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INNOVATIVE TECHNOLOGY FOR FABRICATION OF ANTIWEAR LAYERS FOR FORGING TOOLS

INNOWACYJNA TECHNOLOGIA WYTWARZANIA WARSTW PRZECIWZUŻYCIOWYCH NA NARZĘDZIA DO KUCIA NA ZIMNO

Key words:

cold forging tool, nano- and micro-particle solid lubricant, laser texturing, coating

Słowa kluczowe:

narzędzia do kucia na zimno, nano i mikrocząstki smarów stałych, obróbka laserowa, powłoka

Summary

Cold forging tools are known to be exposed to extremely high loads due to the high forming stresses and the strain hardening of the workpiece material. This paper deals with the study of the influence of laser texturing of hard-coated tool surfaces and micro-channels filled with

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solid lubricants on tool tribological behaviour in cold forging processes. The results of a study of the combination of hard coating with and solid lubricant layers for forging tools show the beneficial effect of nano- and micro-particle solid lubrication in the case of the storage of nanoparticles in the micro-reservoirs at the sliding interface. The use of nanolayered coatings (like nACVIc) seems to be more effective for areas of high contact stresses than a combination of coatings. The use of micro-channels filled with MoS2 nanoparticles seems to be more effective for areas of abrasive wear.

INTRODUCTION

Cold forging tools are known to be exposed to extremely high loads due to the high forming stresses and the strain hardening of the workpiece material. Hence, the improvement of tool technology plays an essential role for increasing the tool life that will improve the innovation and competitiveness of the companies as well as open new product ranges **[L. 1, 2].** Usually, the cold forging tool surface is locally subjected to contact stresses of more than 2000MPa. It is of particular importance for two dominating mechanisms of a tool damage: fatigue and wear limiting tool life. Fatigue is caused by the cyclic loading of the tool. Even at a very early stage fatigue cracks can lead to disruption at the tool surface and thus to the failure of the tool. Wear is caused by the combination of high contact stress and cumulating sliding length and affects in general the accuracy and surface quality of the workpiece. Analysis of three types of forging tools made by authors **[L. 3]** shows that both of these damaging mechanisms are observed limiting tool life. The objective of the research is to increase tool life using two methods: (1) The deposition of hard coatings, and (2) the application of solid lubricant films generated by exfoliation of solid lubricant nano- and microparticles at the sliding interface.

In the last decades, hard PVD and CVD coatings have started to successfully compete with the traditional thermo-chemical treatments, especially in terms of abrasive wear resistance **[L. 4].** In the case of cold forging and cutting tools, deposition of hard PVD and CVD coatings (i.e. TiN, TiAlN, CrN, . . .) have proven to provide considerable enhancement in wear resistance and therefore tool life in numerous cases **[L. 5–7]**. However, the traditional hard coatings such as TiN, TiC and CrN cannot meet forging tool requirements, including good adhesion to the base material to withstand high loads and shearing forces without chipping or peeling, and high toughness and low friction against stamped material **[L. 4]**. The recent monographs reveal the essential progress that has been seen in the field of coating deposition and design, leading to greatly improved tribological properties of contact surfaces **[L. 8, 9]**. Especially carbon-based, multicomponent, and multilayered coatings are the promising candidates to put the concept of "cheap" and reliable coated tools for primary cold forging operations into practice. It is well known that, in cold forging, the process boundaries, the process stability, and the tool life are linked closely to the tribological state in the forming process that prevails at the contact zone of workpiece and tool. The tribological state determines the wear rate and thus the maximum tool life and the quality of the workpiece. It also determines the friction force that is necessary to enable material flow. To allow the production of very complex parts at low costs, industry demands low friction and low wear in the forming zone. To achieve this and due to the ancillary conditions in cold forging – high normal pressure, high sliding velocity, and high temperature – it is common to use complex lubrication systems, mostly based on fluids with extreme pressure (EP) additives and the pre-treatment of the billets. Friction and wear are very important parameters that depend on sliding velocity, material properties, normal pressure, and temperature. These parameters are also significantly dependent on the surface topography of the tool and workpiece. Regarding lubrication, especially in the case of the application of liquid lubricants, the surface of the billet and the tool has to transport a sufficient amount of lubricant into the forming zone. At the same time, it has to retain enough lubricant to make the formation of hydrostatic and hydrodynamic lubrication effects possible, which enables the lubricant to flow into the contact zone of the tool and workpiece thereby separating both. In this context, an ideal surface must feature small valleys with a suitable micro-geometry in which lubricant can be trapped and must yield and release lubricant during deformation, hence acting as lubricant pockets **[L. 10]**. In some cases in bulk metal forming, the demands on the surface are taken into account by generating a similar texture on the surface of the workpiece by means of shot blasting or other methods. This procedure includes two main disadvantages. First, a time-consuming treatment of each single workpiece is necessary, and, second, this effect works at the very beginning of the process only.

