SIGNIFICATION OF TRIBOLOGY BENCH TESTS IN COLD BULK FORMING

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SUMMARY
In the field of bulk metal forming there is no standardized test to analyse friction and wear corresponding to the strip test in sheet metal forming. A lot of test principles were invented in the field of bulk metal forming, the problem is to choose an appropriate one to gain realistic results. In the specific case of bolt manufacturing it is recommended to utilize a test principle which is based on extrusion.

The aim of the introduced project is to replace zinc phosphate coatings on the wire and to enable medium-size companies to rely on an environmentally friendly tribology system. The concept to optimize production is to use thin film coatings on the tools and new lubrication systems. Even surface topographies of tools and wire contribute to the suitability of the tribology conditions.

Keywords: Cold extrusion, Friction test, Tool coating, Wire, Zinc phosphate coating

1 INTRODUCTION
Due to intensified competition industry companies are forced to lower energy consumption and environmental impact.

In the field of cold extrusion zinc phosphate coatings are used as parting layers on the workpiece and lubricants containing oil, soap or molybdenum disulphide to bear the high tribological loads. Application and removal of lubricating systems raise ecological problems such as origination of chemical waste.

The aim is to develop an environmentally acceptable tribology system for cold forming processes. Therefore friction and wear bench tests are required which take the tribological loads of the production processes into account. These laboratory results help to save money and time by designing production processes.

2 TRIBOLOGY BENCH TESTS
Particularly wear tests are known in bulk metal forming. DIN 50322 shows different categories from production trials to basic tests under laboratory conditions. This structure can also be applied to friction tests. Many test principles enable the user to evaluate friction and wear in one test.

Each test may have its special advantages like low expenditure and similarity to forming conditions.

Production trials are realistic but connected with immense costs and the results normally just allow to evaluate the forming possibility of a specific component, often reproducibility is poor [1, 2]. Pin on disc tribometer tests or similar principles cannot meet the conditions of real forming processes because no plastic flow of the workpiece occurs.

Because of this an extrusion test was set up to model the conditions of cold bulk forming. It is the first forming stage of a M16 bolt. Determined by the geometrical similarity of the produced product the tribological loads like contact normal stress, sliding velocity and surface enlargement are similar to many related processes. It is possible to use original material, in this case wire with a diameter of 16.5 mm, from the production process.

For an assessment of the quality of a lubrication system it is more important to be close to reality conditions then to use an abstract test. It should not be unmentioned that many of these abstract tests comprise the opportunity to evaluate friction coefficients which can be used additionally to gain friction conditions for a FEM-simulation.

2.1 Test stand and principle
The test stand is a hydraulic press with an upsetting force of 1000 kN. In this press a tool system is implemented (see figure 1). It consists of a bottom die, the die ring and a centering ring. The die is placed on a plate with a centering hollow. The stamp has a centering section also.

The specimen is inserted in the centering ring and fixed through a light pressing process. The centering ring is removed and the test piece is pressed into the bottom die. The forces can be measured by piezoelectric cells. Because of unchanged material and constant forming conditions for each part it is possible to compare the forces of the changed tribology systems. Higher forming
forces lead to higher friction forces, so generally it indicates an inferior tribology system.

![Figure 1: Extrusion test tool system](image)

2.2 Scheme of trials

The matrix of trials is aimed to show the potential of optimization possibilities concerning hard coatings on the tool and lubricants in conjunction with wire topographies and coatings.

A prior project for dry cold extrusion has contributed to this project. Field production and wear bench tests like in [1, 3] show that wear resistance of CVD coatings is better than PVD coatings for dies in cold forming, which tend to chip off. For this reason CVD TiC/TiN coatings on the tool are analyzed in this study in conjunction with soft coatings like PTFE, WS2 and MoS2 which should have a lubricating function or with layers based on carbon like DLC, MeCH to combine protection against wear and decrease in friction.

The chosen lubricants extend from an ordinary extrusion oil to a pigmented oil and an emulsion. Surface topographies of drawn or hot rolled wire spread from sandblasted parts, bonderized parts to pickled parts as provided from the steel works or wire drawing shops.

3 EVALUATION OF FRICTION AND WEAR

3.1 Variation of tool coatings

The variation of the described hard coatings was carried out with pickled wire without additional application of lubricant to evaluate the dry running properties. Considering these tough conditions, the friction test becomes also a wear test. Figure 2 displays the measured maximum upsetting forces in average of the amount of trials carried out under the same conditions. Normally a series of 50 trials was carried out to be statistically reliable, often with two equally coated bottom dies.

![Figure 2: Upsetting forces versus coatings](image)

Concerning friction the results can be divided into three areas. The group of coatings with low friction like MeCH and CVD TiC/TiN+MeCH, high friction like CVD TiC/TiN+WS2 or CVD+PTFE due to wear phenomenon. These coatings show partial wear in form of removed coating material. In between coatings like CVD TiC/TiN, CVD+MoS2, DLC or uncoated dies can be found.

A MeCH-coating is a metalliferous amorphous hydrocarbon coating [4] which is in general also called a Me-DLC-coating and here present in form of a W-DLC layer. The tested DLC-coating is also named as a-C:H-layer. A close look reveals the local abrasive wear of the DLC- and local chipping of the CVD TiC/TiN+MeCH-coating. For this reason the adherence of carbon based layers on CVD layers was optimized. Both, an improved wear resistance and a decrease in friction forces were achieved. Figure 3 proves the success in the scope of friction forces. The wear resistance is still not sufficient at all and a present challenge for coating companies.

