducing the unit costs of the production of forgings.*

**Keywords:** hot die forging, lubricating system, wear, tribological conditions.

*Praca dotyczy problematyki smarowania w procesach kucia matrycowego na gorąco z uwzględnieniem trwałości narzędzi i oprzyrządowania kuźniczego. Przedstawiono badania literaturowe oraz własne autorów dotyczące wpływu zastosowania środków smarno-chłodzących, ilości dawki i kierunku jej podawania oraz innych czynników wpływających na warunki tribologiczne. Przeanalizowano także obecnie stosowane w przemyśle urządzenia i systemy smarowania. Na tej podstawie autorzy w oparciu o wiedzę i doświadczenie opracowali i zbudowali urządzenie smarujące. Opracowany system, zaimplementowany do przemysłowego procesu pozwala na dobór i zapewnienie optymalnych warunków tribologicznych w procesie poprzez sterowanie ilością i częstotliwością podawanej dawki środka smarnego. Może być ono alternatywą dla manualnej metody nanoszenia środka smarnego, zależnej od czynnika ludzkiego lub w pełni zautomatyzowanych, lecz drogich systemów smarowania. Uzyskane wyniki badań wskazują na potencjalne możliwości wprowadzenia na stałe do pracy zbudowanego urządzenia także do innych procesów kucia poprzez integrację z manipulatorem. Zaproponowane rozwiązanie zapewnia większą stabilność i powtarzalność warunków smarowania oraz pozytywnie wpływa na zwiększenie wydajności procesu wytwarzania, a tym samym znacząco obniża jednostkowe koszty produkcji odkuwek.*

**Słowa kluczowe:** kucie matrycowe na gorąco, system smarujący, zużycie, warunki tribologiczne.

#### 1. Introduction

During the processes of die forging performed at elevated and high temperatures, the tools are subjected to very large, periodical thermal loads from 80 oC to 600 oC, as well as to mechanical loads reaching above 1200 MPa [39]. The primary and most common destructive mechanisms are [13, 27]: abrasive wear [4], mechanical

cracking, plastic strain [23] as well as thermal [9, 36] and thermo-mechanical fatigue [7]. The progression of the loading exerted on the dies and punches is periodical in nature. It is a combination of thermal and mechanical loads arising from the contact with and deformation of the hot preform by the cold tool. A variable thermal load has a particular impact on the die's lifetime. It is the leading cause of fatigue crack formation and changes in the physical and mechanical proper-

ties of the tool's surface layer [3, 32]. At the same time, thermal load intensifies the abrasive wear caused by high mechanical loads, and this translates to a shorter operating life of forging tools and accessories [25, 26].

Lubrication is critical to the lifetime of forging tools. In the standard operating procedure during a semi-closed die forging process (upsetting, flattening, etc.), tool lubrication is not utilized as the flow of the material being deformed is uncomplicated. This is not the case in typical die forging, during which the use of a lubricating and cooling agent is required due to the need to minimize the friction for the purpose of precise filling of the tool's impression with the material. Above all, the application of lubricating and cooling agents reduces the friction between the forged material and the tool material, and insulates the tool's material (impression) against a direct contact with the hot forged material. This effectively reduces the die's surface temperature, thus reducing the intensity of the tempering, oxidation and erosion processes [13]. A flaw of the use of lubricating and cooling agents is the sudden cooling of the surface layer, which may accelerate the thermal fatigue process. In addition, the lubricant also reduces the friction coefficient after the forged metal is released from the die [1, 2, 4]. Not only the properties of the lubricant, but also the method and direction of the feed, size and frequency of the lubricant dosage, play a role in proper lubrication. It is also important to ensure a repeatable and uniform distribution of the lubricant. Currently, non-automated, and providing low repeatability, manually operated lubricating devices are still commonly used in many die forges. For this reason, the application of more or less automated lubricating and cooling devices and systems is currently being adopted more and more frequently, as they enable precise lubricant dosing [12, 18, 22]. The proper lubrication does not only determine whether a forging without defects, such as underfills, will be produced, but also has the benefit of reducing the tool wear [20]. As automation develops, automated lubricating devices and systems are created [5, 11, 17]. Such solutions are easy to use, and have been implemented successfully in German forges, leaders in the automation of production. In addition, owing to the application of manipulators, it has become possible to build a fully flexible system, making it possible to control all the significant lubrication parameters, such as the nozzle position, the time of application, the proportions of substances, etc. [10, 18]. Additionally, such systems are synchronized with the work of the forging unit, which, according to this method of lubricant feeding, eliminates the subjective factor of an experienced human operator [19]. However, this is linked to rather high costs of investment, which may not be balanced out if only the profit resulting from raising the product quality and the tool lifetime are considered.

