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	Project No.
Fraunhofer Institut für Schicht- und Oberflächentechnik	**01.04.2008 – 30.09.2010**
Name of the research institute	Duration of the project

Progress report for the period from 01.01. – 31.12.2008

For the Collective Research NETworking (CORNET)
fundet by the BMWi in collaboration with the

Title of the project:

Load-related Design of Coatings for Forming Tools (LorCoT)

Braunschweig, 22.04.2009	
City, Date	Signature of the project leader

Progress report for the period from 01.01. – 31.12.2008

1 Title of the project

Load-related Design of Coatings for Forming Tools (LorCoT)

2 Project summary

Technical project summary
The potential benefits of tool coating for forming technology, like forging, deep drawing or bending, is generally known within the industry. Yet companies' uncertainty remains in selecting a suitable coating for its individual needs, as negative experience in selecting the wrong coating is not that unusual. This leads to scepticism in the application of coatings and especially new coating systems and forming operations that are relatively new to the field. The benefits for cost savings and a more efficient and effective production process through tool coating are therefore often not reaped.
By means of the targeted research results it should be possible to integrate coating into the construction process of dies, as it has already become state of the art with die materials. Based on the press profile of the die, specifications for the die materials will be produced. This will include limits for material characteristics that are crucial for the successful functioning of the die. According to these guidelines, the material selection and the heat treatment of the material will be derived. On the other hand, the selection of die coatings within the design process has been based almost exclusively on past experience and this leads to significant uncertainties. By reaching the established research goals an important contribution for the effective application of die coating will be achieved.
Functional guidelines for tool coatings will be developed based on the analysis of the research results and the determined correlation between tool loading, layer characteristic and application suitability. These guidelines will consider the loading conditions of the concrete forming operation. Furthermore, testing guidelines will be developed which contain the description of the test process and the boundary conditions to be observed.

Economic impact/Potential to exploit the R&D results
The research project is especially important for SMEs. Since the manufacturing of forming tools, tool coatings and the realization of sheet metal parts is a domain of SMEs, the use of the project results can have a significant impact on the market position and the economic situation of these enterprises. Based on the determination of layer characteristics and the identification of critical tool loadings in forming processes (sheet metal forming, bulk metal forming), the basics for the process-related characterization and consequently guidelines for the process-related design of tool coatings can be developed. These results can be used by coating manufactures, tool manufactures as well a by part manufacturers.
The target development of test methods for the evaluation of the layer/coating characteristics will contribute to an improvement of the process stability especially in the forming process. However, these tests can be also used by the coating and tool manufacturer for the quality assurance.
In consideration of the above mentioned effects of the project results concerning

- an opening of new markets,
- the saving and generation of new jobs and
- a higher qualification of the employees

The project will also influence the life quality. Save jobs, high qualification and a challenging work are important precondition for the satisfaction of the employees!

3 Technical and scientific methodology

Forming processes with a wide application field (deep drawing, bending) will be investigated concerning the intensity and extent of the incurred tool loading. These investigations will be based on the aspects: Geometry elements within the part geometry, sheet material and thickness, tool material, drawing and bending radii, size of the area to be coated, kind of coating and used lubricant. In order to achieve realizable results within the projected period, the loading analysis will be focused on a partial spectrum which will be selected by the project consortium.

The design and construction of a testing tool is planned to investigate the application properties of the coated tool components. Numerous loading conditions achieved through varying the active tool geometry and by modifying the technical process parameters can be used to realize a defined formed part. This requires a tool design with exchangeable active parts so that the testing of tool coatings under different loading conditions is possible with a reasonable amount of effort. In consideration of these aspects, the realization of a deep drawing tool seems to be an appropriate solution.

The objective of the FE simulation of the selected forming process under consideration of the tool and process variants is the localization of loading peaks on the tool surface and the estimation of the loading size. The simulation results will then be verified by forming tests using measuring films for pressure determination.

The test tools for the forming tests will be coated together with tool components which will be used for the determination of coating characteristics in destructive test procedures. These tools are identical to the forming tools and the coating process will be conducted according to the test program. To guarantee the transferability of the investigation results, the coating processes, pre-treatment procedures and coating devices will be used that reflect the state-of-the-art in industrial coating. Reference specimens of the same tool material and with the same surface conditions as the test tools, as well as polished specimens will be coated in order to determine the influence on the coating characteristics. Similar reference specimens will be used in the coating chamber to control the uniformity of the coating process.

