Introduction of a new analysis method of the lubricant film to investigate an indirect workpiece lubrication

Christoph Müller, Deniz Yalcin, Peter Groche
Institute for Production Engineering and Forming Machines, Technische Universität Darmstadt

Cold forging is a material and cost efficient process. However, common lubrication systems are often harmful for the environment. Thus, many new ecological approaches exist. Promising are the single layer lubricants, which until now are applied like the common two layer systems. In order to improve their applicability, it is essential for the development of new concepts to gain information about the distribution of the lubricant film. Consequently, this paper introduces the analysis of the lubricant film with UV indicators in the lubricant. With this method, the lubricant on the tools can be analyzed and it enables the introduction of an indirect lubrication of the workpieces with a tool lubrication. This approach allows a selective lubricant distribution and a significant improvement of the process chain.

Introduction

Cold forging processes are characterized by a good material usage. Also, after the forming process, cold hardening and unharmed flow lines resolve into advantageous material properties. Moreover, good geometrical tolerances and smooth surfaces can be gained. Due to the fact that a heating operation is not necessary, it is more environmental friendly than hot forging. Having high tool costs and time consuming mounting processes, cold forging is especially efficient for huge lots. Thus, it is often used to produce screws and parts for the automobile industry [Alt04].

Due to the high yield stresses at room temperature, tremendous tribological loads occur. These are contact normal stresses up to 3,000 N/mm² [Ste99, Hem99, Rae02] and surface enlargements between 8 [Rae02] and 50 [Bay11]. The relative velocity can reach values up to 500 mm/s [Gro13] and the sliding distance of 100 mm [Mue13b, Gro14a]. The dissipation of the friction and the forming energy into heat induces temperatures to the tools of 200°C [Bay94, Wib95] and the local temperatures can rise up to 600°C [Bay94]. However, these values often are not systematically gained, although the environmentally friendly tribological systems react sensitive to too high tribological loads. Thus, simulations to further investigate them were conducted [Mue14b].

Due to these high tribological loads, only high-performance tribological systems can prevent adhesion [Bay10]. They highly affect the efficiency of the production process [Rup97]. The most common one consists of a conversion coating and a lubricant [Rae02, Hu00]. For low alloyed steel, the conversion coating is zinc phosphate [Bay94, Lan08, Rau88]. For stainless steel, iron oxalate is necessary [Lan08]. As lubricant, molybdenum disulfide, polymer, soap or oil can be used [Bay94, Nit04, Bay10, Nit09, Ull04]. However, these tribological systems have a high impact on the environment [Bal96, Bra00]. Hence, new tribological systems as porous layers [Are08] or electrolytical phosphating [Bje97] were developed. However, the most promising ones are the single layer lubricants. They can be divided into polymers, molybdenum disulfides and salt wax coatings with integrated lubrication (salt wax) [Sch13, Bay13, Bay10]. They are more environmental friendly. Though, they have a limited capability. Thus, to use them for all cold forging processes, a further optimization is necessary. Besides an improvement of the lubricant itself, new tribological concepts are required. However, until now, the single layer lubricants still are applied on the workpiece with the common equipment in baths. Hence, only a uniform film thickness is feasible.

Experiments with the Sliding Compression Test have revealed the high impact of remaining lubricant on the friction behavior. It reduces, compared to a cleaned workpiece surface, the friction coefficient about 30 %. A similar effect could be gained with a prelubrication of the tools with the lubricant, which was also used for the workpieces. Moreover, such a prelubrication can prevent adhesion on rough surfaces. Finally, first tests have shown that a lubrication of the specimens could be avoided by the use of a tool lubrication [Mue13a, Gro14b, Mue14b, Mue14c]. To further investigate a tool lubrication, a technique to observe the lubricant distribution is essential. Thus, this paper presents a new technique to analyze the lubricant behavior and uses it to investigate an indirect workpiece lubrication with the help of a tool lubrication.