This is why an intensive search is currently underway for new solutions concerning both lubricants dedicated for specific forging applications and modern automated lubricating devices ensuring optimal friction conditions, which, at elevated temperatures, are even more critical to hot and semi-hot industrial die forging processes. Further research and development work in this field is completely justified from both the scientific and financial perspective, as the problem of effective lubrication continues to be unsolved and poses a significant challenge to many research centers and industrial enterprises.

**The aim of the paper is to analyze the results of studies concerning the effect of the amount, frequency and application manner of the lubricating agent, as well as the use of a proprietary cooling and lubrication sys-**

**tem, on the durability of the forging instrumentation in hot die forging processes.**

## 2. Analysis of the state of the problem and research of factors influencing the operation of tools in die-forging processes

It should be emphasized that there is a lot of space devoted to the research and analysis of the properties of lubricants used in hot forging processes in the available literature [1, 11, 12, 21, 24, 35]. In addition, a continuous technological development has led to an increase, outside the research centers, in studies and industrial applications involving lubricants dedicated to specific processes on the very competitive lubricants market. The leading manufacturers of lubricants in the world include such companies as: Acheson, Fuchs, Henkel/Bechem, Houghton, Oelheld, etc., as well as Naftochem from Poland.

In addition to the undisputed role of lubricants, the important factors influencing the lubrication are the appropriate method of applying the lubricant technology as well as the lubricant dosage. Currently, the most popular method of lubrication is the use of a direct, manual spray lubricant performed by the blacksmith during the process. Its main flaw is a non-uniform distribution of the lubricant, which causes a non-uniform die temperature distribution and, in effect, a faster local wear of the tool. Only in the case of transfer presses, fully automated systems and lubricating devices are used, synchronized with the work of the whole aggregate.

In the vast majority of works in the subject literature, the most space is devoted to lubrication systems in cold forging processes [31], mainly for aluminum [33], or cold and warm processes [5, 6, 28], while there is definitely less focus on the case of systems and devices destined for warm and hot forging [29, 34, 37]. Even in the extensive review paper by Altan's [1], you can only find brief information about lubrication systems, which is more related to the selection of lubricants than lubricating devices. On the other hand, in the work [30], you can find information about the devices and systems equipped with the forging sets used in the Japanese forging industry, but also in the quoted work, there is no data on lubrication systems. Also interesting are the results of the European Research Project "Brite-Euram" [31] on the development of environmentally friendly systems for the lubrication of tools in the hot-forging of steel. For example, in the paper [2], in a study conducted by a German-Japanese team based on experiments during production, guidelines were developed, such as a

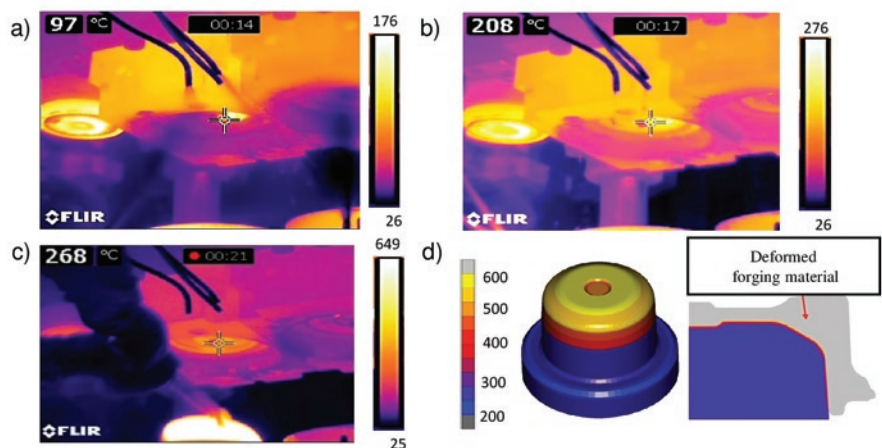


Fig. 1. Thermograms with temperature distributions on top punches used in the process of forging a disk: a) tool lubrication cycle – the temperature at the marked point is 97°C, b) 3 seconds after the end of lubrication – temperature increase by over 100°C, c) just after the forging process – about 1 second after deformation, d) temperature field on the analyzed punch at the time of forging (contact) determined by numerical modeling

scheme for the selection of the optimal lubrication systems to increase durability of the forging tools. In turn, the study [20] presents selected factors affecting the quality of lubrication and tool wear. The work [35] is also noteworthy, in which the authors presented the possibilities of modeling the direction and amount of lubricant dosage.

