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HIGH PERFORMANCE MANUFACTURING – DEFINITION AND AIMS

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ABSTRACT
High Performance Manufacturing (HPM) technology 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 optimization 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 on high-tech materials. This technology will bundle requirements and knowledge from a broad group of mainly SME manufacturing companies specialised in machining of grey cast iron for use in the automotive industry. This goal is to define standardised manufacturing HPM strategies trough combining appropriate choices of:

+ *Reference materials of specific characteristics*
+ *Machining tools (mould and dies), methods and indicators (e.g. Tool wear)*
+ *Optimised manufacturing processes*

Central European manufacturing companies are virtually unable to compete with low-price producers from Eastern-Europe or Asia. The most pressure comes from manufacturers of relatively simple parts in low cost countries. Central European manufacturers are confronted with a disadvantage in terms of labour costs. Therefore they need to focus on sophisticated high-tech pars and high-tech manufacturing technologies. Manufacturing high-tech parts also involves the use of innovative and expensive materials, or even composite materials. To successfully utilise these high-tech materials, machining and manufacturing processes must be constantly improved to shorten product development cycles trough increased use of rapid prototyping, technology platforms and faster production – all under cost constraints to meet global competitive conditions

Keywords: High performance manufacturing, Grey cast iron, Machinability, Tool life, CBN

1. INTRODUCTION
1.1. State of art
European manufacturing is currently facing high pressure to perform in 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 as illustrated in figure 1 below.
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 standard in power to eight ratio, fuel efficiency and safety. Development of new products requires improvements in reliability, shows the demand for narrower tolerances and components of highly complex geometry.
To successfully produce parts in small and large scale and utilise these high-tech materials, machining and manufacturing processes must be constantly improved to keep up with shortened product

development cycles, increased use of innovative technologies and faster production – all under cost constraints to meet global competitive conditions. Especially in the fields of automotive and aerospace industries, the OEMs reduce development costs by involving suppliers of components to suppliers of systems. The suppliers have to support the OEMs in research and development issues. The optimisation of components and systems encompasses the performance of functions, durability and the effectiveness in manufacturing costs.

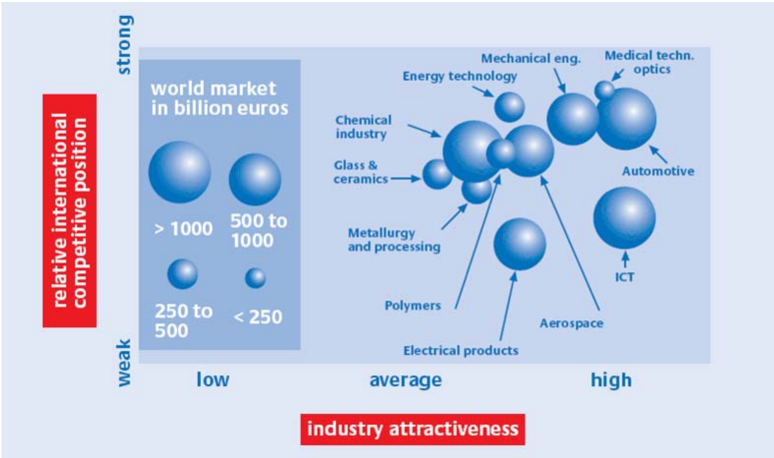


Figure 1: Relative competitive position of Central Europe industries in an international comparison Source: Evaluation of the MaTech Support programme, Arthur D. Little, 2003.