An accurate, reproducible characteristic determination is needed to derive the correlation between coating properties and the application properties of PVD layers. To do this, the use of standardized test procedures including scratch tests, modified scratch tests (multi-pass scratch-test, scratch-tests with constant loading) and hardness measurements are planned. Modified scratch tests allow a load-dependent simulation of the wear behaviour of hard material layers. The positions for the coating characterization on the test tools before their use will be selected based on the technical coating aspects (edge effects or limited accessibility for the coating) and according to the size of locally occurring loadings. The focus of these investigations will also be placed on the various scratch tests.

The goal of the experimental investigations is to verify the results from the FEM simulation in regard to the size of the coating load and to evaluate different loading condition on the tool coating. This allows the load-dependent wear behaviour of the coating to be investigated under true application conditions.

Functional guidelines for tool coatings will be developed based on the analysis of the research results and the determined correlation between tool loading, layer characteristic and application suitability. These guidelines will consider the loading conditions of the concrete forming operation. Furthermore, testing guidelines will be developed which contain the description of the test process and the boundary conditions to be observed.

The derived work packages and their leadership are summarized in the following table:

Work Package	Party
1. selection of relevant forming processes	IWU
2. conception, design, realization of test tooling	DIMEG
3. FEM simulation of loading conditions of test tooling	TECOS
4. coating of tool components and specimens for determination of layer characteristics	IST
5. determination of layer characteristics on reference	IST
6. experimental investigation with active tool components	IWU
7. analysis and systematization of test results	IWU
8. development of a standard procedure for the generation of specifications for the design of tool coatings	IST
9. development of a standard procedure for the evaluation of coatings on active tool components	IST
10. final report	IWU

4 Progress status of the tasks and achieved results during the report period

During the reported period the Fraunhofer IST was involved in the work packages 1, 4 and 5. The accomplished work and achieved results can be summarized as follows:

Work package 1: selection of relevant forming processes

The objective of this first project step was the investigation and analysis of forming processes with a wide application field concerning the intensity of occurring tool loadings. Evaluation criteria were

- geometry elements inside the global part geometry
- sheet material / thickness
- used tool materials
- size of drawing / bending radii
- coating scope of active tool components
- coating system
- lubrication system

To guarantee a universally valid statement despite of the variety of parameters within the planned time period, the analysis was supported by each national project consortium (selection of relevant part spectrum).

Task of the Fraunhofer IST within this work package was the selection of relevant coating systems in dependency on the used sheet material, the expected dominant wear mechanism (adhesive or abrasive), the forming temperature and the expected loading. According to these criteria the following coating systems were selected for the determination of layer characteristics on reference specimens using standardized tests in work package 5.

Titanium based coatings: (for high loads and high abrasive wear)

- TiN
- TiAlN

Chromium based coatings: (for high loads and high forming temperatures)

- CrN
- CrVN (reduced friction)

Boron based coatings: (for high forming temperatures and high adhesive wear)

- TiB_2
- TiBN

Carbon based coatings: (for dominant adhesive wear e.g. for aluminium forming)

- a-C:H with Titanium adhesion layer
- a-C:H + plasmanitriding (additional plasmanitriding for higher load resistance)
- a-C:H:Ti
- a-C:H:W
- CrN + a-C:H (additional CrN interlayer for higher load resistance)
- CrN + a-C:H:W (additional CrN interlayer for higher load resistance)

Work package 4: coating of tool components and specimens for determination of layer characteristics

The test tools for the forming tests will be coated together with tool components which shall be used for the determination of coating characteristics in destructive test procedures. These tools will be identical to the forming tools and the coating process which will be conducted according to the test program. To guarantee the transferability of the investigation results, the used coating processes, pre-treatment procedures and coating devices has to reflect the state-of-the-art in industrial coating.

In preliminary tests reference specimens of the same tool material and with similar surface conditions as the test tools, as well as polished specimens were coated with the above-mentioned coating systems in order to determine the influence on the coating characteristics. Similar reference

specimens will be used in the coating chamber during the coating of the test tools to control the uniformity of the coating process.

In order to evaluate the influence of complex sample geometries (e.g. grooves or shoulders) on the coating characteristics a dismountable holder with cavities for flat samples was designed and built (see Fig. 1).