As shown in the introduction, the processes of hot forging is performed under extreme operating conditions, which means that they are among the most difficult manufacturing processes to carry out. The authors of the article have been conducting numerous studies of the impact of the tribological conditions on the exploitation of forging tools for many years now [15, 16]. For example, Fig. 1 presents the results of the research on the influence of the lubricant application on the temperature changes on the tool surface during the forging cycle.

As can be observed on the basis of the thermograms taken by a thermal imager (Fig. 1a-c), the temperature on the tool's surface at a selected point is approx. 100°C (Fig. 1a) over the course of only about 7 seconds of the forging process, at the time of the final lubrication phase, which lasts about 2-3s (Fig. 1a). After the next 3 seconds, the temperature rises rapidly up to the mean "working" temperature of the tool in the forging process (Fig. 1b). Just after the forging – deformation – over the next 4 seconds – the temperature of the tool increased by 60°C (Fig. 1c) as a result of the conversion of the strain work to heat.

Research employing numerical modeling was also conducted, showing that, at the time of the contact between the formed material and the punch, the temperature increases to over 500°C (Fig. 1d). Such dynamic temperature changes on the tools' working surfaces may significantly reduce their lifetime in the absence of properly selected lubrication parameters, due to excessive periodical overcooling or non-targeted feeding of the lubricant dose, which is unsynchronized with the work of the forging unit. It seems that even the most aptly selected lubricant will not have a significant impact on the temperature distributions.

Fig. 2a presents a standard manner of lubrication used in crank presses, which is a manual adjustment of the lubricating nozzles, according to the decision and experience of the operator.

The lack of sufficient control over the lubrication process and the inappropriate adjustment of the nozzles at the beginning of the process are the causes of a non-uniform wear (Fig. 2b and Fig. 2c), which, in turn, causes a more intensified damage, shortening the tool opera-

tion time, and in the case of a long operation, possibly affecting the shape of the forging.

Do not synchronize the exposure of the lubricant to the work of the forging press and/or forging transfer for subsequent tools (Fig. 3a). An inappropriately selected dose of the cooling and lubricating agent can be the cause of premature wear of the tools as a result of thermal shocks (Fig. 3b).

An incorrectly selected dose of the cooling lubricant may cause premature cracking of the tools and underfills of the tool's cavity. It is the reason for an increased pressure value caused by the occurrence of an air pocket in this place, accelerating the formation of micro-cracks and the so-called Rebinder effect (Fig. 3c). The solution to this problem can be elimination of the human factor through the introduction of a precise dosing system and sequencing of the lubricant.

The development of automation has led to the emergence of newer solutions, which enable a more precise and accurate application of the lubricating material. At present, several types of technical solutions for the application of lubricating coatings can be distinguished [24]. Due to a high efficiency and a short time of lubricant application, automated solutions are realized on the basis of direct spraying. The latter is performed through a system of nozzles, which spray the lubricant onto the die during the change of the charge material. The construction of the nozzle depends on the applied lubricant and parameters, such as the spraying pressure and the lubricant's viscosity. An advantage of such a lubricating method is the easiness of directing the lubricant stream and the creation of a thin insulating layer on the surface of the tool. In addition, automated systems usually have a lubricant preparation station or a mixture thereof to maintain a uniform composition throughout the volume. A prior preparation of the lubricant reduces the possibility of deposition of the particulate matter in the pipes and nozzles, which results in a longer time between the service work performed on these devices. In order to obtain a uniform spray coating, the nozzles are positioned in such a way so as to reflect the curvature of the tool. The disadvantage of using classic nozzles is their high cost, size and the problem with the use of large-sized hammer dies.