The global market and competition keep the OEMs to ongoing value and performance analysis to introduce their products to the highest technical standard (benchmarks, S-curve appraisal). In order to be highly competitive on the world market the OEMs more and more concentrate on their core competences and hand over development tasks to the supplier industry in consequence. The specific know how of technology-driven companies, even small companies, should be used for innovations. To take up the requirements on product optimisation, it is necessary to look for new technologies and improvements in conventional production processes in new or application specific tailored materials regarding accuracy, quality and costs, e.g. the use of laser notching instead of reaming in conrod machining or laser honing instead of the conventional process.
Central Europe is home to many small and medium-sized enterprises (SME) as suppliers with limited possibilities and resources in research and development (i.e. number of employees in research, comprehensive know-how, and methods and financing). Therefore the HPM technology implementation covers the region of Central Europe and consists of partners with the cultural and economical linkage to eastern countries, as well as the approach to the economic power of Central Europe industries with international leading automotive and aerospace companies.

1.2. Aimed technical targets

The importance of SMEs in production, processing and services has considerably increased in Central Europe in the past two decades. In important industries — as also in the sector of development for new materials and manufacturing processes — SMEs now play a key role in the innovation system. They frequently occupy specific niches in the value-adding chain between basic research, applied research, product and application development, where they perform the function of direct suppliers, subcontractors or service providers and either produce individual components for large enterprises or offer tailor-made system solutions or services (Figure 2). Owing to the flat hierarchies in SMEs, in-house decisions and information paths are short, the structures flexible and the staff highly motivated and over proportionately creative. Start-up companies stimulate competition, contribute to the renewal and restructuring of traditional industries, accelerate technical progress and the development of high-tech areas and ensure the rapid spread of new technologies.

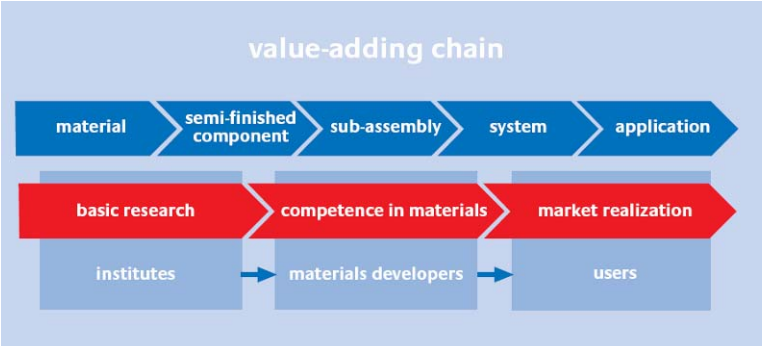


Figure 2: Value-adding chain.

Increased outsourcing of value-adding activities from large enterprises (OEMs) also often results in a new, vertical division of efforts between SMEs, large companies and research institutions. SMEs have become competent, flexible and important cooperation partners in their respective special fields.

On account of their limited resources SMEs are generally not able to conduct intensive research or realize material-based innovation processes from the development and testing of new manufacturing technologies up to its application. Instead, specific core capabilities are frequently developed, which are marketed as widely as possible. Particularly important for the success of SMEs is their constant access to new know-how (also from basic research) and close connections to big industry, component suppliers and other links of the materials and manufacturing process value-adding chain. Successful establishment in the market requires active and intensive technology transfer.

The RPM's aim is therefore to improve chances for SMEs in Central Europe by reducing obstacles in the innovation process of new technology applications especially in the fields of cutting technologies in new materials and contribute towards lastingly strengthening the SME sector. Within the framework of HPM, it can be provided specific SME support for research-intensive pilot implementations for establishing selected technologies on the market.

High Performance Manufacturing (RPM) technology 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 technology bundled requirements and knowledge from a broad group of mainly SME manufacturing companies specialised in machining lightweight materials and economical materials like Grey cast iron for use in the automotive industry. The goal is to define standardised manufacturing HPM strategies (Figure 3) though combining appropriate choices of [1]:

+ Reference materials of specific characteristics
+ Machining tools (mould and dies), methods and indicators (e.g. Tool wear, Specific Cutting Force)
+ Optimised manufacturing processes

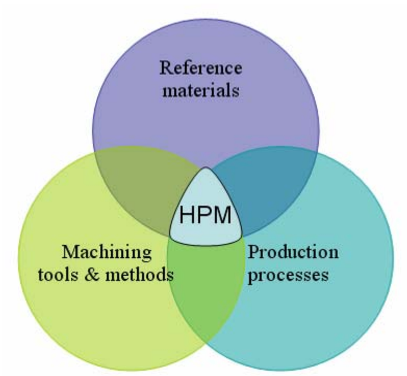


Figure 3: Definition of standardised HPM strategies.