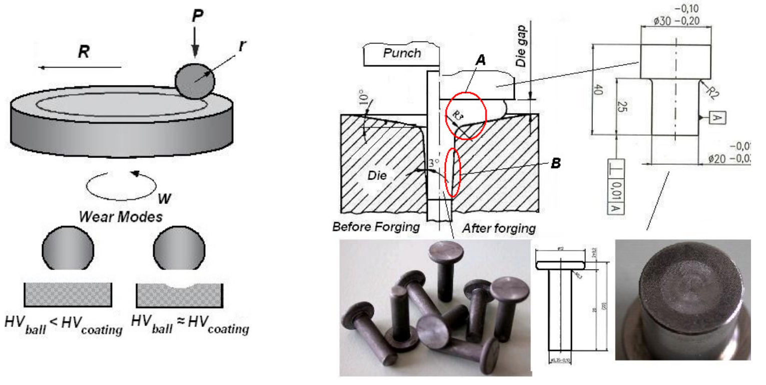
The aim of this paper is to examine the joint application of hard coatings and solid lubricants for forging tool life enhancement, while taking into account the wear and high-cycle fatigue fracture of the tool, since the locations for the fatigue and wear failure are different. This paper deals with the study of the influence of laser texturing of hard-coated tool surfaces and micro-channels filled with solid lubricants on tool tribological behaviour in cold forging processes. The research was carried out by means of laboratory friction tests and industrial lifetime test series under conditions of pilot production.

EXPERIMENTAL PROCEDURE

Evaluation of the friction and wear parameters of hard PVD and PECVD coatings with solid lubricant nano- and micro-particles was accomplished by ball-on-disc friction tests (**Fig. 1a**) and heading tests which were performed by the heading tool (**Fig. 1b**) installed on a 500KN mechanical press with 80 strokes/min. The geometry of the die, punch, and workpiece are shown on **Fig. 1b.** The tool for the heading tests was equipped by two dynamometers, so that the pressing and ejector forces can be measured during each test.

The effect of solid lubrication with MoS2 nano- and micro-particles was studied using ball-on-disc tests with tester T-10 at normal loads 6-8N and rotation speed 200rpm. The disc samples with diameter of 40mm and the balls of diameter of 10mm are made of tool steel SW7 with a hardness of 62-63HRC, and discs are coated with three types of coatings (Black Top:TiC, TiAlN, DLC2:CrN+C). The friction coefficient and wear parameters were defined based on the measurement of friction force and ball weight.

Microstructure examinations were performed at the Institute of Metallurgy and Material Engineering of PAN in Kraków with the use of a Tecnai G2 F20 transmission microscope. Samples were cut directly from the tools with the use of Ga+ ions by FIB type Dual Beam manufactured by FEI with the ion share based upon the scanning microscope. The chemical composition of the coatings was determined by energy-dispersive electron probe microanalysis using elemental standards. Photographs of the tool surface were made with the use of Inspect S electron-scanning microscope manufactured by FEI, including an EDS X-ray micro-analyser manufactured by EDAX in the Metal Forming Institute in Poznań.



a b

Fig. 1. Testing procedures: a) ball-on-disc test with two wear modes; (b) – heading test: *A* – area of high-cycle fatigue of tool (punch and die), *B* – area of abrasive wear of die

Rys. 1. Metodyka testowania: a) test kulka–dysk; b) test ścierania; ***A*** – obszar wysoko-cyklicznego zmęczenia narzędzia (stempel i matryca), ***B*** – obszar ściernego zużycia matrycy

Testing covered three types of coatings (Black Top:TiC, TiAlN, DLC2:CrN+C), which were applied onto forging tools and samples for tribological tests. The coatings were deposited by Gazela Company, Slovenia.