The sole idea of automating the process of lubrication does not solve the analyzed problem. An example of this can be an automated method of lubrication on a crank-type press equipped with a transfer of forgings, as is the case, for example, of the process of a constant velocity joint body forging. In this process, the tools are lubricated by a specially constructed ejector with nozzles. Six nozzles evenly spaced around the periphery, every 60°, supply grease when the forging is ejected, when the ejector is in the upper position. The effect of this is the interior of the die being covered with a layer of grease with varying intensity, depending on the proximity of the nozzle, as well as an uneven wear (due to adhesion) on the perimeter of the die (Figure 4a).

On the tool surface, one can observe a clear difference between the green and yellow areas (Fig. 4b) and the dark ones, reached by a smaller amount of the lubricating liquid. In the same process, in order to analyze the influence of the amount of the lubricant dosage on the changes in the temperature inside the tool (Fig. 5), the authors measured this parameter. A K-type thermocouple inserted into one of the dies was used for this purpose. The measurement showed that a two-fold increase in the amount of the lubricant causes a temperature drop at the surface of

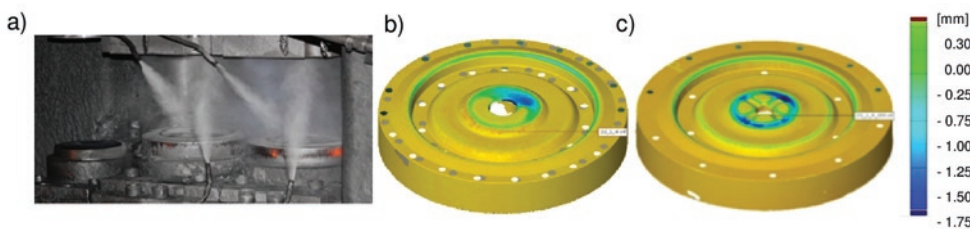


Fig. 2. a) Manual manner of lubricant supply; b) tool wear in the case of non-uniform lubrication and c) tool wear in the case of uniform lubrication



Fig. 3. Inappropriate lubrication: a) bad synchronization of the lubricating system with the forging process b) too intensive lubrication - no evaporation of the liquid from the lubricant mixture, c) crack in die inserts' corner – Rebinder effect



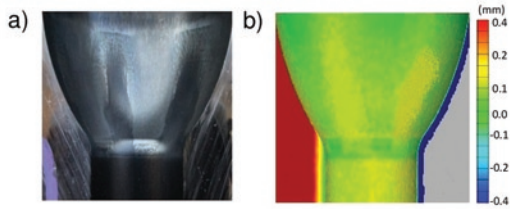


Fig. 4. Non-uniformly worn tool surface: a) digital image b) scanning results

the die of about 100 °C. In addition, when analyzing the entire course, it can be observed how important it is to optimize and control the lubrication process for the entire life of the tool and not just a single forging operation.

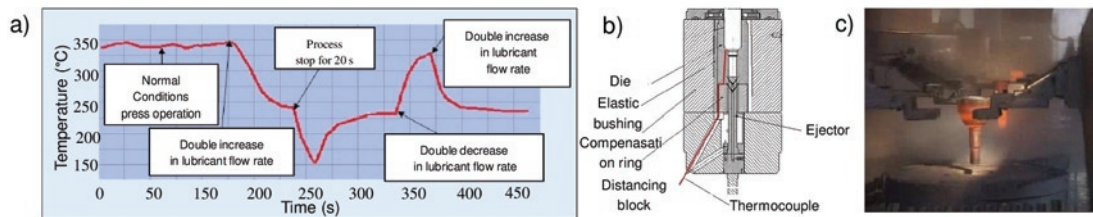


Fig. 5. a) A view of the die temperature change during forging with marked most frequently occurring process disturbances, b) the scheme of the thermocouple mounting into the tool, c) transfer of forgings on the transfer press

Similar studies regarding the temperature on the surface of forging tools during the forging cycle are presented in [8].

Currently, an increasingly common method of lubrication, especially in modern automated forging machines, is the use of manipulators' arms that accurately and repetitively insert the lubrication heads between the tools. These are high-performance systems that, because of their price and complexity, are more and more often used in cold forging [10]. The leading manufacturers of lubrication systems based on manipulators include: AED Automation, SMS Group, Renite, Spay. However, a currently used, yet much cheaper than the expensive manipulators, and at the same time a highly automated lubrication system designed for hot die forging is a device developed by Jerko Company (Fig. 6) [19]. This system has a special lubrication plate inserted between the upper and lower tools that applies a layer of grease. Such a solution will be used in Kuźnia Jawor (the Jawor Forge) as part of a research project.

