Collective Research for High Performance Manufacturing

Herzig, N.[*,1]**; Meyer, L.W.**[1]**; Musch, D.**[1]**; Halle, T.**[1]**; Trebels, J.**[2]**; Gudergan, G.**[2]**;**
Piontkowski, T.[3]**; Hild, S.**[4]**; Bleicher, F.**[5]**; Puschitz, F.**[5]**; Dorn, C.**[5]**;**
Kuen, P.[6]**; Palatin, T.**[6]**; Balažic, M.**[7]**; Kopač, J.**[7]**; Šostar, A.**[8]

[1] Chemnitz University of Technology, Materials and Impact Engineering,
09107 Chemnitz, Germany
[2] Research Institute for Operations Management, Pontdriesch 14/16,
52062 Aachen, Germany
[3] Industrial and Automotive Region West Saxony,
Lessingstraße 4, 08058 Zwickau, Germany
[4] Competence Center Automotive Region Aachen / Euregio Maas-Rhein,
Theaterstraße 35-39, 52062 Aachen, Germany
[5] Vienna University of Technology, Institute of Manufacturing Technology,
Karlsplatz 13, 1040 Vienna, Austria
[6] Automotive Cluster Vienna Region, Giefinggasse 2,
1210 Vienna, Austria
[7] University Ljubljana, Department of Machining Technology Management,
Asherceva 6, Sl-1000, Ljubljana, Slovenia
[8] Toolmakers Cluster of Slovenia,
Kidrečeva ulica 25, 3000 Celje, Slovenia

[*] corresponding author: norman.herzig@mb.tu-chemnitz.de, phone/fax: +49 371 531 36122 / 836122

Abstract

Central European manufacturing companies, especially small and medium sized enterprises (SME), are virtually unable to compete with low-price production from Eastern-Europe or Asia. The most pressure comes from manufacturers of relatively simple parts in low cost countries. Therefore, these SMEs need to focus on sophisticated high-tech parts and high-tech manufacturing technologies including machining of innovative materials.

Within this project, a transnational research team was formed containing partners from Germany, Austria and Slovenia. The project was funded by AiF, FFG and MHEST within cornet platform for pre-competitive collective research. A minimum of six SMEs from each of the three countries are organised in national user groups discussing demands for research, possible solutions, and progress of research activities. Hence, specialists on the scientific fields of material science, manufacturing processes, cutting tools and tool machines work together with SMEs in user groups to improve manufacturing processes and to enhance quality and tool life time and lead to High Performance Manufacturing (HPM). Based on basic and application specific investigations, an optimisation of machining processes, an increase of tool life time and quality of products and, hence, a reduction of costs shall be reached. One of the great advantages of this kind of research is that SMEs are directly included in research activities at the universities and results obtained during project work are directly transferable to SMEs in so called HPM pilot implementation projects.

Within this paper, a discussion of the project idea and the best way of practise are discussed. Exemplarily, the basic approach of the project is presented and the implementation of HPM pilot site implementations into SMEs is discussed.

Keywords: Collective Research, High Performance Manufacturing

1. Introduction

Continuing globalisation leads to increased influence not only on consumer goods markets, but on industrial goods markets, too. Increased influence of Asian and East European producers leads to increased competition pressure for Central European companies, especially within manufacturing industrial sector [1]. Hence, low price consumer goods are used for lasting opening of new markets by so-called low price production countries. Due to low production costs, competitors are able to offer so called low price consumer and industrial goods (penetration pricing). Especially, for mass products which can be substituted easily

Central European companies are nearly not able to hold one's own within price competition, which is mainly due to higher personnel costs during manufacturing processes [2], [3].

However, in such competition situation higher goods prices are not tolerated by customers. Hence, in direct consequence proceeds are reduced. If small and medium sized enterprises (SME) want to hold one's own, significant lower margins have to be accepted and a short period of surviving shall be ensured. However, strategically an optimisation of the manufacturing processes and of the cost structure is required.