RESULTS AND DISCUSSION

Results of ball-on-disc tests exhibit the strong friction coefficient dependence on the type of coating (**Fig. 2**). The solid lubrication with MoS2 particles (addition of 1gr of MoS2 powder directly onto the disc surface, **Fig. 1a**) diminishes the friction coefficient to f = 0.1–0.15 for all types of studied coatings. However, in this case, the supply of MoS2 particles to a sliding interface is not controlled, and the majority of particles are not being entrapped into the contact area. The controlled slow release of solid lubricant–to the interface is achieved by the application of micro-channels filled with MoS2 particles. It results in a friction coefficient of about 0.03–0.05 during the whole friction test time.

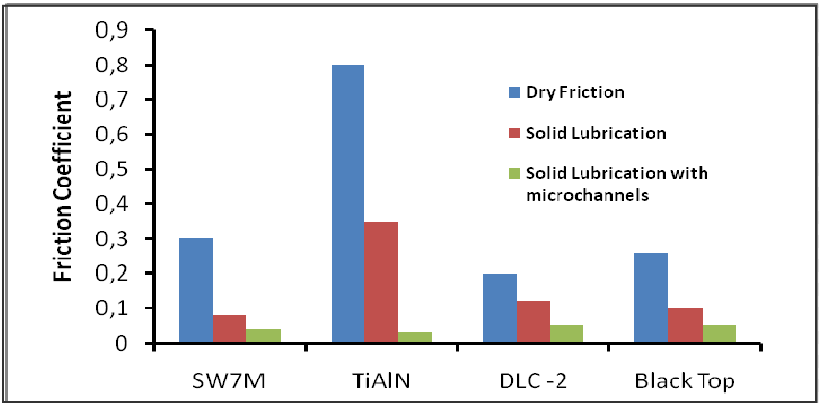


Fig. 2. Friction coefficients of hard coatings with solid lubrication by nanoparticles and nanoparticles in micro-channels

Rys. 2. Współczynniki tarcia powłok z nanocząstakami oraz nanocząsteczkami w mikrokanałach smarów stałych

Surface textures (**Fig. 3**) can improve the tribological state by "lubricant pockets." The laser micromachining provides the possibility to generate such pockets on tool surfaces with high precision (uncoated as well as coated) and with a high flexibility considering the arrangement and geometry of the textures. Surface texturing has already proven to increase tool life distinctly in some industrial applications, e.g. for punches in backward extrusion **[L. 1]**. Friction and wear are, among other parameters, significantly dependent on the surface topography of the tool and the workpiece. In the case of lubrication, especially with liquid lubricants, the surfaces of the billet and the tool have to transport a sufficient amount of lubricant into the forming zone. At the same time, it has to retain enough lubricant to enable the formation of hydrostatic and hydrodynamic lubrication effects, which allow the lubricant to flow into the contact zone of tool and workpiece **[L. 1]**. In our case of nano- and micro-particles application, the quasi-hydrodynamic regimes of solid lubrication seems to be achieved with the similar effect of low friction coefficients. Another task of the surface micro-channels is to store wear debris. Extremely smooth surfaces, as often used for cold forging tools, neither support the transportation, storage and distribution of lubricant nor the transportation of wear particles. From this viewpoint, the tool surface must feature small valleys with a suitable micro geometry in which lubricant can be trapped. That will lead to a delivery of lubricant during deformation, hence acting as the solid lubricant pockets.