In addition, the device enables a program selection of the nozzles to be active when feeding the lubricant, which further increases the flexibility of the system.

As shown above, despite the undeniable continuous technological development and the development of new technical solutions, the old, often unreliable and non-repetitive, lubrication devices are still used for most typical forging sets, which are additionally supported



Fig. 6. The view of: a) the panel of the lubrication system with a system of active (selected) nozzles by Jerko[19], b) lubrication plate with nozzles, c) manipulator with gripper inserting a preform, d) entry of lubrication plate and lubrication

by the operators, responsible for the lubrication quality in the forging process. On the basis of the presented research and the analysis of the literature, it can be noticed that the key issue in the case of lubrication is primarily the method and direction of administration, as well as the amount (volume) and time of the lubricant-cooling agent dosage. These factors are of decisive importance, and if they are not properly selected, they significantly reduce the lifetime of the tools and may even cause premature damage to the tooling. This is also reflected in the reduced quality and accuracy of the dimensions and shapes of the forgings. The analysis makes it possible to conclude that the greatest influence on the wear of forging tools, omitting the aspect of the choice of the lubricant, is exerted by the precise setting of the volume of and the frequency of exposure to the lubricant-cooling dose. Some-

what less relevant is the direction of the lubricant feed to the surface of the dies. The optimal direction of spraying is the direction normal to the surface of the tool. However, due to the complicated tool shapes, it is in most cases impossible to implement. With an increasing complexity of the dosing system, i.e. extension of the spray head or automation system, the

cost of the lubrication system increases significantly. The currently existing commercial solutions have been built based on the knowledge and experience of the companies creating these systems for selected industrial applications. In the literature, there is no information about the design and selection criteria for the proper lubrication system, especially for forging processes at elevated temperatures.

### 3. The concept of the proprietary lubrication system

In response to the presented state of knowledge, research results and demand, the authors have built, on the basis of their experience, a prototype lubrication and cooling system dedicated to the forging processes of yoke type forgings. The built-in dosing and distributing system is the first stage in the construction of a comprehensive, flexible lubrication system. In the next stage, it will be expanded by a manipulator and a nozzle system. This will enable further testing and determine the optimal method of proper spraying of the lubricant (Fig. 7). This is another solution of this type developed by the authors [15]. In the previously used lubricating apparatus in the process of forging a fork (yoke), the operator, by means of a "subjective" valve, regulated the dose of the lubricant and its exposure time through a lubricating nozzle. This resulted in a lack of lubrication stability, as well as a variability of the tribological conditions in the forging process. In comparison

to the previous versions, the currently installed lubrication system has been partially modernized, and standardized components have been used, which enables easy servicing of the device in the industrial operation process as well as an easy access to the commonly available parts, which significantly reduces the cost of the device. The device has been made and tested on the production line at Kuźnia Jawor, which is the main recipi-

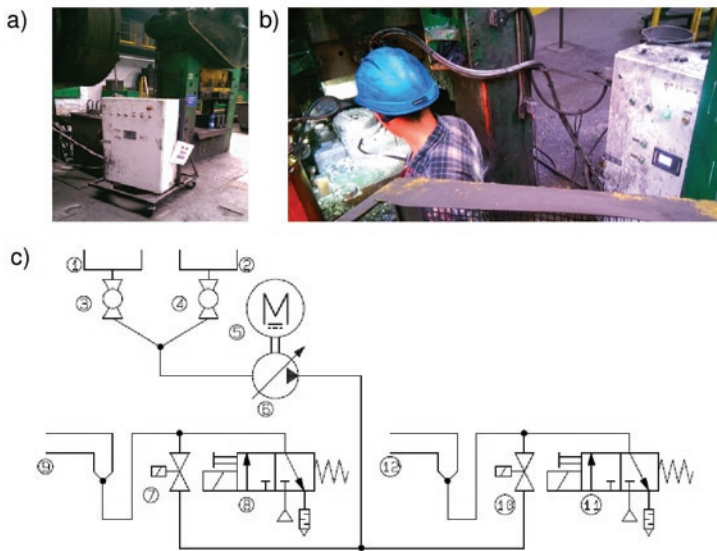


Fig. 7. a) A picture of the dosing and lubricating device allowing for adjusting the volume of the lubricant, b) the view of the connected and working device during the industrial forging process, c) diagram of the pneumatic system

ent of the system. The conducted tests made it possible to confirm the high efficiency of the hot forging process and allowed to improve it, which translates to high quality and lowered production costs. In the present solution, a particular attention was paid to the device's operating cycle (turn of sequences), as well as the number of doses and the direction of the lubricant application.