Experiments

In order to examine the new technique for the analysis of the lubricant film and the tool lubrication, a special tribometer is necessary. Due to its capability, the Sliding Compression Test was used. Its principal is shown in Figure 1 on the left side. For the investigations, the test divides the forming process into a compression and a sliding sequence. First, during the compression, the specimen is formed into an engraving of the punch and the contact normal stress and the surface enlargement are set. Afterwards, during the sliding with a defined relative velocity, all forces are measured. Thus, a friction coefficient can be calculated by the division of the friction force through the normal force. One advantage of this test stand is the direct measurement of the friction force and thus, a time depending friction coefficient can be calculated. Also, the tribological loads of cold forging can be reached and varied individually. Having small rods as specimens, all lubricants can be applied with the common equipment. The tools, the sliding plates, are simple rectangular blocks and can be coated easily. Also, a swift and cheap rework of them allows examinations of the separation which often damage the tool already during the first test. Additionally, the test can be performed with a short preparation time and one test is conducted swiftly [Gro13, Mue14a].

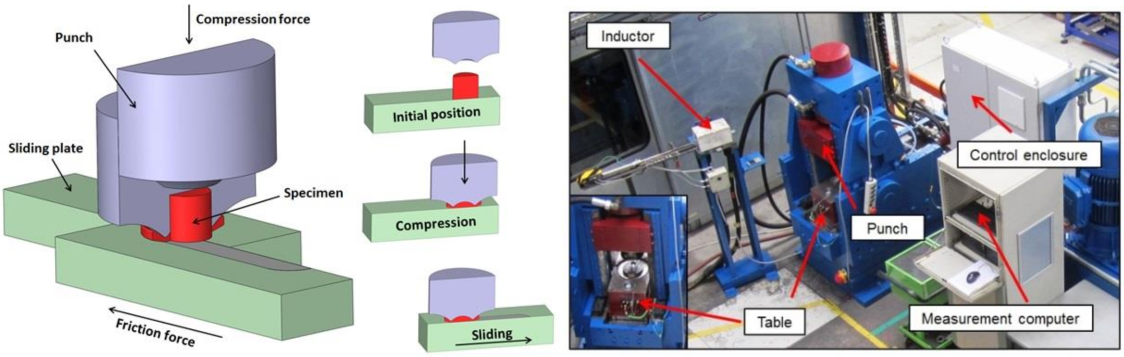


Figure 1: Principal and photo of the Sliding Compression Test [Gro13, Mue13a]

The Sliding Compression Test at the PtU is implemented on a hydraulic press. This test stand has two independent axes and can reach compression forces up to 1,000 kN. The relative velocity can rise up to 500 mm/s and the sliding distance is limited to 100 mm. The test stand is also equipped with a heating system, which enables tool temperatures of 400°C and a preheating of specimens. For low alloyed steel, the existing tooling can induce contact normal stresses up to 3,000 N/mm² and average surface enlargements of more than 11. The press, the control enclosure, the computer and the inductor are shown in Figure 1 on the right side. The Sliding Compression Test already was used to investigate the influence of the surface roughness of the specimens [Koe07, Gro09], the relative velocity [Han12, Zan13] and the temperature [Zan14] on the tribology.

For the investigations presented in this paper, the punch Hydrostat v2 [Mue13b, Gro14a] was used. The specimens were made of 1.7139, had a height of 15 mm and a diameter of 15 mm. Their surfaces were blasted with iron balls having a diameter between 1.0 mm and 1.6 mm. The gained surface roughness S_a is about 4 µm (+- 20 %). The tools (sliding plates) are made of 1.2379, hardened to 61 HRC and polished.

Analysis of the lubricant film

Up to now, an analysis of the lubricant distribution on the tools as well as the specimens is not possible, because the available techniques are not suitable. Different techniques are defined in DIN EN ISO 3882. However, in practical use is only the weighing of the specimen coating. Therefore, the specimen is weighed after the lubrication and after a cleaning process or before and after the lubrication. The difference between the two values is the amount of lubricant. This technique is limited to measure an average over the complete surface. A distribution cannot be regarded.