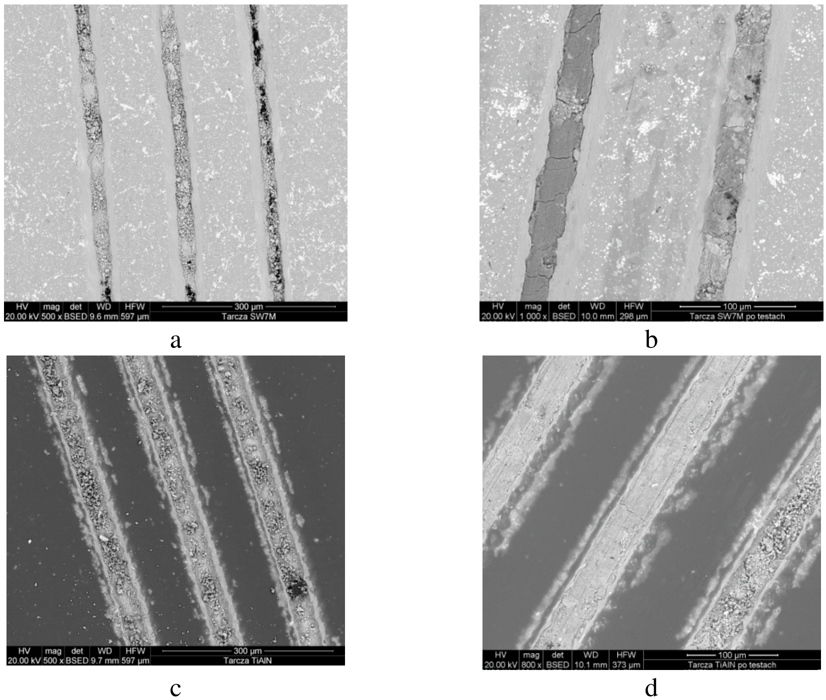


Fig. 3. SEM images of microchannels filled with MoS2 nanoparticles (a, b) – SW7M steel: (a) – before friction test, (b) – after friction test; (c, d) – TiAlN coating: (c) – before friction test, (d) – after friction test

Rys. 3. Obrazy SEM mikrokanałów wypełnionych nanocząsteczkami MoS2 (a, b) – stal SW7M: – przed testem tarcia, (b) – po teście tarcia; (c, d) – powłoka TiA1N: (c) – przed testem tarcia, (d) – po teście tarcia

The beneficial effect of the slow release of solid lubricant particles on wear resistance is seen in **Figure 4.** The wear is diminished by two orders of magnitude. It seems that the permanent generation of a solid lubricant film is achieved due to continuous exfoliation of solid lubricant particles at the contact area. These friction conditions are similar as those of the area ***B*** (**Fig. 1b**). Thus, it is possible to effectively decrease the abrasive wear of the forging tool by a combination of hard coatings with solid lubricant nanoparticles.

The results reveal the high effectiveness of TiALN coatings from the viewpoint of fatigue resistance. The effect of solid lubricant application has some specific features, such as the influence of oil on the cold forging contact conditions. The presence of oil in this case had two effects. The first effect was beneficial in that the presence of the additional oil compensated for the local absence of coating.

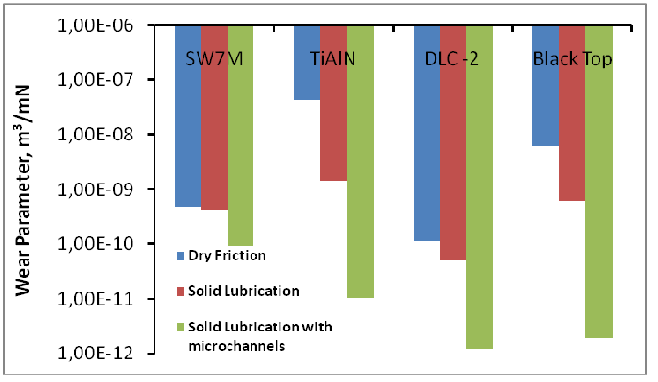


Fig. 4. Wear of hard coatings with solid lubrication by nanoparticles and nanoparticles in microchannels

Rys. 4. Ścieranie powłok twardych z nanocząsteczkami oraz z nanocząsteczkami w mikrokanałach smarów stałych

The second effect of the additional oil was harmful. It caused the appearance of zones completely without coating; however, the phenomenon was not observed without additional oil. The oil can have a "washing" effect that removes the stearates trapped in the interstices of the coating and reveals the substrate. A similar case is described in **[L. 11].** The coefficient of friction then increases abruptly. The use of nanolayered coatings (like nACVIc) seems to be more effective for area ***A*** than the combination of coatings and laser texturing.