Arthur and Little [4] have shown that cost optimisation potentials within the segment of mass goods production has been nearly exhausted during last decades. Furthermore, a reduction of cost positions (e.g. personnel costs) is not appropriate as a realistic alternative. However, a strategically change for small and medium sized enterprises of Central European manufacturing industry is required.

Larger optimisation potentials may be offered by differentiating from competition by concentration on innovative materials and enhanced manufacturing technologies, and by alignment on economically suitable niches. Creation of an innovation projection allows manufacturing of new and better products. Using new technologies and materials and by open up new fields of applications a distinct mark within international competition can be developed. Therefore, a substitution of products from accustomed markets can be avoided. Hence, an alignment on quality competition leads to a suitable approach for the field of problems described above.

2. High Performance Manufacturing – a manufacturing strategy

2.1 Demands for High Performance Manufacturing - Motivation. European manufacturing industry is currently faced with high competition pressure in performing terms of operating efficiency and quality. Innovative production concepts, as well as high performance technologies are needed to improve cost and time factors in order to keep up with international competition. Advancing state of the art in mechanical engineering is an essential competitive factor for the European automotive, aerospace and mechanical engineering industries, which represent main industries illustrated in Figure 1.

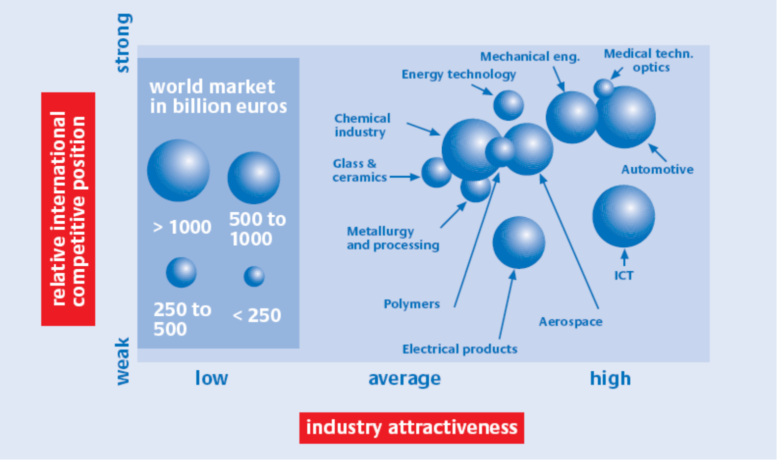

Figure 1. Relative competitive position of Central Europe industries in an international comparison [5].

These industries are highly dependent on innovative applications of light-weight, high-strength materials such as high-alloyed steel, light metals, titanium alloys, plastics, ceramics and composite materials to achieve new standards in strength to weight ratio, fuel efficiency, crash worthiness and safety. The development of new products requires improvements of

reliability and lead to the demand of narrower tolerances and components of highly complex geometry.
Especially, small and medium-sized enterprises (SME) as suppliers of OEM's are faced with the new demands. Unfortunately, SME's are characterised by limited possibilities and resources in research and development. Hence, future challenges in research and development mostly cannot be handled by their own. Therefore, an international funding platform was created. The focus is leading on pre-competitive collective research activities, especially to support small and medium sized enterprises. However, HPM project (High Performance Manufacturing) is one of the pilot projects. The project consortium covers the region of Central Europe and consists of partners from Germany, Austria and Slovenia with the cultural and economical linkage to eastern countries, as well as the approach to the economic power of German industries with international leading automotive and aerospace companies.