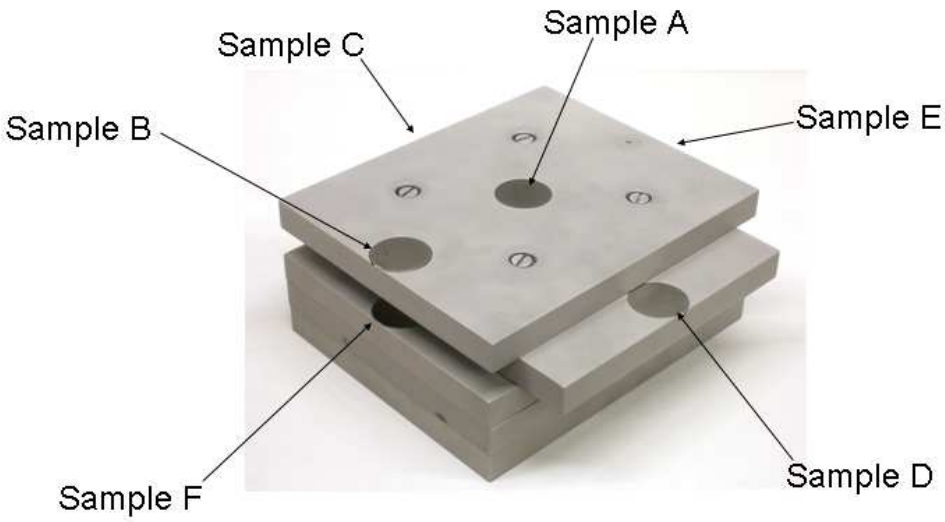


Figure 1: Dismountable sample holder to evaluate the coating characteristics in grooves, on shoulders and near edges.

Work package 5: determination of layer characteristics on reference specimens using standardized tests

An accurate, reproducible characteristic determination is needed to derive the correlation between coating properties and the application properties of PVD layers.

The following standardized test procedures were applied to characterize the coated samples from work package 4:

- Test of adhesive strength by Rockwell-test to VDI 3198
- scratch test according to DIN VENV 1071 part 3
- modified scratch tests (multi-pass scratch-test, scratch-tests with constant loading)
- hardness measurement according to DIN 50359 1
- wearing tests
- determination of coating thickness
- determination of friction coefficient

The first results of the coating characterization are summarized in the table 1 and figure 2 and 3. Next steps are the systematization of the test results and the characterization of different coated samples from the dismountable sample holder (Fig. 1).

Table 1: Results of the coating characterization on flat samples

Coating	**Thickness** [µm]	**Vickers hardness** [HV 0,05]	**Wear** [$m^3m^{-1}N^{-1}10^{-15}$]	**Scratch Test Lc_2** [N]
TiN	4,3	2563	3,25	60 - 65
TiAlN	3,4-3,7	2476	6,05	26 - 28
CrN	3,1-3,5	1589	7,26	>80
CrVN 13%	5,1-5,4	2185	3,29	30 - 35
CrVN 27%	5,9-6,1	2278	4,49	35 - 43
TiB_2	3,7-3,9	2043	1,84	13 - 14
TiBN	3,9-4	1186	4,55	30 - 33
a-C:H with Ti interlayer	2,4-2,6	2575	0,9	28
a-C:H plasmanitrided	3,8-3,9	2081	0,92	43-49
a-C:H:Ti	3,9-4,1	1727	3,66	19-25
a-C:H:W	3,5-3,9	1317	2,54	38-40
CrN + a-C:H	7,3	2068	0,88	41-48
CrN + a-C:H:W	6,2-6,4	1271	3,01	65-73