In the past, the search for new and improved manufacturing technologies was mostly characterized by the application of empirical methods (trial and error). In recent decades, however, a deeper understanding of the structure-property relations of materials, tools, process and machine tool behaviour have also been gained in production science due to successes in analysis. This knowledge and the enormously increased computing power make it already possible today to sometimes predict material and manufacturing process properties by modem methods of modelling and simulation before the material or component is produced. Traditional empirical methods are complemented by theoretical predictions or replaced in the ideal case by Finite Element Methods (FEM).

2. REQUIREMENTS AND TRENDS OF HPM

Due to the increasing competitive nature of the commercial automotive and aircraft markets, environmental issues and affordability are the prime market drivers. In both sectors, the implication of this is a market requirement for faster, quieter, safer, cheaper, stronger, lighter and of course cheaper products. Beside this new products now face stringent economic and environmental demands, to reduce operational costs by producing, more economical and reliable products with an increased operating life.

To meet these requirements new materials are being used. In many applications, iron based materials such as grey cast iron and alloys with increased special need properties are replacing steel. New innovative materials are appearing, which meet the environmental impact laws for the future mass production of passenger cars, trucks, aircrafts… Example of innovative materials using in aircraft is presented on figure 4, [2]. Unfortunately the increasing use of these new materials is being limited by the lack of knowledge concerning the related machining processes.

One aspect to meet all mentioned requirements the automotive and aircraft designers are producing larger, thinner complex (monolithic) parts, which can be assembled more easily without the recourse to jigs and fixtures (Table 1). This is forcing manufacturers to consider using more exotic alloys, complex composites and mixed metal matrices, with a large impact on machining technology.

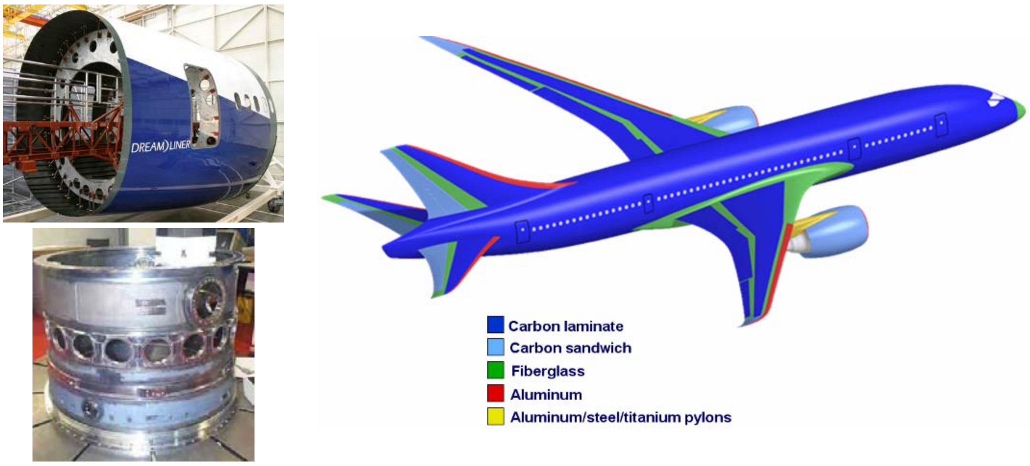
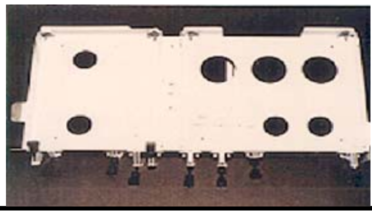


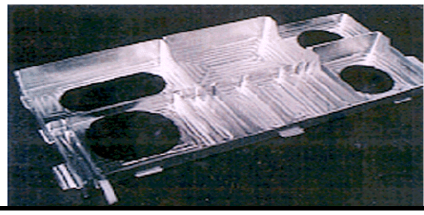
Figure 4: Innovative material used in aircraft industry (Boeing, AMRC 2006).