The described solution enables precise and repeatable metering of the dose to be dispensed, with the simultaneous possibility of varying the proportions for the subsequent nozzles, as well as the possibility of freely setting the sequence of the air blow and the application of the lubricant. For this purpose, a peristaltic pump (6) with a stepper motor (5) is used in the device shown in the diagram (Fig. 7c), which enables precise metering of the dispensed lubricant liquid (1).

The distribution of the dosed liquid to the upper (9) and lower (12) nozzles is carried out via two diaphragm valves (7 and 10) controlled pneumatically (8 and 11). After the quantity (volume) of the liquid is measured, the latter is distributed to each nozzle, i.e. the upper and lower nozzles. The developed solution makes it possible to push the lubricant to a special blow-out nozzle, developed by the authors, through flexible conduits using compressed air. The compressed air is additionally used to spraying the liquid, it is the blowing air. The order of feeding the lubricant-cooling medium, as well as the time of push

and blow, are set by the operator using a simple HMI panel. A properly selected ejection time and amount of lubricant favor a proper spraying of the fluid, inhibiting the processes of graphite accumulation in the bends of the dies and the water remaining on their surface.

Fig. 8a shows a diagram of the device's operation and an exemplary work cycle diagram of the device. The regulation of the liquid phase content in the lubricant-cooling mixture consists in changing the operating time of the dosing pump. The device has an additional tank with clean water (designated as no. 2 in Fig. 7c) for cleaning, thus maintaining constant lubrication parameters. The choice between the container with the lubricating liquid and the one with the clean water is carried out with the use of ball valves (marked as no. 3 and 4 in Fig. 7c). The system is also equipped with an anti-sedimentation stirrer, which makes it possible to maintain the homogeneity of the graphite suspension in the water. The preliminary studies have shown a highly satisfactory operation of the device under industrial conditions. The next stage of development of the elaborated devices for the delivery of the lubricating-cooling agent will be the integration of the manipulator (Fig. 8b).

#### 4. Comparison and analysis of the results of scanning performed on the applied forging tools by the newly developed and previously used lubrication system

Fig. 9 presents exemplary collective results obtained from the scanning of lower die inserts used in the preliminary forging of producing forgings type yoke with various numbers of forgings and under different tribological conditions (as a result of changing the lubrication system).

Before scanning, the inserts were cleaned of residual grease and scale. Next, the scanned digital images were processed to form a cloud of points and converted into a triangular mesh and then referred to the CAD model. The presented exemplary comparative results of the die insert scans (Fig. 9) transformed into a digital image indicate that, when the new lubricating-cooling device was used, enabling precise settings of the lubricant dose, a reduction in the tool wear was observed. The preliminary tests have shown that the use of 10ml of lubricant (a mixture of graphite with water in the ratio 1:20) during spraying for 2s provides the best results. In addition, it can also be observed that the provision of "better" lubrication conditions for the tool in the case of the insert (Fig. 9a) caused some displacements in the wear of selected tool zones compared to the tool with the old lubrication system. For example, the tool shown in Fig. 9b shows wear in places where the final parts of the

forging arms are shaped, while for the tool shown in Fig. 9a (with the new lubricating system) no traces of wear are visible in this area (marked with a red ellipse). This can be explained by the fact that, as a result of the introduction of the newly developed lubrication system into the process, the tribological conditions changed, which caused changes in the occurrence of destructive mechanisms in selected areas of the tool.