2.2 Objectives of the project. High Performance Manufacturing (HPM) strategy comprises new developments to reduce primary process times and lead times significantly by the means of enhanced cutting abilities, adapted tooling and machine concepts combined with integrated examination and optimisation of the process chain. The overall objective of High Performance Manufacturing is to increase efficiency and quality of production processes associated with rapid and successful introduction of high-tech materials. This collective research project within the CORNET (Collective Research Network) programme bundles requirements and knowledge from a broad group of mainly SME manufacturing companies specialised in machining lightweight materials for use in the automotive industry. The goal is to define standardised manufacturing HPM strategies (Figure 2) by combining appropriate choices of

- reference materials of specific characteristics,
- machining tools, methods and indicators and
- optimised manufacturing processes.

Industrial standard data will be enriched with application specific information compiled into a database and accompanied by best practice HPM guidelines. These will both be established through the cooperation between the industry sectors in each participating country, coordinated by the national industry associations participating in the project.

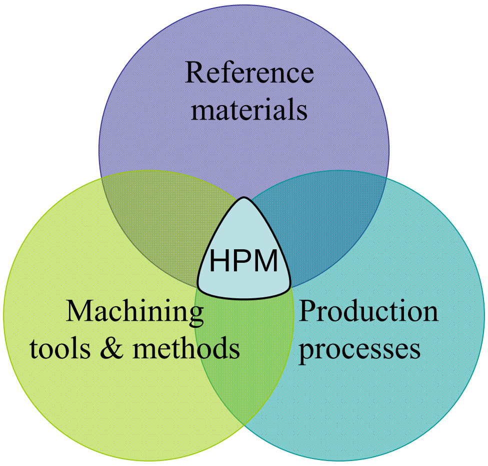

Figure 2. Definition of standardised HPM strategies.

In the past, the search for new and improved manufacturing technologies was mostly characterised by the application of empirical methods (trial and error). However, in recent

decades a deeper knowledge of the structure-property relations of materials, tools, processes and machine tools behaviour have been gained in production science due to improved methods of analysis. Using newly developed methods of modelling and finite element simulation which implies the knowledge described before, the process behaviour of manufacturing operations can be described and an optimisation of production processes can be reached without applying time and cost consuming empirical methods.
However, HPM project offers a platform for SME to enhance their manufacturing processes, especially if new materials are going to be processed. Therefore, an interdisciplinary project team containing specialists in material science, manufacturing processes and manufacturing technology was formed.

2.3 Project team and user groups. The HPM project team consists of industrial associations in each country as the head of a large group of companies which are organised within a network. University partners from each country with a specific field of research are implied (Figure 3). Hence, an interdisciplinary project team was formed,

Figure 3. HPM project team.

Additionally, a minimum of six SME from each of the three countries are organised in national user groups discussing demands for research, possible solutions, and progress of research activities. Hence, scientists and users work together in the user groups to improve manufacturing processes and to enhance quality and tool life time and, hence, lead to High Performance Manufacturing.

3. Results and discussion

3.1 Basic tests. The goal of the project is to produce validated reference parameters for a best representative sample of High Performance Manufacturing (HPM) indicators. It is necessary to define the sample HPM indicators which will combine the most common HPM reference parameters for materials, machining tools and methods, and production processes. Of course, there are thousands of variations of these three parameters. Therefore, the sample HPM indicators are identified as the most often used parameter sets by SMEs, which is evaluated by a comprehensive analysis and data collection based on a questionnaire at the beginning of the project.
Basic tests are used to get a deeper basic knowledge about the relations between these three parameters. A comprehensive data collection based on extensive material analysis and cutting tests leads to a better understanding of the property relationships between materials and manufacturing processes. The basic tests include the variation of so-called basic reference parameters of cutting technologies, e.g. cutting speed, feed rate, cutting depth, geometry of cutting edge of the tool, chip flow (structure-borne noise), chip deflection, forces, stress, wear

of cutting tools, costs for a tool tip and resulting process calculation parameters. To find relations between material behaviour and cutting process parameters it is essential to know the material behaviour under loading conditions which match the e.g. strain rates, strains and temperatures of real HPM manufacturing technologies [6]. Therefore, high rate material testing under compressive and torsion loading is added. For basic analysis different materials of technical relevance were chosen (1045 steel, AlSi9Cu3 alloy, grey cast iron GJL250, Böhler steel M315). The 1045 unalloyed carbon steel was defined as the reference material.