Because of that impact the specific requirements for HPM are connected with:

- + Modern machine tools (DCG)
- + Modern machining (cutting) material
- + CAM software and strategies
- + Engineering knowledge (development, research,…),
- + Machinability database from tool maker and from cutting tests in two phases (basic tests and application oriented tests)
- + Modelling and simulation of machining operations in new materials using Finite Element Modelling (FEM) technologies

Table 1: Application of HPM on manufacturing monolithic part, where 73% of cost reduction has been achieved (Boeing, AMRC 2006).





	Was	Now
Number of pieces	44	6
Number of tools	53	5
Technology design and fabrication [h]	965	30
Fabrication [h]	13	8.6
Assembly man–hours	50	5.3
Weight [kg]	4.35	3.88

3. HPM IN AUTOMOTIVE PARTS PRODUCTION

The rapid progress in the science and technology of materials is resulting in the emergence of a wide range of advance engineering materials of desired properties for advanced applications. These are materials with special characteristics that assure product needs. Mentioned remarkable technological characteristics could be: high strength-to-weight ration, high strength at elevated temperatures excellent wear resistant. But this kind of special characteristic could have also product with high geometrical specifications and without special mechanical charges. In that case the economy part of material has to be considered.

These materials offer attractive options for engineers working on component design. Unfortunately the same material properties responsible for superior product performance render the transformation of such materials into useful products by traditional machining processes very difficult, if not impossible. The lack of appropriate machining technology is thus a major impediment to exploiting these advanced materials. It cannot be over emphasized that the successful application of a particular material for high technology application is contingent upon the development of a cost effective machining technology and relates directly to the materials machinability. In spirit of high tech materials in automotive sector, the need of cost effective grey cast iron still brings up problem related with the machining technologies which will be presented in next chapter.

3.1. Problem introduction – machinability of grey cast iron

In machining automotive parts, surface quality, tolerances are the most specified customer requirements where major indications of surface quality on machined parts are appearance of burr and surface roughness. Both properties are mainly results of process parameters such as tool geometry (i.e. nose radius, edge geometry, rake angle, etc.) and cutting conditions (feed rate, cutting speed, depth of cut, etc.). In finish turning, tool wear becomes an additional parameter affecting surface quality and appearance of burr of finished parts [3]. Finish turning process can be defined as turning of semi manufacture into finished components. The greatest advantage of using finish turning is the reduced machining time and consecutiveness increase of productivity and complexity that require additional manufacturing processes to satisfied quality and geometry requirements.

Automotive part which machinability is deal with in this work is made of grey cast iron. A grey cast iron part provides locations for a fully floating bearing system for the shaft which can rotate at a few thousand rev/min. CNC machinery turns and drills specified part faces and connections.

Besides, the particularity is that its dimensional tolerances are tight with quite high surface quality requests. Since, machined part is a workpiece that is not exposed to high mechanical stress, special requirements of alloy grey cast iron are not given. Consequence the hardness and strength of used grey cast iron are low, because of reduced costs of such material.

It is known that the grey cast irons are relatively soft, but very abrasive. So using of CBN cutting tools, with their high abrasion resistance is the best choice for machining grey cast iron. Another reason for choosing CBN tools is permitting grey cast iron cutting at feeds and speeds much higher than conventional cutting tool materials – High Speed Cutting. Because CBN tools maintain a sharp cutting edge, part surface finishes are excellent, close tolerances are easy to obtain, and dramatic productivity increases can be expected. Finally, from the view of ecology in mainly cases coolants are eliminated altogether.

