Dry Metal Forming Open Access Journal

Fast Manuscript Track

Edited by Frank Vollertsen
Available online at elib.suub.uni-bremen.de www.drymetalforming.de

Dry Met. Forming OAJ FMT 2 (2016) 044-049
Received 15 April 2016; published 09 May 2016

Recommendations for Dry Forming of 16MnCr5 and 42CrMo4 in Cold Forging

Fritz Klocke[1], Rafael Hild[*1], Daniel Trauth[1], Patrick Mattfeld[1], Kirsten Bobzin[2], Tobias Brögelmann[2], Nathan Kruppe[2]

[1]Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Steinbachstr. 19, 52074 Aachen, Germany
[2]Surface Engineering Institute (IOT), RWTH Aachen University, Kackertstr. 15, 52072 Aachen, Germany

Abstract

In general cold forging processes are performed with the use of lubricants to avoid adhesive wear between the tool and the workpiece. Recent research aims on a lubricant-free forming process. That would lead to savings of the ecological, economic and legislative disadvantageous lubricants. The absence of lubricants goes along with increasing tool loads and growing tribological needs. These needs are compensated by novel tool coatings and a surface structuring of the workpiece. In this contribution recommendations for dry metal forming in cold forging are given based on performed tribotests with a Pin-on-Cylinder Tribometer. It contains the presentation of the tribometer and a summary on the performed experiments. Based on the experimental analyses recommendations for a future dry forming process are given. In future work these recommendations will be validated in an industrial dry metal forming process.

Keywords: dry metal forming, tribotesting, coating, (Cr,Al)N, surface structures

1 Introduction

The automotive industry relies on fast production times, high material utilization and the associated energy and resource efficiency. Cold forming processes combine these characteristics. The benefits are accompanied by higher tribological loads. These loads rise even further with the need for more accuracy [1]. Friction is reduced using liquid and solid lubricants. In favor of ecological, economic and legislative reasons these lubricants should be substituted. In previous researches biodegradable lubricants and/or physical vapor deposition (PVD) coatings for cold forming were surveyed by the Surface Engineering Institute of RWTH Aachen University (IOT). Lugscheider et al. developed a (Ti,Hf,Cr)N PVD-coating for cold metal forming applications [3]. Bobzin et al. enhanced this coating with a CrN toplayer to interact with a biodegradable lubricant for environmentally benign metal forming. Furthermore, a special tool coating with self-lubricating disulfides for dry metal forming was investigated by Vollertsen [4]. New approaches aim to substitute lubricants completely and by that significantly contribute to waste reduction and the goal of a lubricant-free factory [5]. Murakawa addressed the field of dry forming in sheet metal forming using DLC films [6]. Kataoka expanded these researches by investigating DLC thin film adhesion and the use in dry deep drawing [7]. The positive results lead to an adaption for the case of dry metal forming [8]. Contact pressures as well as the surface expansion are higher in cold bulk metal forming than in sheet metal forming. This goes along with increased tool loads. In a dry cold metal forming process these loads rise even further.

Figure 1 shows two approaches of substituting lubricants. The approaches are based on the investigation of the interacting parts in a metal forming process. A reduction of friction is achieved either by a tool coating or by the generation of a surface topography on the workpiece. In cooperation with the Surface Engineering Institute (IOT) both parts are researched. The IOT investigates new surface coatings for the tool. They develop a self-lubricating coating based on a TiHfCrN and a CrAlN PVD-coating [9]. These coatings are investigated regarding friction and fatigue behavior [10].

*E-mail address of corresponding author: r.hild@wzl.rwth-aachen.de

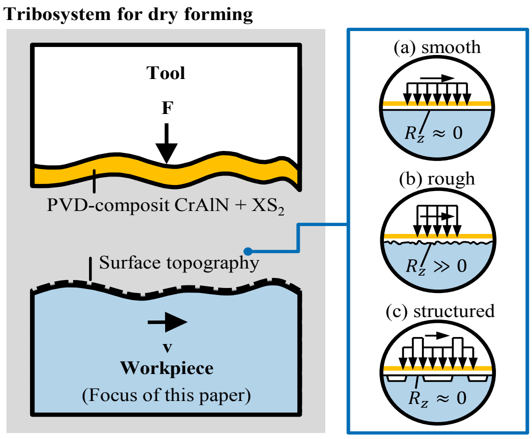

Figure 1: The IOT focusses on a (Cr,Al)N PVD-coating. The WZL researches surface structures on workpieces.