From basic tests detailed results about the complex property – process – relationships of cutting processes can be expected. Especially, process forces (e.g. cutting force) are obtained, which can be used for process evaluation concerning machinability of different materials and the expected tool wear. Additionally, the mechanical behaviour of the materials under real cutting process conditions are considered and represented within the process window of cutting technologies. Hence, using the results of the basic tests a new method for the optimised selection of process and tool parameters can be developed.

Using the example of the 1045 unalloyed carbon steel the basic HPM approach can be illustrated. Figure 4 shows the material microstructure from which an average grain size of approximately 15 μm can be evaluated. To obtain the mechanical behaviour of the material the flow stress behaviour was determined under compressive loading over a wide range of strain rates (see Figure 5). Hence, thermally activated flow stress behaviour was found. It means, the yield strength is increased with increasing strain rate. This may have a strong influence on the machining operation process, because the larger strain rate sensitivity of the material is, higher process forces can be assumed and, hence, a strong influence on surface quality and tool lifetime and costs are expected.

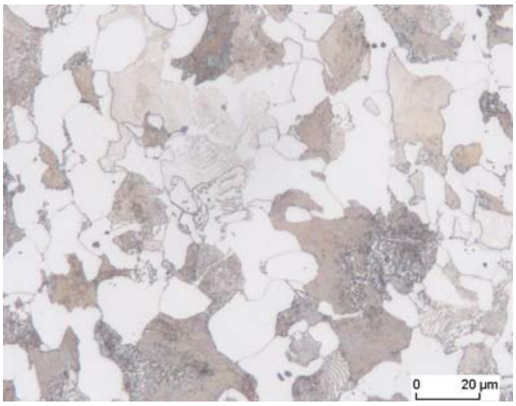

Figure 4. Microstructure of 1045 unalloyed carbon steel.

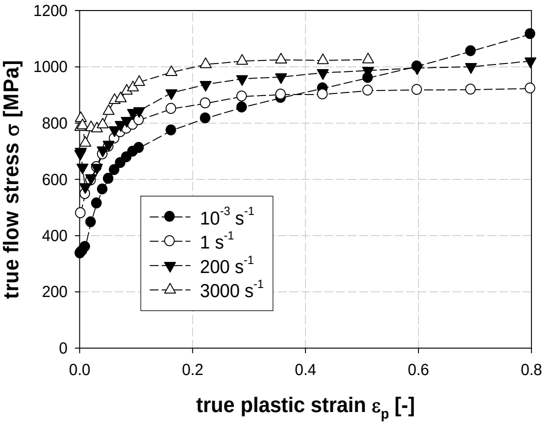

Figure 5. Flow stress behaviour of 1045 steel at different strain rates.

Using the experimental results, material models can be developed which describe the mechanical flow stress behaviour of the material as a function of strain, strain rate and temperature. For the 1045 unalloyed carbon steel the Zerilli-Armstrong [7] equation was used (eq. 1).

$$\sigma = \Delta\sigma_G + \exp\left[\left(-\beta_0 + \beta_1 \ln \dot{\varepsilon}\right)T\right] + K_0 \varepsilon^n \qquad (1)$$

Therefore the material behaviour can be implemented into finite element calculation programs which allow the numerical simulation of machining operations (e.g. Figure 6).