The problems found when machining this automotive part were the high wear rate of cutting tools and the presence of burrs on workpiece edge. This study is, therefore, very important, since its goal is to analyze, through tests, the main mechanisms of wear when machining grey cast iron central housing of turbo charger. Thorough understanding at the phenomena implicit in this process, solutions based on scientific analysis will be proposed, in order to enhance process quality and reduce its cost.

There are numerous machining factors that affect surface quality in turning using CBN cutting tools [4], but effects is hart to adequately quantify. This influences are, workpiece material microstructure, tool geometry, tool wear, workpiece geometry and burrs, vibrations…

From the statistic research [5], it is known that in hard turning practice, industry chooses the correct tool geometry less than half of the time, uses proper machining parameters only about half of the time, and uses cutting tools, especially CBN, to their full life capability only one third of the time, what also happened in current research topic. This sub-optimal practices cause loss of productivity for the manufacturing industry. Improvements to the current process planning for finish turning are needed to improve cost effectiveness and productivity.

Cast iron solidifies with separation of graphite is called grey cast iron due to the fact that fracture surfaces appear grey because of the exposed free graphite. It is an alloy with 2 to 3.5 % carbon and 1 to 3% silicon content, and is one of the most free machining ferrous materials. A typical structure is presented on figure 5. In all grey cast iron grades free graphite is present in the form of flakes of various sizes and distributions. In grey cast iron it is presented 1 or 2 % of cementite, which is cause of fast cooling of alloy. On the opposite case, slow cooling of grey iron with a high content of carbon and silicon, will yield in a matrix with a high content of free ferrite and large flakes of graphite.

From a machinability point of view the microstructure, which is almost synonymous with hardness, is totally dominant. The hardness and strength of the grey cast iron describes: quantity, size and distribution of graphite flakes, the amount of free ferrite and lamellar pearlite. Machinability can be improved with C, Si, S and Si/Mn alloying elements. The opposite effects have elements like Mo, Mn and Cr.

Figure 5: Graphite flakes in pearlite matrix.

Grey cast iron is widely used for engine blocks, brakes and so on, due to its low cost and excellent moldability. Carbide and ceramic cutting tools are conventionally used for machining grey cast iron that features easy to cut properties. However, due to the growing demand for high speed, high efficiency and high precision cutting and long life tools, CBN cutting tools are replacing conventional tools. In general, cutting tool life is longer and tool cost is lower in the cutting of grey cast iron than in the machining of other ferrous materials. However, machinability of grey cast irons varies depending on their microstructures and the pearlite/ferrite ratio. Even now that the application of CBN cutting tools in machining is very common, the problems in grey cast iron machining remain unsolved. Under the circumstances, the development of cutting tools that provide stable machining quality and long tool life for the machining of grey cast irons with a large variety of machinabilities is anticipated.

The quality and the integrity of the finish machined surfaces which are represent under term machinability, are affected by workpiece material microstructure, which is almost synonymous with the hardness. The workpiece material hardness of an unalloyed grey cast iron is between 90 and 275 HBN [6]. It is also known that the surface roughness of grey cast iron decreases with increasing hardness [7]. Furthermore, workpiece hardness has a profound effect on the cutting life of the CBN tools.

3.2. Experiment design

The tests of tool wear were carried out using CBN tools during the finishing turning process of grey cast moulded semimanufacture (Figure 6).

Figure 6: Machined part before (a.) and after machining (b.).

Tool wear was investigated on three main critical cutting operations that will be detailed presented in continuation. During tests two CBN tools worked consecutively. They were used with the same preferences, but were from different tool makers. All tests were carried out in the machining line of the manufacturing plant.
An OKUMA LT 10–M CNC lathe was used for the carrying out of the cutting experiments in this study, the flank wear of cutting tools was measured and recorded in the experiments. The CNC lathe is used to perform dry cutting on grey cast iron.