Consequently, a new technique was developed. To analyze the lubricant distribution, UV indicators were added to the lubricant. Less than 0.1 % of these particles in the lubricant are sufficient. Thus, the lubrication process is not influenced and they can be added to all polymers as well as salt waxes. With the help of black light, the fluorescence of the indicators can be used to measure the distribution by taking a photo in a dark room. A photo of a lubricated sliding plate is shown in Figure 2. On the left side, the normal photo is given. On the right side, it is in black and white as well as a color revision. In this context, dark areas have more lubricant than lighter ones. The measurement of Figure 2 reveals an inhomogeneous lubricant film on this sliding plate.

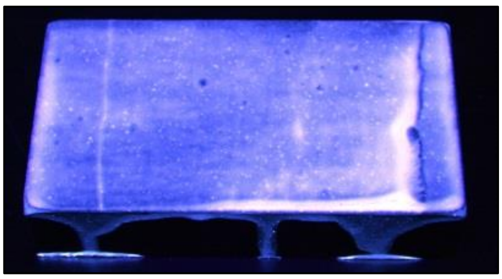
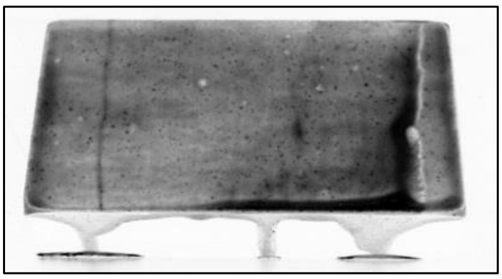


Photo as it was taken



Black and white as well as a color revision

Figure 2: Lubricant distribution of a sliding plate

To use this technique, it is crucial to investigate the influence of the UV indicators on the capability of the lubricant. Therefore, Sliding Compression Tests were conducted with a salt wax. One series of this lubricant was with and one without the UV indicator. The averages of three tests of every series are shown in Figure 3. In total, five tests were conducted. However, the first as well as the second test are influenced by the new lubrication on the sliding plate and must be omitted. The presented results reveal no significant influence, because both friction coefficients, regarding the error bars, are similar. Accordingly, UV indicators can be added into the lubricant.

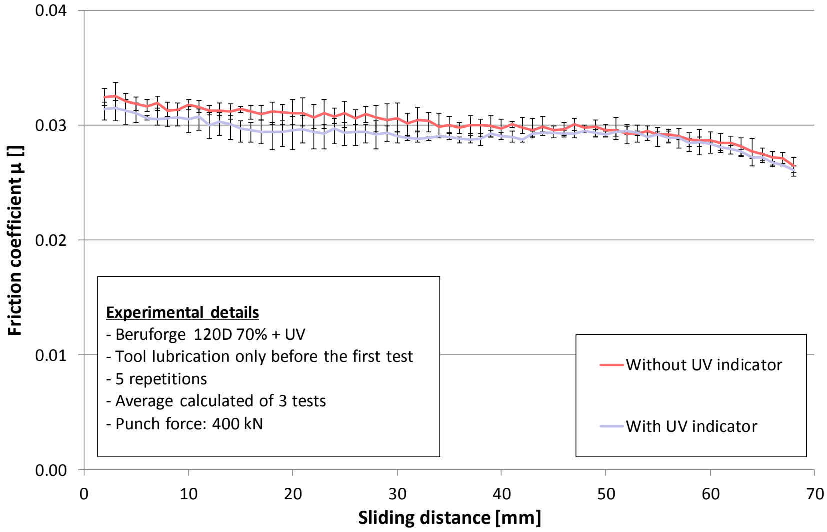


Figure 3: Influence of the UV indicator on the capability of the lubricant

Also important is the workability under industrial conditions and thus, the lubricant with the UV indicators has to prove the applicability on a common forming process. In Figure 4, three pictures of the specimen after the forming with the salt wax including UV indicators under black light are shown. The distribution of the lubricant of these parts can be analysed. On the lateral surface, some lubricant is left and in the middle the film thickness is higher. On the unformed face side, all of the lubricant remains. In contrast, in the cup, there is nearly no lubricant detectable.

Figure 4: Distribution of the lubricant after the forming process

An additional application of the UV indicators in the lubricant is the scratch and the adhesion detection. During the forming process, the UV indicators are pressed into rough structures of the surface. Afterwards, a cleaning cannot completely remove them from the cavities. Two different sliding plates after the cleaning with water and a scrubber are shown in Figure 5. On the left side, thin scratches on the former polished surface can be detected. On the right side, the larger dark area reveals adhesion. Both kinds of wear are hard to detect without the UV indicators.