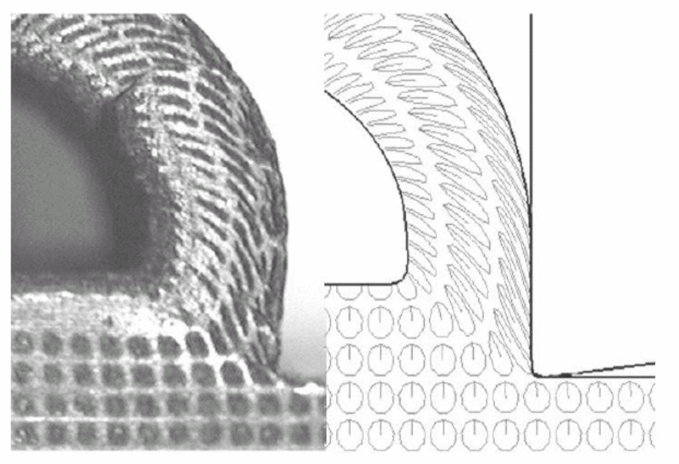

Figure 6. Comparison of real and simulated machining operations [8].

From Figure 6 can be seen, using numerical techniques cutting operations can be treated and show a good agreement between real and simulated processes. Additionally, process forces, temperatures and pressures may be predicted and can be used for optimised tool and process parameter selection.

Furthermore, using an empirical wear model, from cutting simulation and the resulting process characteristics (e.g. contact forces, temperatures, etc.) tool wear can be calculated (Figure 7). Tool lifetime can be predicted and an optimised tool selection is possible. Hence, production costs may be reduced using these results by choosing an optimum between process times (process parameters like e.g. cutting speed, feed rate, etc.) and tool lifetime (consideration of tool wear predictions).

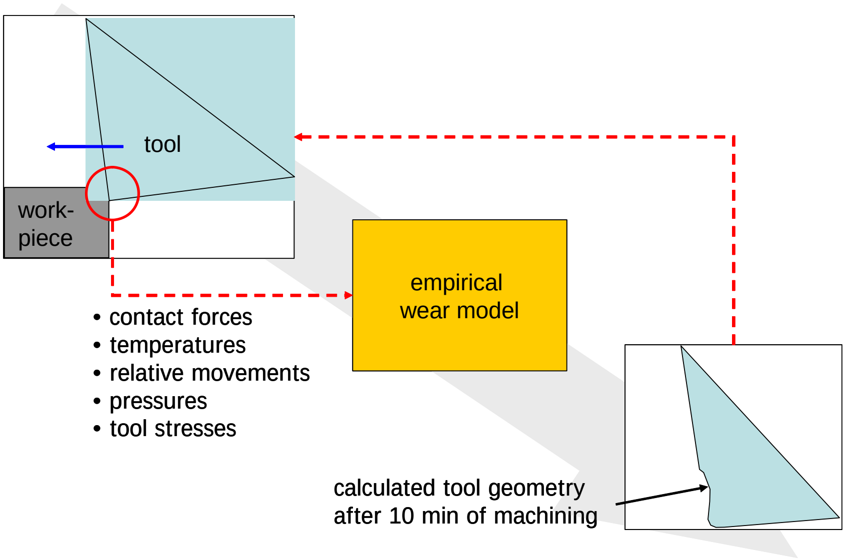

Figure 7. Empirical wear model for tool wear prediction using finite element analysis.

SMEs normally have no possibilities for performing basic investigations for their own. Additionally, for SMEs usually no finite element calculation programs are available. However, the results can be used by SMEs and partially transferred to their own processes. Especially, the detailed knowledge of property – process interaction can help for optimised selection of process parameters. As a result of basic tests the material and process based causes of the interaction relationships can be expected, too. Hence, statements in principal about the machinability and treatability of the materials are possible. This may help in cost estimation and to ensure required quality. All results are published within a internet based database platform (see section 3.3) and can be used by members of the national user groups for free.