The Laboratory for Machine Tools and Production Engineering (WZL) investigates surface structures on workpieces [11]. Firstly, different surface structures as shot peened or knurled, were modeled in a FE-software [12]. Secondly, these shot peened and knurled surface structures were tested by a tribometer and the results compared to the simulation [13]. The numerical and experimental analyses give a suggestion that dry metal forming can be successfully integrated in production processes [14].

The approach of this paper is divided in three steps. Section 2 gives an overview to performed researches and results of dry forming. In Section 3 the results of the tribotesting are presented. These results lead to a recommendation regarding dry metal forming in the Section 4. Section 5 gives a short summary and an outlook for future work.

2 Preliminary works

Section 2 contains the description of a novel Pin-on-Cylinder Tribometer. The Pin-on-Cylinder tribometer was used to distinguish the influence of the surface structure on the frictional shear stress. The tribotesting results were used to validate a numerical model of the surface structure.

Conventional tribometers are used to analyze friction between two materials or wear of a tool material under certain boundary conditions. To fulfill these demands a continuous contact between the materials and the application of a normal load is needed. During actual tribotesting the same frictional path is used. A surface structure is smoothed after one revolution and the influences of the structure itself on the friction cannot be seen. To overcome that, the mechanism of a Pin-on-Disc tribometer was coupled with a turning lathe. With the combination of the rotational movement and the axial load with an axial feed a new frictional path is achieved. A numerical optimization was used to predict the longest frictional path possible. During the experiments the normal force is measured. After the tribotesting the frictional path is analyzed and the contact area can be measured. From the contact area and the normal load the frictional shear stress is calculated.

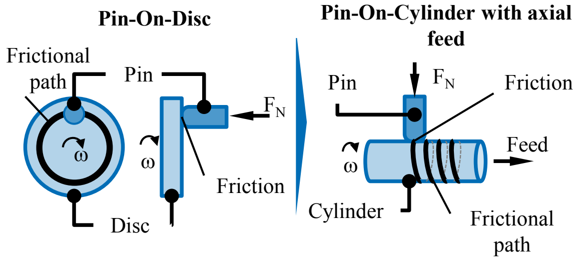

Figure 2: Illustration of the principle of the developed Pin-On-Cylinder tribometer to investigate surface structures. Legend: ω = angular velocity.

3 Tribotesting results of different surface structures

As tool material the 1.3343 high-speed steel and the 1.2379 cold work steel are used. Five different contact conditions were chosen. The first contact condition is created by an uncoated tool and without lubricants. Furthermore there are two contact conditions with a coating, TiHfCrN and CrAlN, which are also tested without a lubricant. And the last two conditions are again with an uncoated tool but with the use of the lubricants WISURA 3080 and WISURA 3368. As workpiece material the steel 42CrMo4 and 16MnCr5 are used. The workpiece materials were tested in an untreated state and with four different surface structures. These surface structures were generated by shot peening with ceramic, steel and corundum beads and by knurling. To investigate different stress states normal loads of F_N = 640 N and F_N = 2600 N were applied.

Figure 3 shows an extract of results of the field of experiments for 42CrMo4 and 1.3343 only. The influence of a surface structure is seen at every state in the tribotesting results, but it slightly differs with the use of a coating or a higher normal load. In general a knurled surface structure helps to lower the frictional shear stress the most. A shot peened surface structure with corundum beads has the same effect, but not for all combinations. With an uncoated tool and a normal load of F_N = 2600 N other shot peened structures show a lower frictional shear stress.

Another tendency is derived from the use of coatings. With lower normal forces the frictional shear stress is lowered significantly. This tendency is diminished with a higher normal force, but is still visible. Compared to the lubricated tribosystem, a combination of a coating with a surface structure leads to equally high results. Focused on the lubricated tribosystems, they show the tendency that a surface structure of the workpiece always leads to lower frictional shear stresses.