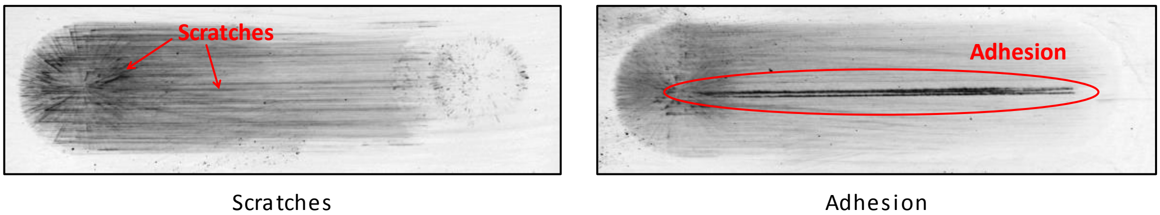


Figure 5: Detection of scratches and adhesion with UV indicators

The use of UV indicators in lubricants enables the detection of the lubricant distribution without influencing the lubrication process and the capability of the lubricant. Moreover, it is easy to add them to the lubricant and they can be used for the detection of scratches as well as adhesion. However, to use the technique for a production process, an automated measurement system is necessary. Also special cameras can be used to additionally detect the amount of lubricant.

Indirect lubrication of the workpiece

The main topic of this paper is the indirect lubrication of the workpiece with the tool lubrication. Previous investigations already have shown the high influence of remaining lubricant on the tribology. The friction coefficient was more than 30 % lower compared to cleaned tools. Further tests have revealed that the tool lubrication has a similar effect. Also, only a lubrication of the sliding plate is sufficient to prevent adhesion during the Sliding Compression Test [Mue13a, Mue14b].

The idea of an indirect lubrication for a forward extrusion is shown in Figure 6. This concept bases on a polished tool and a rough as well as a cleaned specimen. In a first step, the tool is lubricated. Therefore the lubricant is sprayed on the heated tool and dried immediately. Afterwards the workpiece is inserted into the tool. To prevent damaging the lubricant film, the diameter of the workpiece must be smaller than the one of the die. Subsequently, the forming starts and the punch moves downwards. When the tip reaches the forming area, the workpiece bulges and it is pressed at the die. Now, the lubricant is trapped in the rough surface of the workpiece. During further movement, the lubricant is transferred from the smooth die surface and enters the forming area together with the specimen.

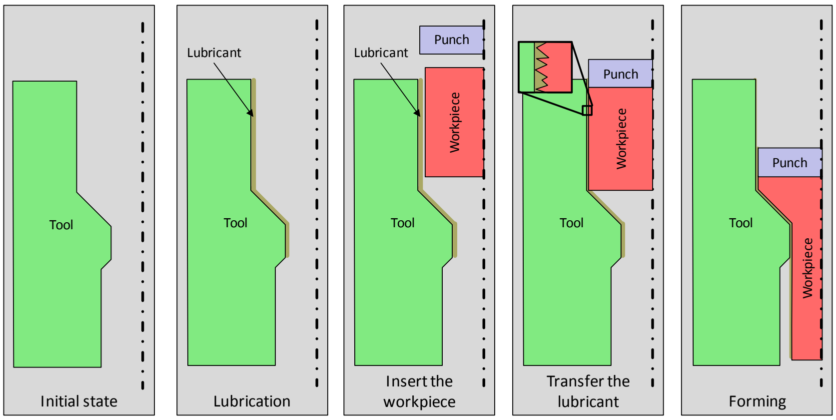
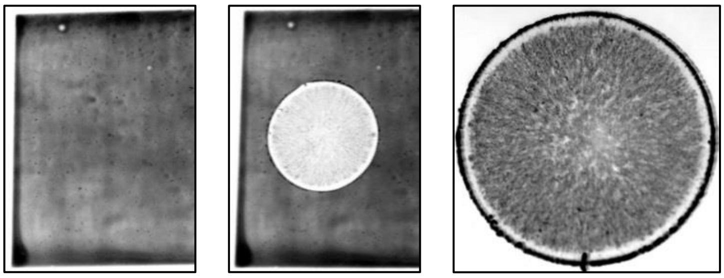