3.2 Application specific analysis: Based on the results of the comprehensive analysis obtained by using a questionnaire for SMEs application specific field problems and process parameters were studied. Such parameters include e.g. speeds, feed rate, and width of cut, chip thicknesses, forces, wear, tools, machine tool, work piece geometry and characteristics. Material analysis including metallographic investigations, hardness and flow stress measurements as well as terms of quality assurance including accuracy of work piece geometries and the surface roughness are covered.
Application specific problems are solved by universities in direct cooperation with one SME of the national user groups. Thus, it can be assured that special knowledge and core competences are kept confidential. However, the method of solution and the principal results are available for each member of the national user groups due to HPM internet based database. Within this task support for applying innovative processes and technology transfer directly to SMEs is given.
Two examples shall illustrate the field of application specific analysis. The HPM project is focused on cutting problems with defined tool geometries and edges. However, there is no restriction in materials which are going to be machined. Hence, a variety of different materials including conventional steels and aluminium alloys as well as new composite materials and natural materials (wood) are investigated within the project. Most tasks worked out can be summarised as problems with tool lifespan and tool wear. Therefore, to reach an economical advantage and to save production costs an increase of tool lifetime shall be reached. One simple approach was used for machining of glass fibre reinforced materials like shown in Figure 8.

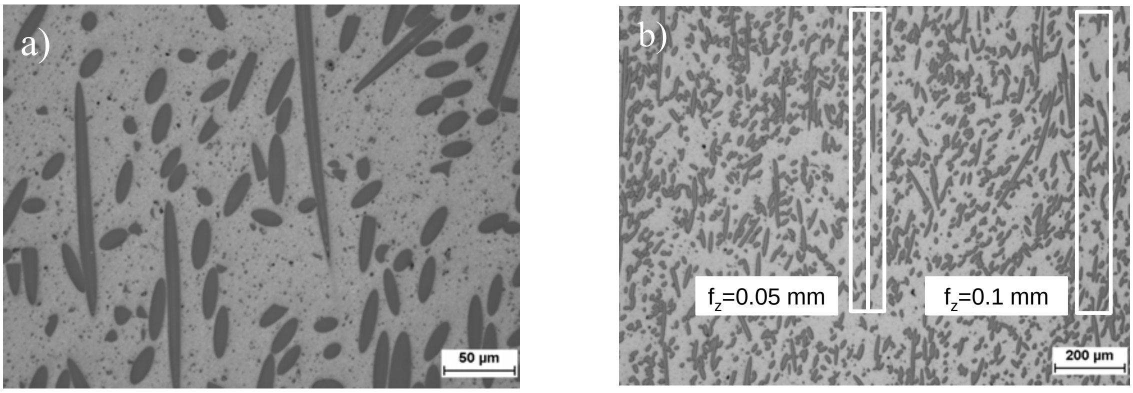

Figure 8. Short glass fibre reinforced material: a) 50 scale and b) 200 scale.

Machining of glass fibre reinforced materials often causes large abrasive tool wear which lead to less tool lifetime and high tool costs. By now there are nearly no process parameters known which are based on empirical or scientific studies. Process parameters are chosen by experience of companies itself. In the case of Figure 8 a feed of f_z = 0.05 mm was chosen. It can be seen that using a feed of 0.05 mm the process characteristic is in the same order of magnitude like the material characteristic (microstructure) itself. Hence, several fibres have to be cut during machining. Due to high strength of the glass fibre and their highly abrasive character strong tool wear can be observed. Increasing the feed to 0.1 mm tool lifetime was doubled. Due to decrease of the amount of glass fibres to be cut during machining compared to the cutting volume itself tool wear was reduced significantly. However, by combining simple material characteristics and process parameters a significantly increase of tool lifetime and a decrease of tool costs were reached.

A more complex approach was chosen for high alloyed high temperature resistant steel cast alloys. These materials are used for exhaust system components in automobile industry. They are characterised by high strength at elevated temperatures. Hence, a strong increase of tool wear is expected for machining such materials. Firstly the causes of the “bad” machinability have to be cleared. Therefore, a detailed material analysis was done using scatter electron microscopy (SEM) and EADX measurements. Hence, the chemical composition of the material can be determined locally. Chromium and niobium carbides were found which are characterised by their high strength at high temperatures and cause high tool wear during machining operations. Figure 9 and 10 show the microstructure of such a material and an EADX measuring result.