These experiments were repeated with the steel 16MnCr5. As the material has hardness half as high as of the 42CrMo4-steel the results are as concisely. It also shows that a lubricated tribosystem always benefits from a surface structure on the workpiece. It is seen that a knurled and corundum shot peened surface structure lead to the lowest frictional shear stresses. But in the end the difference between a dry and uncoated tribosystem are not as high as seen in Fig. 3.

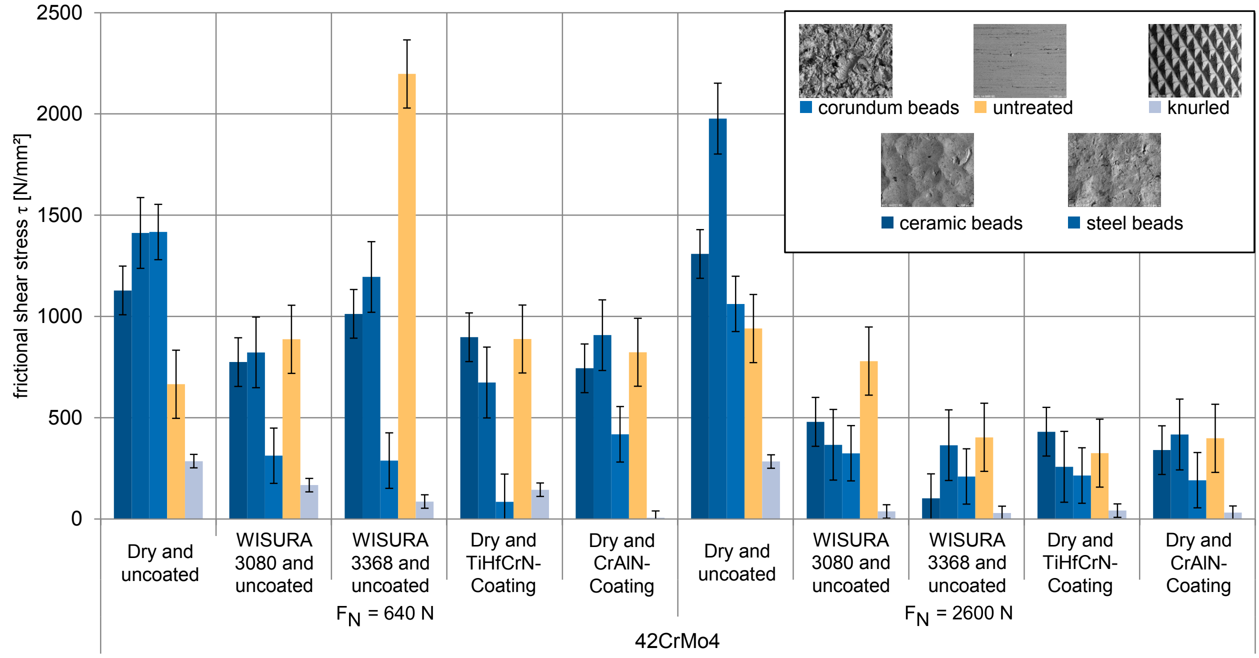

Figure 3: Frictional shear stresses with different surface structures, different tool materials and their coating

4 Recommendations based on performed tribotestings

In Section 4 recommendations for a tribosystem in dry but also lubricated metal forming processes are given based on experimental results. The recommendations are presented using Harvey-Balls, Tab. 1.

Table 1: Harvey-Balls and their meanings

	Improvement	Degradation
Degressive	◔	◔ (dashed)
Linear	◑	◑ (dashed)
Progressive	◕	◕ (dashed)
Exponential	●	● (dashed)

The recommendations cover the materials from the tribotestings given in Section 3. In addition the tribotesting results with the tool material 1.2379 and also with the workpiece material 16MnCr5 are included.

In Table 2 recommendations for an untreated surface structure are given. The initial state is without the use of lubricant and a tool coating. The best results concerning low frictional shear stress can be reached by using the 42CrMo4 steel with the high-speed steel 1.3343. The tribosystem should be supported by the lubricant WISURA 3368, or with the aim to perform a dry forming, with the CrAlN coating. This coating is less supportive at higher normal loads. The tool material 1.3343 is harder than 1.2379. The workpiece material 42CrMo4 as well is harder than 16MnCr5. Due to higher hardness adhesion is prevented and lower frictional shear stresses evolve. The coating supports even more. In general, an overview of Tab. 2 suggests, that an untreated surface structure should be avoided. All lines consist of more rises of the frictional shear stress as reductions.