Figure 6: Concept of the indirect lubrication

Before this concept can be tested, the possibility to transfer lubricant from the tool to the specimen was investigated in compression tests. Therefore, the Sliding Compression Test was used and the heated tools (cooled down before the test) were lubricated with a roller. The distribution of a salt wax including the UV indicator is shown on the left side of Figure 7. On this polished tool, a blasted sample was formed with the punch Hydrostat v2 to 400 kN. In the middle of Figure 7, the lubricant film under black light is shown again. It indicated that in the area of the compression, a high amount of lubricant is removed from the tool. This lubricant is transferred to the workpiece, which is shown on the right side.

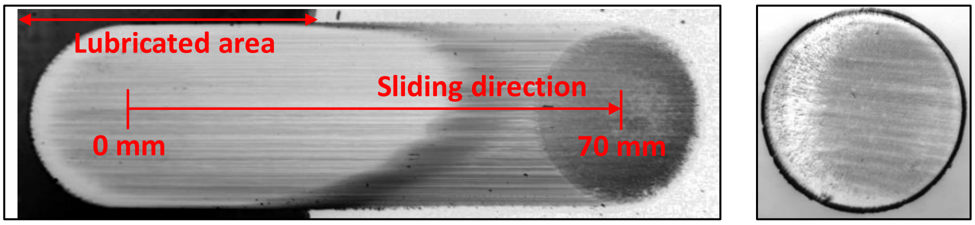


Sliding plate before the compression | Sliding plate after the compression | Specimen after the compression

Figure 7: Transfer of the lubricant during the compression

Five repetitions of the compression tests have shown similar results. Thus, these specimens were used for the Sliding Compression Test. They were inserted into the press like a common specimen. During the compression sequence, no more forming occurred and only the force of 400 kN was applied. Although the sliding plates were cleaned before the tests, all specimens have shown no adhesion over the complete sliding distance of 70 mm. Consequently, workable lubricant can be transferred by a compression from the tool to the workpiece.

However, in contrast to a forming operation, the specimens were separated from the tools. The real condition can be represented by a partly lubrication of the sliding plate. On the left side of Figure 9, the sliding plate after the Sliding Compression Test over 70 mm and a compression force of 400 kN is shown. The specimens were blasted and cleaned. In return, the polished sliding plates were lubricated with the salt wax coating. Additionally, on the right side, the lubricant transferred to the specimen is shown.

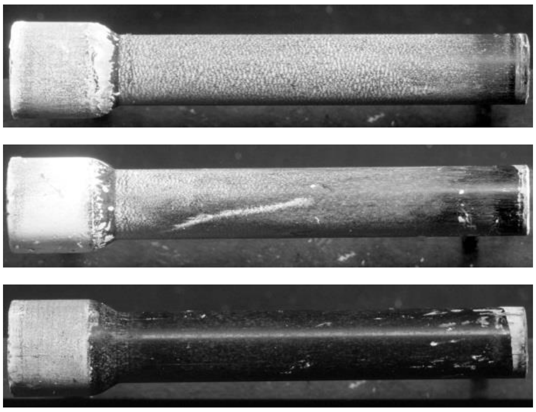


Sliding plate

Specimen

Figure 8: Partly lubricated sliding plate after a Sliding Compression Test

During all tests with partly lubricated sliding plates, no adhesion occurred. Regarding the remaining lubricant, the disposition of the lubricant into the unlubricated area can be detected. There is even more lubricant left than in the lubricated area. Consequently, only a minor amount of lubricant remains on the specimen.



Only workpiece lubrication and remaining lubricant on the tools

Workpiece and tool lubrication

Only tool lubrication

Figure 9: Indirect lubricated specimen of a forward extrusion

All these tribometer tests help to understand the process and to predict its workability. Nevertheless, only a real forming operation can verify the workability of an indirect lubrication. Thus, forward extrusion processes were conducted with lubricant only on the workpiece, on the workpiece as well as the tool and only on the tool. Due to a missing tool heating system, the lubricant was brushed on the die and afterwards dried with a hot fan. The workpieces were blasted and the sliding plates were polished.