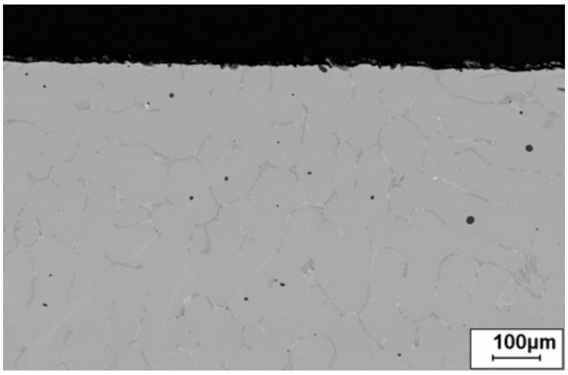

Figure 9. Microstructure of a high alloyed high temperature resistant steel cast alloy.

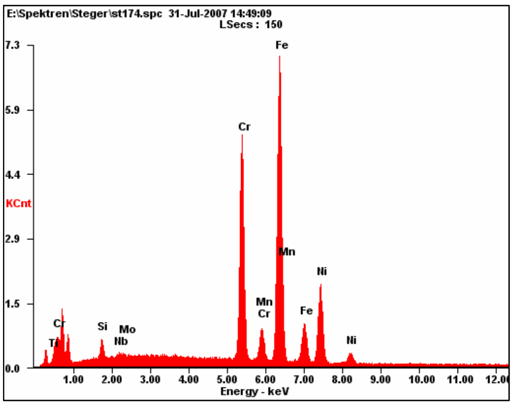

Figure 10. EADX measurement.

Additionally, micro hardness measurements (HV1) were done and summarised in Figure 11. A strong increase of micro hardness in the surface layer was found. The values were nearly twice as high as the base material. This is caused by cooling process after casting the material. However, due to strong hardness increase a strong increase of tool wear during machining the surface of the material (so-called cast skin) is expected.

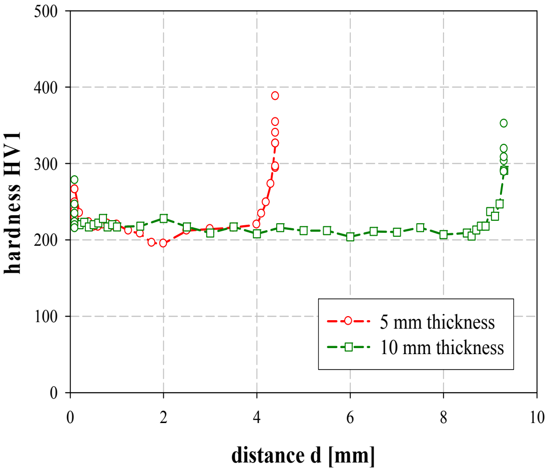

Figure 11. Results of the micro hardness measurements using HV1.

Based on the material analysis results detailed cutting tests (turning) were performed using different insert geometries and tool coatings. The process forces were measured using a piezoelectric force measuring platform. Therefore, process forces in all three dimensions were measured. The evaluation of the test results shows strongly dependent process forces from tool geometry. E.g. the specific cutting force kc1.1, which is one indicator of tool wear, varies from 1350 to 1600 N/mm². However, an evaluation of all test data allows a ranking of appropriate tool geometries. These results are the basis for further investigations on tool lifetime. Nevertheless, the material based causes for high tool wear were identified. The results can be used by SME and may lead to an adjustment of process parameters during casting of the material, because during casting process and the following cooling procedure the material properties are defined.