The recommendations for the shot peened and knurled surface structures are compared to the initial state of an untreated surface structure, which has its own initial state in a dry contact with an uncoated tool. The next recommendations are valid for corundum shot peened surface structure, Tab 3. The resulting surface structure is rough and hardened throughout the shot peening process. A rougher surface structure is smoothened in faster. This leads to a higher contact area and a lower frictional shear stress. Compared to Tab. 1 the first line consists of both positive and negative influences in equal parts. For an uncoated tool the best re-

Table 2: Recommendations for untreated workpiece surface

	Untreated workpiece material	42CrMo4				16MnCr5			
	Tool material	1.2379		1.3343		1.2379		1.3343	
	Contact force F_N [N]	640	2600	640	2600	640	2600	640	2600
Contact condition	Dry and uncoated	○	○	○	○	○	○	○	○
	Lubr. Wisura 3080 and uncoated	-	-	◑	◑ (dashed)	-	-	◑ (dashed)	◔ (dashed)
	Lubr. Wisura 3368 and uncoated	-	-	◕	● (dashed)	-	-	◔ (dashed)	◔ (dashed)
	Dry and TiHfCrN coating	◑	◑ (dashed)	◕	◑ (dashed)	◑ (dashed)	◑ (dashed)	◑ (dashed)	◑
	Dry and CrAlN coating	◑	◕ (dashed)	◕	◕ (dashed)	◕ (dashed)	◕ (dashed)	◑	◑

Table 3: Recommendations for corundum shot peened workpiece surface

Corundum shot peened workpiece material	42CrMo4				16MnCr5			
Tool material	1.2379		1.3343		1.2379		1.3343	
Contact force F_N [N]	640	2600	640	2600	640	2600	640	2600
Contact condition: Dry and uncoated	●	◔	◷	◌	◐	◐	◶	◷
Contact condition: Lubr. Wisura 3080 and uncoated	-	-	◕	◕	-	-	●	○
Contact condition: Lubr. Wisura 3368 and uncoated	-	-	●	◕	-	-	◐	◷
Contact condition: Dry and TiHfCrN coating	●	◕	●	●	◔	○	◔	◍
Contact condition: Dry and CrAlN coating	●	◶	●	◐	◕	○	◕	◌

sults for a contact condition can be reached with the lubricant WISURA 3080. This first line shows no negative effect compared to the initial state. The combination of the TiHfCrN coating without any lubricant is able to reduce the frictional shear stress even more. But used on a 16MnCr5 workpiece it results in higher frictional shear stresses as compared with a lubricant and in some parts even higher ones than in the initial state. In the end a first improvement is visible for a combination of the shot peened surface structure with a coating. Frictional shear stresses as low as with a lubricant were reached.

Next the ceramic shot peened surface structure is examined, Tab 4. The surface stochastically evolved rather in a flat geometry. The ceramic bead particles have rather a round geometry and at the same time have a lower hardness than the corundum beads. The use of these beads results in a flatter surface than the corundum shot peened one. The softer and flatter surface structure leads to a slower smoothing. By means of a slower smoothing the contact area is lower and the stresses rise. So the recommendations for that surface structure are nearly equal those given before, but in some points not as good as for the corundum shot peened structure. Overall it is shown that this surface structure should be used just with the harder workpiece material 42CrMo4. The results for 16MnCr5 are not so uniform as for 42CrMo4. More experiments are required to recommend a certain stress area where this surface structure can also be used for 16MnCr5. As actually stresses are irregular in forming processes and not predictable without the knowledge of friction, the use of this surface structure should be avoided for higher loads.