As Figure 9 reveals, none of the forward extrusion processes has shown any adhesion patterns. However, the sole tool lubrication has higher punch forces and nearly no lubricant is left in the formed area after the experiment. In contrast, in the unformed area, much lubricant remains. Also, the lubricated specimens with additional tool lubrication have less remaining lubricant than the ones without tool lubrication. It seems that the lubricant was washed off the workpiece. Consequently, the remaining moisture in the lubricant was detected as the occurring problem. There was even liquid lubricant on the tip of the workpiece after the forming process, which still could be seen on the tip of the formed workpiece. Thus, further tests with a heated tool are planned. Nevertheless, forming tests with an indirect workpiece lubrication are possible.

Conclusion

This paper presented an improvement of the lubrication processes for cold forging. Therefore, first a technique to measure the lubricant distribution with the help of UV indicators in the lubricant was presented. These indicators do not influence the workability of the lubricant but they help to understand the disposition of lubricant. This method was used to further investigate the indirect workpiece lubrication by the tool lubrication. The transferability of lubricant from the tool to the workpiece was proven in compression test and Sliding Compression Test with partly lubricated tools. Finally, a forward extrusion process confirmed the applicability of the new concept.

References

[Alt04] Altan, T.; Ngaile, G.; Shen, G. S. (2004): Cold and Hot Forging. Fundamentals and Applications. ASM International, Materials Park, Ohio.

[Are08] Arentoft, M.; Bay, N.; Tang, P.; Jensen, J.; Paldan, N.; Mizushima, I.; Eriksen, R. (2008): Deposited Micro Porous Layer as Lubricant Carrier in Metal Forming. Proceedings of International Conference on Technology of Plasticity, 9, p. 211–216.

[Bal96] Baldy, C. (1996): Recycling zinc phosphate sludge. Metal Finishing, 94-11, p. 23–24.

[Bay10] Bay, N.; Azushima, A.; Groche, P.; Ishibashi, I.; Merklein, M.; Morishita, M. et al. (2010): Environmentally benign tribo-systems for metal forming. Annals of CIRP, 59, p. 760–780.

[Bay11] Bay, N.; Eriksen, M.; Tan, X.; Wibom, O. (2011): A friction model for cold forging aluminium, steel and stainless steel provided with conversion coating and solid film lubricant. Annals of CIRP.

[Bay13] Bay, N. (2013): New Tribo-systems for Cold Forming of Steel, Stainless Steel and Aluminium Alloys. Proceedings of ICFG Plenary Meeting, 46.

[Bay94] Bay, N. (1994): The state of the art in cold forging lubrication. Journal of Materials Processing Technology, 46, p. 19–40.

[Bje97] Bjerrum, N.; Christensen, E.; Steenberg, T. (1997): Method for electrochemical phosphating of metal surfaces, particularly stainless steel, and application of an aqueous phosphating solution for such a method. Patent: EP0922125 A1.

[Bra00] Brad, G. (2000): Iron phosphating. Metal Finishing, 98-6, p. 52–56.

[Gro09] Groche, P.; Stahlmann, J.; Hartel, J.; Köhler, M. (2009): Hydrodynamic Effects of Macroscopic Deterministic Surface Structures in Cold Forging Processes. Tribology International, 42, p. 1173–1179.

[Gro13] Groche, P.; Müller, C.; Stahlmann, J.; Zang, S. (2013): Mechanical Conditions in Bulk Metal Forming Tribometers - Part One. Tribology International, 62, p. 223–231.

[Gro14a] Groche, P.; Müller, C.; Keller, M. (2014): A new concept of the Sliding Compression Test to independently investigate the Contact Normal Stress and the Surface Enlargement. Advanced Materials Research, 939, p. 473-480.

[Gro14b] Groche, P.; Müller, C.; Jahn, A. (2014): Effects of the Tool Lubrication in cold forging. Tribology Letters, 53-3, p. 599–605.