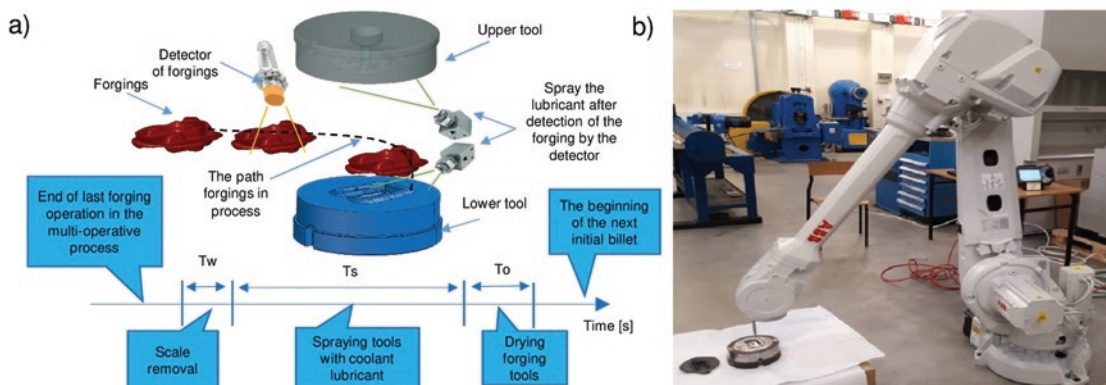


Fig. 8. a) The idea of a lubrication system operation with an exemplary work cycle diagram, b) using the manipulator arm for the targeted feeding of a lubricant-cooling agent



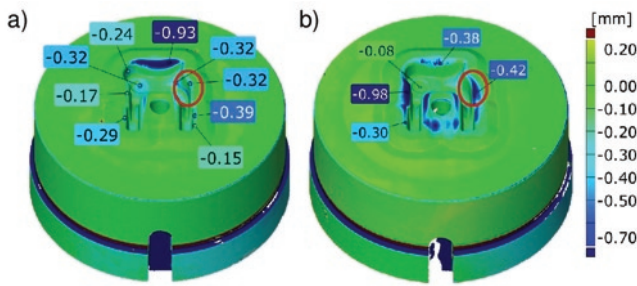


Fig. 9. Scan results of UNIMAX steel inserts used in the hot forging process: a) 16000 forgings with a new lubrication system, b) 16000 forgings with an old lubrication system

In order to determine the wear history of the selected die inserts (Fig. 9), the author's developed and partially improved reverse scan method was used, proved by the industrial practice to be a useful measurement and research tool. Until now, this method has been applied successfully to axisymmetric objects, with relatively simple shapes and large values of material loss [14,15]. The developed method consists in performing a measurement, with the use of a scanner, of the progressive wear of the selected forging tool (Fig. 10a), demonstrated as its loss of material, and on the basis of the shape changes of the forgings cyclically taken from the forging process, in the form of material increment (Fig. 10b). In order to reproduce the course of tool wear, the method involves scanning of the forgings selected from the production series (every 1000 item) from the total maximum number of forgings produced for each of the selected die inserts. To determine the graph describing the dependence of the volume consumption in

relation to the number of forgings made during the forging process, it is necessary to calculate the change in the measurement volume of the subsequent forgings to the result of 100 nominal forgings, which were leveled with the use of the reference surface.

In this way, it is possible to develop graphs showing the volume changes of the forgings cyclically collected during the process and then scanned. The measurement of the volume changes of the last produced forging for a given die insert is verified with the measurement of the tool volume at the end of the work. Fig. 11 presents an analysis of the volume changes carried out in order to determine the wear history of the selected lower die inserts for various lubrication conditions.

The proposed approach using the reverse 3D scanning method enables a global, but also thorough, description of the material loss, through observations of the volume changes during the forging process, as well as a quick, reliable and practical evaluation of the current state of the forging tools. In addition, the obtained results indicate that, on the basis of the course and shape (trend) of the consumption curves, you can predict the size of the material loss, and consequently control the amount of "tool opening" (flash thickness), and even determine the moment when the tool is withdrawn from further production due to its exceeding the dimensional tolerances.

Analyzing the determined wave forms of consumption curves in the aspect of the impact of the new lubrication system, it can be concluded that its introduction to the process provides more repeatable tribological conditions and reduced material consumption, especially in the final period of its exploitation. This leads to more advanced tests regarding both the optimization of the lubricant dose and the direction of its delivery, frequency and additional parameters related to the lubrication process.