![Figure 3: Series with and without oil](image)

To verify the results of the first series under more production-like conditions the experiments were repeated with a salt coating on the wire and a pigmented cold pressing oil. Figure 3 displays the good dry running conditions of the carbon based layers because even a better tribology system can hardly lower friction forces. One reason for this is a low tendency for adhesion.

The requirements and demands of coatings are comprehensive. Surface roughness for instance is one influencing variable. Trials showed in general that
smooth layers provide lower friction. The lubrication bore reliefs have not the same effect as on the wire due to the degree of hardness, so the tool surface does not provide any levelling.

Furthermore, figure 3 shows that a good result of a tool coating in the dry series test conclude to good results with lubricant.

The lubrication system of salt coating in combination with a pigmented cold pressing oil adjusts the differences in friction between the different coatings. But still the test is so reliable that it is possible to distinguish between the group of CVD TiC/TiN+MeCH, especially the optimized one and MeCH which provide low friction and the group of CVD+MoS2, CVD+WS2, CVD+DLC and DLC with its higher friction forces. In between the uncoated and the CVD+PTFE-coating can be found in the ranking. Particularly the soft coatings are supposed to lead to low friction. They demonstrate improved results under these conditions in comparison to the previous test. But the soft surface layers cannot stand the tribology loads in production concerning wear as proved in the dry running test.

3.2 Variation of wire surfaces and lubricants

In the first forming stage of a forming process the salt coated wire parts provide hardly more friction combined with zinc phosphate coated wire. In a multi stage process the salt layer is removed over the stages because it is not a chemical crystal growth on the substrate like zinc phosphate. So zinc phosphate layers can endure high surface enlargements without problems. The pickled wire quality shows higher friction than the zinc phosphate reference system.

Particularly remarkable are the low friction forces of sandblasted wire topographies (see figure 4). Under contact pressure a hydrostatic pressure can be built up in the craters during the forming action. A performed experiment with different roughnesses show that rougher topographies lead to lower friction forces.

The rolled wire parts provide higher upsetting forces than the drawn ones because the annealed wire comes to the last drawing stage and is reduced from a 17 mm to a 16.5 mm diameter which is just accompanied by a little work-hardening.

The variation of different lubricants reveals just a small potential of optimization in this direction which can be seen in figure 5. The pigmented oil and the emulsion adapt more successfully to the process conditions in relation to the standard cold pressing oil. The unsatisfactory results of the oil, which is highly enriched with additives, can be explained by its chemical unstability.

Even an increase in the amount of lubricant cannot decrease friction in general (see figure 6). Every topography is related to a maximum of effectively usable liquid lubricant. Using a higher amount does not influence the friction conditions any further.

4 PRODUCTION FIELD TRIALS

An important asset of laboratory tests is to minimize production field trials and to give planning advice for further tests or tribology systems. A verification of the bench test results is inevitable.

4.1 Production of a M16 screw

This production is a multi stage process. First the wire part is sheared off from a coil. Then the shank is reduced. Afterwards the head is upsetted and a second reduction is done for the threaded section. Not mentioned here are the stages of cutting of the head to a hexagon and rolling of the threads.

The described trials were all carried out with a CVD TiC/TiN coating on the tools of the different forming stages. As lubricant a standard cold pressing oil was used. There is no possibility to make a statement about friction but it is possible to analyse wear occurrences.

The pickled wire leads to fractures of the head upsetting stage die. Probably it is connected with the ejecting procedure of the part. The friction is quite high so the
part sticks to the die surface caused by the lack of a separating coating on the wire.

The salted wire causes a higher wear impression in the third forming stage because the salt coating is removed over the stages and this results in an accumulation of mud in the oil which in addition is a negative effect. Without the wear effects this problem could be solved by filters.

Quite good results are provided by the blasted wire parts. They only lead to superficial fissure in the edge of the head upsetting die. But the handling of this kind of wire is more unpleasant for the workers and the feeding rolls show abrasive wear. This problem may be solved by coatings, too. And it is worth mentioning that the results of the sandblasted wire could be better when not blasted in coil form but in a continuous procedure. So a homogeneously descaled surface quality is achievable.

The currently achieved tool lives with a CVD coating and different wire qualities are still not sufficient under economical aspects. Actually options of optimization exist as far as coating and lubricant are considered. The specific forming procedure with its impact on the wire when touching the tool should be taken into account. Eventually simulation can help to redesign tools and to minimize forces. So the chip off of coatings can be prevented and the following abrasive wear of the substrate may not occur.

4.2 Extended product spectrum

Probably these problems do not set in at forming processes where the decline in impact goes along with more relevancy of friction caused by a bigger contact area. Accordingly, products with greater strain particularly manufactured in one or two stages seem to be more suitable for a phosphate-free production.

Further investigations with a M8 and a M6 screw may confirm this assumption and additional knowledge about drawn wire will be collected. A contrary aspect consists in the demanded precision of this small screws.

5 CONCLUSION

The scope of the project to avoid zinc phosphate coatings to minimize the environmental impact is still a much discussed and challenging topic. The chosen approach to substitute the phosphate coating by the utilisation of wear resisting layers and alternative wire coatings and topographies seems to be practicable. From the environmental point of view it is recommended to relinquish chemical descale at all. Probably it is not possible to realize phosphate-free forming for all parts, but it is the first step to gain information about forming processes where it is likely to achieve the defined goal.

Further optimization potential lies in the performance of the hardcoating but also in the development of new surface topographies and their application. Accordingly the lubricant suppliers are requested to intensify their additives in the field of production with coated tools.

The production field trials indicate a predictability concerning the wear results of the wire variation in the extrusion test. This points out the significance of tribology bench tests within bulk metal forming.

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7 REFERENCES