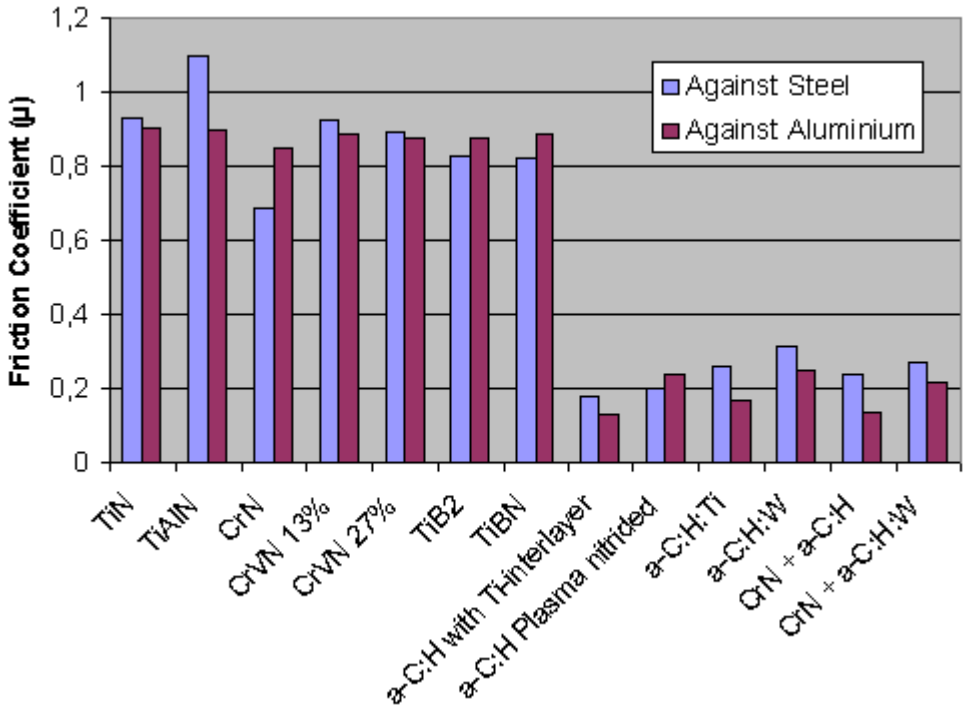


Figure 2: Coefficient of friction of various coatings against steel and aluminium

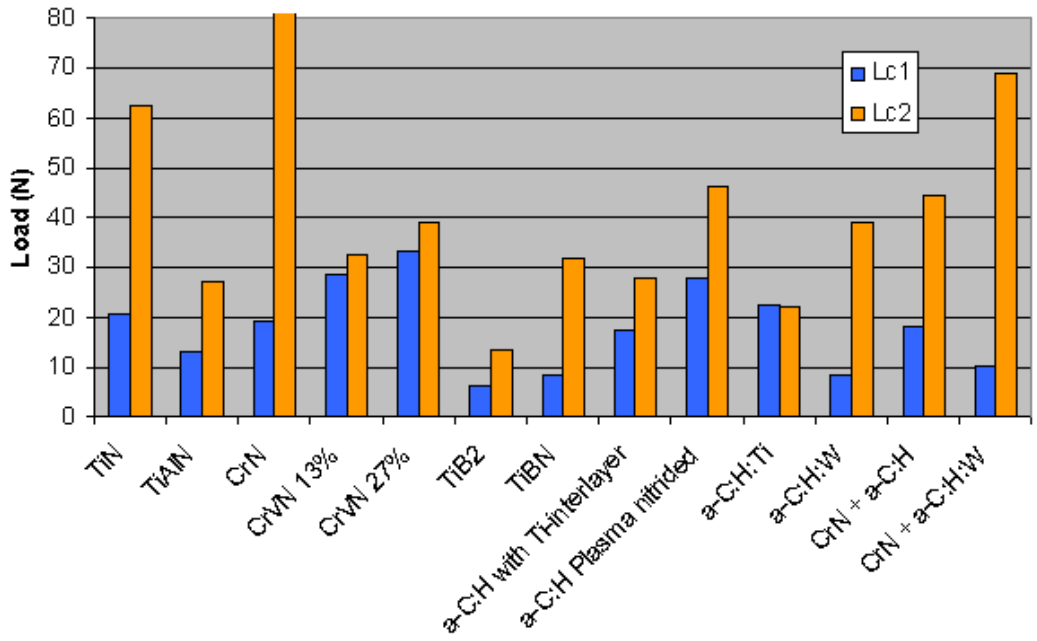
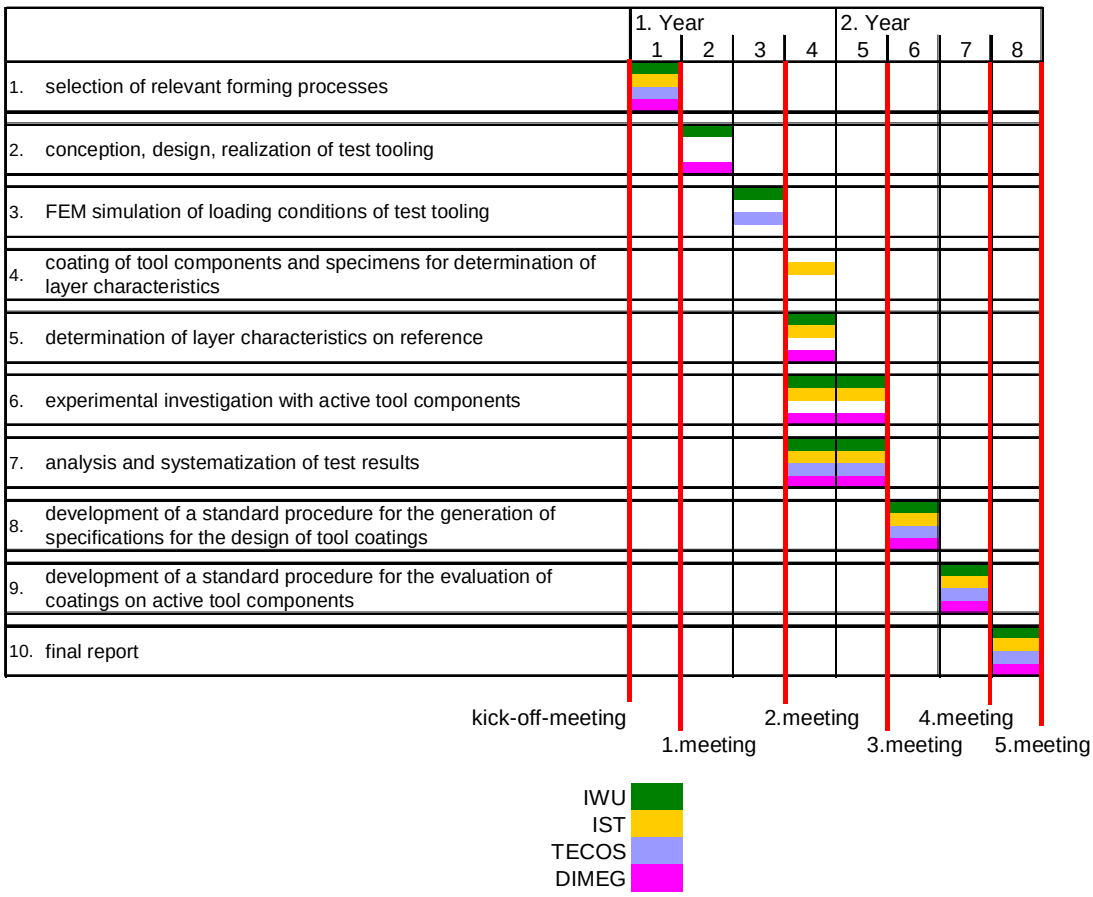