[Han12] Hanisch, T.; Filzek, J.; Müller, C. (2012): Tribological Characterization of Industrial Cold Forging Processes by Laboratory Testing. Proceedings of International Colloquium Tribology, 2012.

[Hem99] Hemyari, D. (1999): Method for the determination of constructive models for friction in bulk metal forming with elevated temperatures. Dissertation, Technische Universität Darmstadt. Shaker Verlag, Aachen. In German.

[Hu00] Hu, Z. M.; Dean, T. A. (2000): A study of surface topography, friction and lubricants in metalforming. International Journal of Machine Tools and Manufacture, 40, p. 1637–1649.

[Koe07] Köhler, M.; Stahlmann, J.; Groche, P. (2007): Effect of structured workpiece surfaces on friction in bulk metal forming. Proceedings of ICTMP, p. 24–26.

[Lan08] Lange, K.; Kammerer, M.; Pöhlandt, K.; Schöck, J. (2008): Extrusion. Springer, Berlin, Heidelberg. In German.

[Mue13a] Müller, C.; Jahn, A.; Groche, P. (2013): Lubrication of Cold Forging Tools with Single Layer Lubricants. Proceedings of ICFG Plenary Meeting, 46.

[Mue13b] Müller, C.; Keller, M.; Groche, P. (2013): Independent Investigation of the Contact Normal Stress and the Surface Enlargement with the Sliding Compression Test. Proceedings of the 16th International Conference on Advances in Material & Processing.

[Mue14a] Müller, C.; Groche, P. (2014): Tribological measurement in cold forging. Proceedings of the 19th International Colloquium Tribology.

[Mue14b] Müller, C.; Rudel, L.; Yalcin, D.; Groche, P. (2014): Cold forging with lubricated tools. Proceedings of esaform, 17, p. 971–980.

[Mue14c] Müller, C.; Rudel, L.; Yalcin, D.; Groche, P. (2014): Cold forging with lubricated tools. Key Engineering Materials, 611-612, p. 971–980.

[Nit04] Nittel, K. D. (2004): Soap and solid lubricants for cold forging. In: Wilfried J Bartz (Hg.): Handbook of tribology and lubrication. 13. edition. Renningen: Expert Verlag, p. 328–339. In German.

[Nit09] Nittel, K. D. (2009): Lubricants for cold forging. Tribologie + Schmierungstechnik, 5/2009, p. 37–41. In German.

[Rae02] Raedt, J. W. (2002): Basics for a lubricant reduced tribosystem of the cold forging with 16MnCr5. Dissertation, Aachen. In German.

[Rau88] Rausch, W. (1988): The phosphating of metals. 2. edition. Leuze, Saulgau. In German.

[Rup97] Rupp, M. (1997): Possibilities and limits of the cold forging of zinc phosphate free wires. Dissertation, Technische Universität Darmstadt. Shaker Verlag, Aachen. In German.

[Sch13] Schoppe, J. (2013): Innovative cold massive forming on phosphate-free semi-finished products. Proceedings of New Developments in Forging Technology, p. 327–334.

[Ste99] Steenberg, T.; Olsen, J. S.; Christensen, E.; Bjerrum, N. (1999): Estimation of temperature in the lubricant film during cold forging of stainless steel based on studies of phase transformations in the film. Wear, 232, p. 140–144.

[Ull04] Ullmann, R. (2004): Tribology and lubrication in bulk metal forming – Compression oils for cold forging. In: Wilfried J Bartz (Hg.): Handbook of tribology and lubrication. 13. edition. Renningen: Expert Verlag, p. 300–311. In German.

[Wib95] Wibom, O.; Nielsen, J. A.; Bay, N. (1995): Influence of the tool temperature on the friction and lubrication on the cold forging of steel. Umformtechnik, 29-2, p. 106–112. In German.

[Zan13] Zang, S.; Müller, C.; Groche, P. (2013): Investigation of the influence of the relative velocity on tribological system of cold forging. Proceedings of the Tribologie-Fachtagung, p. 22/1. In German.

[Zan14] Zang, S.; Müller, C.; Bodenmüller, D.; Groche, P. (2014): Influence of Temperature on Environmentally Benign Tribological Systems in Cold Forging Operations. Proceedings of NAMRI/SME, 42.