3.3 Database. The basic and application oriented tests offer detail process information and a huge amount of measuring data to validate manufacturing processes, especially the cutting tests. An internet-based platform will allow the SMEs to access the database and to anonymously enter data. Confidentiality will be an important issue to encourage participation (i.e. by entering data and information about their manufacturing processes without the fear of losing competitive advantage). The collection of data from the SMEs is the base of the database. Additionally, the experienced data and documented manufacturing parameters (catalogue of tools and parameters) of different tool makers will complete the information standard of the database.

The results of basic and application specific analysis are implemented into the database. Due to the specific character of problems and the different fields of application which are summarised in the national user groups, an evaluation of the data for each of the members is not possible. However, from material and process data and by using a selection methodology the results can be evaluated by each member of the user group itself.

Due to the interdisciplinary of the field of problems and applications different technical languages are spoken. Material science and manufacturing science use different terms for explaining. Hence, misunderstandings are possible and shall be avoided. To ensure an unequivocal understanding of the results a HPM wiki is included into the database. There, technical terms are defined and if necessary explained using text and figures.

However, the database can be defined as a result of the HPM project summarising and disseminating all relevant results. Actually, the database can only be opened by a secret account. However, due to the collective research character of the project in due the results are also available for non members of the project itself.

4. Conclusions

From our work the following conclusions can be drawn:

1. Increased influence of Asian and East European producers leads to increased competition pressure for Central European companies within manufacturing industrial sector.
2. Differentiating from competition by concentration on innovative materials and enhanced manufacturing technologies and by alignment on economically suitable niches may lead to a suitable way of solution.
3. Especially, small and medium-sized enterprises (SME) are faced with the new demands. Unfortunately, SME's are characterised by limited possibilities and resources in research and development. Hence, future challenges in research and development mostly cannot be handled by their own.
4. Collective research connecting SMEs and universities is a suitable way for facing the new challenges, which was realised within the HPM strategy based on basic and application specific analysis.

5. From basic tests a deeper basic knowledge about the relations between specific parameters of material science, machining tools and methods, and manufacturing processes can be expected.
6. Application specific analysis provides solutions for specific problems of SMEs and help to enhance tool lifetime and to reduce tool and production costs, respectively.
7. For dissemination of the project results an internet-based database was chosen. There, all results are summarised and can be evaluated by the SMEs in their own specific characteristic. Due to the interdisciplinary of the project and different technical languages used in material and manufacturing science, a HPM wiki is installed explaining relevant technical terms.

5. Acknowledgement

The authors would like to thank the Austrian FFG, the German AIF and the Slovenian MHEST for financial support of this work which is part of the European Collective Research Network (CORNET).

6. References

1. European Communities, 2008. External and intra-European Union trade. *Office for Official Publications of the European Communities.* Monthly statistics 1/2008, Luxembourg.
2. Homburg, C.; Krohmer, H., 2006. Marketingmanagement: Strategie – Instrumente – Umsetzung – Unternehmensführung. 2. Auflage, Gabler Verlag, Wiesbaden, Deutschland.
3. Dean, J., 1950. Pricing policies for new products. In: *Harvard business review* **28** (11/12).
4. Little, A.D., 2004. Innovation Excellence Studie 2004 – mit Innovation gegen Stagnation, Präsentation der Studienergebnisse, Wiesbaden.
5. Little, A.D., 2003. Evaluation of the MaTech Support Programme.
6. Halle, T; Meyer L.W., 2004: Influence of different material models on the result of numerical high speed cutting simulations, In: *1st International Conference on High Speed Forming*. Dortmund, 133-142.
7. Zerilli, E.J.; Armstrong, R.W., 1987. Dislocation mechanics based constitutive relations for material dynamics calculations, *J. Appl. Phys.* **61** (5), 1816–1825.
8. Halle, T., 2005. *Zusammenhänge zwischen Spanvorgängen und dem mechanischen Werkstoffverhalten bei hohen Dehnungsgeschwindigkeiten*. Dissertation, Technische Universität Chemnitz, Germany.