Figure 3: Critical loads of the various coatings measured with the single-pass scratch-test

5 Compliance with the work program

The tasks executed by the Fraunhofer IST are in compliance with the initially planned time schedule (Table 2). Task 4 + 5 were started somewhat earlier than planned. Due to a time delay at the Italian partner DIMEG an extension of the project term of 6 month was applied and conceded. This will cause a corresponding time delay in the following work packages in 2009.

Table 2: Initially planned time schedule



6 Appropriation of the funding and adequacy of the conducted work

The tasks were executed in accordance with the funding schedule by 2 scientists (Wissenschaftliche Mitarbeiter, Dipl.-Ing.), 1 engineer (Technische Angestellte, Dipl.-Ing. Fh) and 1 student assistant (wiss. bzw. stud. Hilfskräfte).

All studies conducted within the framework of the project were necessary to achieve the planned results. New research findings, which would supersede some of the planned tasks, are not known up to now.

7 Dissemination and exploitation of the project results

During the project progress the work of the research institutes is supported by the attendant companies of the project consortiums, which consist of coating manufacturers, tool manufactures and tool users. During regular project meetings, the progress and achieved results regarding the milestones will be presented and discussed. Consequently, the know-how and knowledge transfer from the science into the practice is guaranteed from the beginning of the project.

Additionally, the project results will be published with the help of presentations during international congresses, articles in professional journals and with the help of an own website. In this case, the internet offers the chance to inform a wide range of interesting companies. Additionally, the enterprises of the project consortium and their main activities can be presented. This leads to an increase of the awareness level of the companies. Furthermore, workshops and seminars will be organized which represent an effective tooling for the dissemination of the project results. Additionally, the generation of a website

8 Research Performers

Research Performer 1:	Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik (IWU) Chemnitz, Germany Prof. Dr.-Ing. habil. Prof. E. h. Dr.-Ing. E. h. Reimund Neugebauer (Head of Organisation) Dipl.-Ing. Matthias Demmler (Contact Person)
Research Performer 2:	Fraunhofer-Institut für Schicht- und Oberflächentechnik (IST) Braunschweig, Germany Prof. Dr. rer. nat. Günter Bräuer (Head of Organisation) Dipl.-Ing. Martin Weber (Contact Person)
Research Performer 3:	Slovenian Tool and Die Development Center (TECOS) Celje, Slovenia Gašper GANTAR (Head of Organisation) Gašper GANTAR (Contact Person)
Research Performer 4:	DIMEG- Universität Padova (DIMEG) Padova, Italy Prof. P.F. Bariani (Head of Organisation) Andrea Ghiotti (Contact Person)