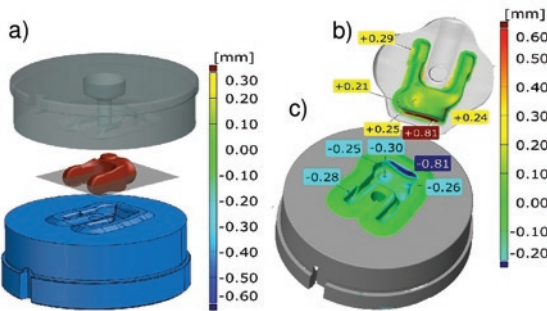


Fig. 10. The idea of the inverse method: a) set of forging tools for the second operation, b) comparison of the last forging results and c) matrix insert after 16000 forgings, in the form of changing the shape of the surface

### 5. Conclusions

The study has presented an analysis of the effect of the cooling and lubrication agents, their dosage amount as well as time and direction of application, and also the lubrication devices, on the wear of forging tools. As it has been demonstrated, the amount of the lubricant and the manner of its supply still constitute a current scientific problem. The performed analysis has shown that it is important to determine the optimal dosage of the lubricant as well as the way in which it is applied. Only through a complex long-term analysis of the given forging process it is possible to select the optimal tribological conditions ensuring stability and repeatability of the production process. That is why, at present, a big emphasis is put on the development of cooling and lubrication devices, as they are the ones which can ensure repeatable conditions of the tools operation, as opposed to the still

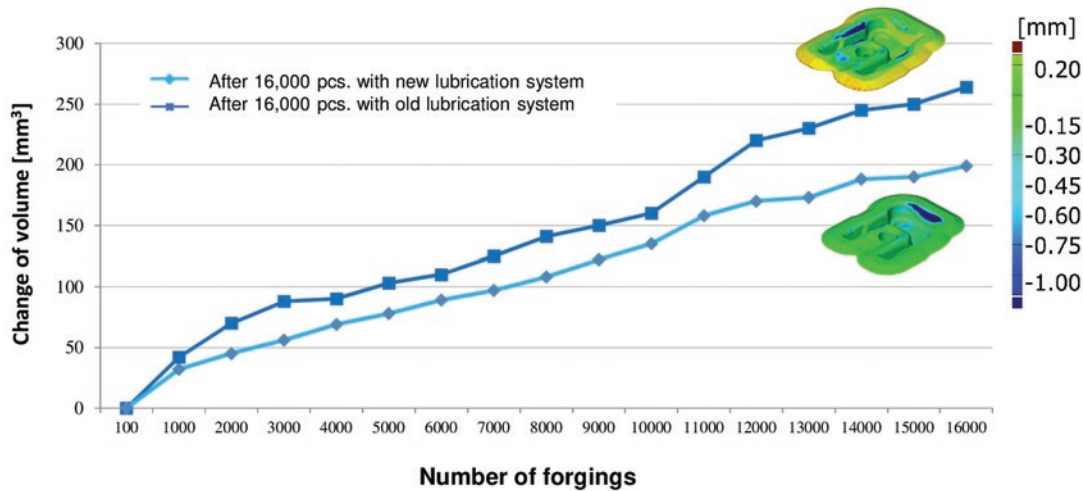


Fig. 11. Comparison of wear curves (history) determined on the basis of the original reverse scan method

commonly applied manual lubrication systems, affected by the subjective human factor. Although the die forging processes performed at elevated temperatures are similar, each of them requires an individual approach. And so, each process should be looked at separately and selected individually, which also refers to the parameters of its exposition and the lubrication technique. The cooling and lubrication system developed by the authors presented in the paper makes it possible to select and ensure the optimal tribological conditions of the process as

well as to examine the effect of the amount and frequency of the lubricant dosage on the wear of the tool for the given process. The preliminary test results have demonstrated the usefulness of this device in the hot forging process of producing a fork type forging, in place of the currently applied, providing low stability, manually controlled lubricating devices. And so, it is justifiable to perform further, more advanced, research aimed at the selection of the optimal lubricant supply as well as other lubrication settings, which may also be connected

with modernization of the elaborated device. Also, further investigations will be performed in relation to both the selection of the cooling and lubrication agent and its optimal temperature, in order to reduce the temperature gradient between the core and the working surface of the tools, causing thermal fatigue. The planned research also includes the use of a manipulator's arm for the examinations and tests of the selection of the proper direction and precision of the lubricant supply into the tool's impression.

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