3.2.1. Workpiece material

Part is cast and gets to the machining line unworked. The unmachined part gets there, where for example most outer diameter has to be machined 3mm in depth with turning process. Most important preference of workpiece material is its hardness. For that reason hardness of used grey cast iron was measured and is shown in figure 7. Measurements were done on two parts, belonging to two different moulding series. It can be seen that hardness on sampling place is changing with the distance from the surface. Average hardness by Vickers method is about 210 HV1.

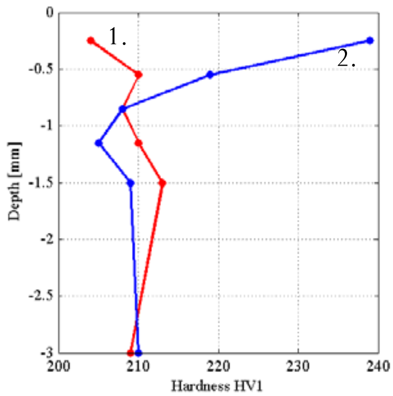
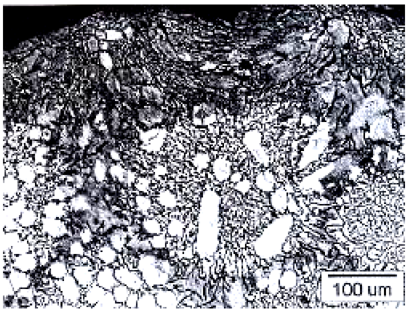


Figure 7: Hardness of two example moulded semimanufactures, measured on different depths.

Mostly is fast tool wear consequence of hard particles with high hardness. In grey cast iron that particles may be free cementite or phosphoric eutectic, but in this case there is no presence of hard inclusions.
Grey cast iron has a perlitic structure with lamellar graphite. Graphite in dealing material is mostly A type, on some places (mostly on surface) can also be found graphite type B and D. In central part of cast, the grey cast structure is mostly perlitic, where density of ferrite is less then 5%. On the surfaces

the microstructure on some part is ferrite and is the same in depth, especially on the part of workpiece, with most outer diameter. Ferrite structures are located in pearlite like island areas. So on such a part is concentration of ferrite more than 5 %, locally also more than 10 % to almost 100 % (Figure 8). Chemical structure of material that is added by foundry is presented below in figure 8.



DIN 1691	CE [%]	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Sn [%]
GG20	4,06	3,5	2,2	0,55	0,025	0,05	0,08	0,007
	Cu [%]	Mo [%]	Ni [%]	V [%]	W [%]	Sc [%]	Rm [MPa]	HBN
	0,1	0,01	0,06	0,01	0,012	0,96	220	190

Figure 8: Microstructure of grey cast iron near surface with chemical structure.

3.2.2. Cutting tools

Because of all advantages that are mentioned above (introduction), CBN cutting tools (Table 2) were used. For the comparison tool were used from manufacturers M_a and M_b. Cutting tool geometries were negative and are compared in figure 9. Shapes of cutting tools are different, dependence of cutting technology and will be defined in next section.

Because grey cast iron materials are not particularly hard, but exhibit well wear resistance characteristics making them very abrasive to cutting tool materials. Rough machining grey cast iron requires the chamfering of the cutting edge. The skin of grey cast iron is usually rough, hard and contains impurities such as sand from the casting process. These and the larger depth of cut mean much more pressure on the cutting edge. The chamfering of the insert strengthens the CBN cutting edge, thereby, ensuring consistent and maximal tool life.