The next recommendations are valid for a steel shot peened surface structure, Tab 5. The beads are equally round as the ceramic ones, but softer. The generated surface structure is rather flat compared to the corundum shot peened surface and equal to the ceramic shot peened structure. The resulting surface structure is not hardened as much as the ceramic or corundum ones. At the initial state a positive influence can be seen only for lower normal forces and the use of 1.2379 as tool material. A shot peened surface structure just lowers the frictional shear stress with decreased normal loads. The best results were reached with 1.3343 tool material and every contact condition except the dry and uncoated one. There is no combination of contact conditions, tool material and workpiece material, which throughout leads to lower frictional shear stresses. Concluding it has to be stated that the steel shot peened surface structure is the least aimed shot peened structure. The benefits are neither very high nor continuous for any combination.

The last considered surface structure is generated by knurling, Tab. 6. Compared to the shot peened structures a knurled one is even. Knurling results in the highest roughness and at the same time the lowest hardness of the surface structure compared to the ones before. The combination of these properties supports a lower

Table 4: Recommendations for ceramic shot peened workpiece surface

Ceramic shot peened workpiece material	42CrMo4				16MnCr5			
Tool material	1.2379		1.3343		1.2379		1.3343	
Contact force F_N [N]	640	2600	640	2600	640	2600	640	2600
Contact condition: Dry and uncoated	◐	●	◍	◶	◐	◔	◌	◍
Contact condition: Lubr. Wisura 3080 and uncoated	-	-	◕	◷	-	-	◐	◶
Contact condition: Lubr. Wisura 3368 and uncoated	-	-	●	◶	-	-	◐	◶
Contact condition: Dry and TiHfCrN coating	◐	◐	◕	◍	◕	◷	◐	◌
Contact condition: Dry and CrAlN coating	◔	◶	◶	◷	◍	◶	◶	◌

Table 5: Recommendations for steel shot peened workpiece surface

Steel shot peened workpiece material		42CrMo4				16MnCr5			
Tool material		1.2379		1.3343		1.2379		1.3343	
Contact force F_N [N]		640	2600	640	2600	640	2600	640	2600
Contact condition	Dry and uncoated	◔	◑ (dashed)	dashed tick	dashed tick	◕	○	dashed tick	○
	Lubr. Wisura 3080 and uncoated	-	-	◕	◕ (dashed)	-	-	◔	◑ (dashed)
	Lubr. Wisura 3368 and uncoated	-	-	◕	◔ (dashed)	-	-	◔	◔ (dashed)
	Dry and TiHfCrN coating	◑	◔ (dashed)	◕	○	○	○	○	◔ (dashed)
	Dry and CrAlN coating	◕	◔	◕	◑ (dashed)	◕ (dashed)	◕ (dashed)	◕ (dashed)	◔ (dashed)

frictional shear stress. Due to the rather soft surface the smoothing of the surface is reached faster. At the same time the tool interacts with the surface peaks, so the normal load is applied on a smaller surface, the flow stress is reached faster and the surface is flattened in faster. Overall the knurled surface structure leads to the lowest frictional shear stress and thus to the best results. Independent of the contact conditions it nearly always leads to an improvement of the friction state. The only degradation can be found with the use of the lubricant WISURA 3080, 16MnCr5-steel and a normal load of F_N = 2600 N. The smoothing process with the use of a lubricant benefits from evolving lubricant pockets, which also lower the frictional shear stress. Experimental investigations of a lubricated contact condition with the tool material 1.2379 are still to be done. Respectively all experiments, the combination of a dry forming with the TiHfCrN coating leads to the best results and might support a dry full forward extrusion process.

5 Summary and outlook

Based on the purpose of a lubricant-free factory different approaches for dry metal forming in cold forming were presented. For a detailed investigation experimental investigations were done. Based on these results recommendations for surface structures in dry but also lubricated metal forming were made. Overall it is stated that a rough and not hardened surface structure on workpieces supports metal forming processes. This was best fulfilled by the knurled surface structure. It positively influenced a dry metal forming process and also a lubricated forming process.

In further work the results need to be transferred to an industrial forming process for example full forward extrusion. In modern forming processes workpieces with a surface structure and a sulfate coating are used and support a productive forming process. The influences of different surface structures are not known yet and need further investigation. Tribotests revealed the tendency that dry metal forming can be fulfilled. However, as the stresses vary over the process and different tribostates evolve a prediction of these specific results has to be experimentally investigated.