CONCLUSIONS

The results of the study of a combination of hard coatings with solid lubricant layers for forging tools are as follows:

- The beneficial effect of nano- and micro-particle solid lubrication is obtained in the case of the storage of nanoparticles in the micro-reservoirs at the sliding interface. It is especially effective in combination with PVD/PECVD coatings.
- A nano- micro-particle solid lubrication of areas of high-cycle fatigue and abrasive wear of a die is an effective tool to increase its longevity. The methods of lubrication depend on the type of the tool wear.
- The use of nanolayered coatings (like nACVIc) seems to be more effective for area ***A*** than a combination of coatings and laser texturing.
- The use of micro-channels filled with MoS2 nanoparticles seems to be more effective for areas of abrasive wear.

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REFERENCES

1. Wagner K., Volkl R., Engel U., Tool life enhancement in cold forging by locally optimized surfaces, J. of Mat Proces. Techn., 201 (2008). 2–8.
2. Lee H.C., Lee Y., Lee S.Y., Choi S., Lee D.L., Im Y.T., Tool life prediction for the bolt forming process based on high-cycle fatigue and wear, J. of Mat. Proces. Techn., 201 (2008). 348–353.
3. Borowski J., Rybak T., Ignatiev M., Weinert H., Dobrovnik I., Leshchynsky V., Nanocomposite PVD coatings applied to cold plastic forming tools, Materials Science Forum, Vol. 674 (2011), 105–112.
4. Podgornik B., Zajec B., Bay N., Vizintin J., Application of hard coatings for blanking and piercing tools, Wear, 270 (2011), 850–856.
5. Rutherford K.L., Bull S.J., Doyle E.D., Hutchings I.M., Laboratory characterization of the wear behaviour of PVD-coated tool steels and correlation with cutting tool performance, Surf. Coat. Technol., 80(1996), 176–180.
6. Stoiber M., Panzenbock M., Mitterer C., Lugmair C., Fatigue properties of Ti-based hard coatings deposited onto tool steels, Surf. Coat. Technol., 142–144 (2001). 117–124.
7. Imbeni V., Martini C., Lanzoni E., Poli G., Hutchings I.M., Tribological behaviour of multi-layered PVD nitride coatings, Wear, 251 (2001). 997––1002.
8. Holmberg K., Matthews A., Coatings Tribology: Properties, Mechanisms, Techniques and Applications in Surface Engineering, Elsevier, Amsterdam 2009.
9. Donnet C., Erdemir A., Tribology of Diamond-like Carbon Films: Fundamentals Applications, Springer, NY, 2009
10. Popp U., Engel U., Microtexturing of cold-forging tools – influence on tool life, Proc. IMechE Part B: J. Engineering Manufacture, Vol. 220 (2006), 27–34.
11. Dubois A., Dubar L., Dubar M., Oudin J., Characterization of friction at the tool–billet interface in the cold forging of steel, Mec. Ind. (2000) 1, 639–649.

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Streszczenie

Narzędzia do kucia na zimno poddawane są bardzo dużym obciążeniom ze względu na wysokie naprężenia oraz umocnienie podczas kształtowania. W niniejszym artykule przedstawiono analizę wpływu zmiany powierzchni narzędzi z twardymi powłokami oraz mikrokanalikami wypełnionymi nanocząstkami smarów stałych na właściwości tribologiczne narzędzi dla procesów kucia na zimno. Analiza otrzymanych wyników zastosowania powyższej kompozycji powłok dla narzędzi kuźniczych wykazuje korzystny efekt zastosowania nano- i mikrocząstek smarów stałych w mikrokanalikach na powierzchniach trących. W przypadku obszarów o wysokim naprężeniu stykowym bardziej efektywne od zastosowania kompozycji powłok wydaje się być zastosowanie powłok nanowarstwowych (takich jak nACVIc). Zastosowanie mikrokanalików wypełnionych nanocząstkami MoS2 jest bardziej efektywne dla obszarów charakteryzujących się zużyciem ściernym.