Acknowledgements

The research was funded by the German Research Foundation (Deutsche Forschungsgemeinschaft DFG) within the priority program „Dry metal forming – sustainable production through dry processing in metal forming (Trockenumformen – Nachhaltige Produktion durch Trockenbearbeitung in der Umformtechnik (SPP 1676)).

References

[1] F. Klocke: Manufacturing processes 4 – Forming, Springer, (2013).

[2] H. Czichos, K. H. Habig: Tribologie-Handbuch. Tribometrie, Tribomaterialien, Tribotechnik. Springer, (2010).

[3] E. Lugscheider, K. Bobzin, C. Pinero, F. Klocke, T. Massmann: Development of a superlattice (Ti,Hf,Cr)N coating for cold metal forming applications. Surface and Coatings Technology, 177-178 (2004) 616-622.

[4] F. Vollertsen, F. Schmidt: Dry Metal Forming: Definition, Chances and Challenges. Int. J. Precision Engineering and Manufacturing – Green Technology 1/1 (2014) 59–62.

[5] M. Murakawa, N. Koga, T. Kumagai: Deep-drawing of alumi-

Table 6: Recommendations for knurled workpiece surface

Knurled workpiece material		42CrMo4				16MnCr5			
Tool material		1.2379		1.3343		1.2379		1.3343	
Contact force F_N [N]		640	2600	640	2600	640	2600	640	2600
Contact condition	Dry and uncoated	●	◕	◕	◕	●	◑	◑	◑
	Lubr. Wisura 3080 and uncoated	-	-	●	◕	-	-	●	◑ (dashed)
	Lubr. Wisura 3368 and uncoated	-	-	●	●	-	-	●	◕
	Dry and TiHfCrN coating	●	◕	●	●	●	◕	●	◕
	Dry and CrAlN coating	●	◕	●	●	●	◑	●	◕

num sheets without lubricant by use of diamond-like carbon coated dies. Surf Coat Tech 76 (1995) 553–558.
[6] M. Murakawa, S. Takeuchi: Evaluation of tribological properties of DLC films used in sheet forming of aluminum sheet. Surf Coat Tech 163 (2003) 561–565.
[7] S. Kataoka, A. Motoi. Improvement in DLC thin film adhesion and its application to dry deep drawing. J. Jpn. Soc. Technol. Plast 46/532 (2005) 412–416.
[8] S. Kataoka, M. Murakawa, T. Aizawa, H. Ike: Tribology of dry deep-drawing of various metal sheets with use of ceramics tools. Surf Coat Tech 177–178 (2004) 582–590.
[9] J. Lin, B. Mishra, J.J. Moore, W.D. Sproul: Microstructure, mechanical and tribological properties of $Cr_{1-x}Al_xN$ films deposited by pulsed-closed field unbalanced magnetron sputtering (P-CFUBMS). Surface and Coatings Technology, 201 (2006), 4329.
[10] K. Bobzin, T. Böhmermann, S. Bastürk, F.Klocke: Development of an in situ Plsama Treatment of X155CrMoV12 for a (Cr,Al)n PVD Tool Coating for Dry Metal Forming in Cold Forging. Dry Metal Forming Open Access Jorunal (2015) 57-62
[11] P. Mattfeld: Tribologie der zinkphosphatfreien Kaltmassivumformung. PhD-Thesis RWTH Aachen University (2014).
[12] D. Trauth, F. Klocke, P. Mattfeld, A. Klink: Time-Efficient Prediction of the Surface Layer State after Deep Rolling using Similarity Mechanics Approach. Procedia CIRP 9 (2013) 29–34.
[13] D. Trauth, F.Klocke. P. Mattfeld, K. Bobzin: Multiscalfe FE-Studies of Contact Stresses of Dry and Lubricated Shot Peened Workpiece Surfaces. Dry Metal Forming Open Access Journal (2015) 11-16
[14] D. Trauth, R. Hild, P. Mattfeld, S. Bastürk, T. Brögelmann, K-Bobzin, F. Klocke: Advances in dry metal forming of low alloyed steels for cold forging using a (Cr,Al)N tool coating and surface structures on workpieces. In: Proceedings of the 12th international conference THE "A" coatings in Manufacturing Engineering, Hannover, Germany, March 31st – April 1st (2016)