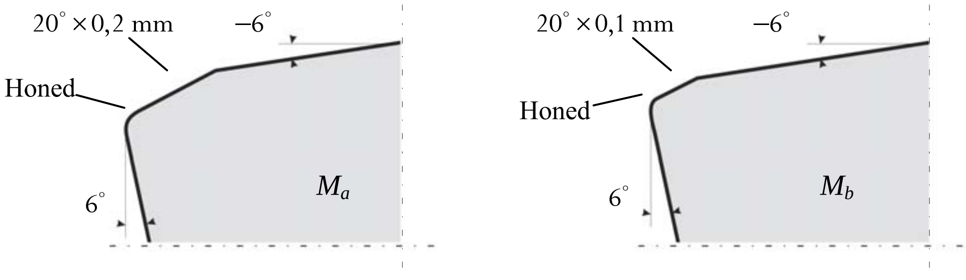


Figure 9: Comparison of cutting tool geometries.

Table 2: Composition and properties of used CBN cutting tools.

CBN content approx vol. [%]	Average starting grain size [um]	Matrix /Binder	Format	Knoops hardness [GPa]	Fracture toughness [mPam/2]	Thermal conductivity [$Wm^{-1}K^{-1}$] (20°C)
90	22	Al Ceramic	Solid	30.4	5.8	130

3.2.3. Cutting operations

One–cut and two–cut machining strategies were used. Three critical cutting operations were analysed in the way of tool wear. All three are presented in figure 10. Cutting speed is changing with workpiece diameter, 4000 rev/min (up to 1382 m/min). And dry cutting was performed.

Tool *T1A* has rhomboid shape (CNMN 120416S), tool *T2A* has triangle shape (TNMN 110304S) and Tool *T6B* has also triangle shape (TNMN 110304S). Current industry using feed rates and depths are presented in table 3.

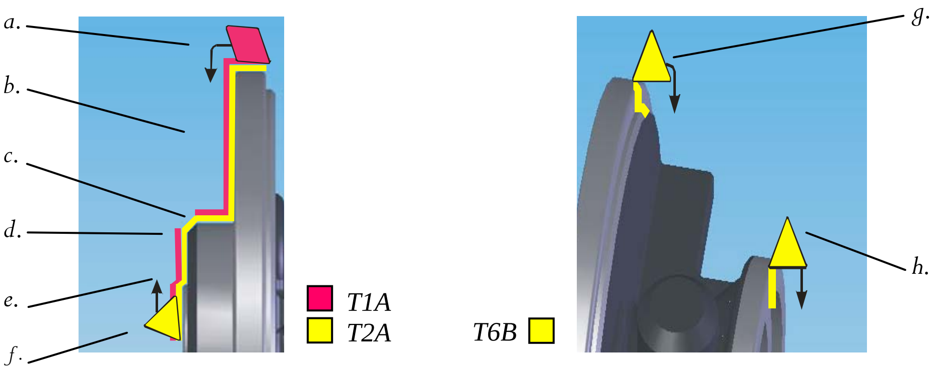


Figure 10: Metal removes machining strategy (left. two-cut, right. one-cut).

Table 3: Cutting parameters for cutting tool T1A.

Operation		a.	b.	c.	d.	e.	f.	g.	h.
Feed rate [mm/rev]	*T1A*	0.35	0.35	0.35		0.35	0.35		
	T2A	0.2	0.2	0.15	0.15	0.2	0.2		
	T6B							0.08	0.1
Depth [mm]	*T1A*	~2	~2.5	~1.8	~2	~2	~2		
	T2A	0.3	0.3	0.3	~0.3	0.2	0.2		
	T6B							2.2	~1

* ~ approximate cutting depth is given, because of moulding dependence.

4. RESULTS OF TOOLS WEAR

The flank wear is observed with tool maker's microscope; with an error of 0.001 mm. Results of wear accompaniment carried out in the machining line of the manufacturing plant are presented in figures 11, 13. There is presented tool wear for *T6B* which is most critical. Other tools wear have similar mechanisms but the wear rate is slower. Measuring frequency was 1scan/20workpieces and was obtained with the need of at least ten flank wear measurements in forecasted tool life. The real tool life was 140 machined workpieces for M_b cutting tool and 100 machined workpieces for M_a cutting tool.

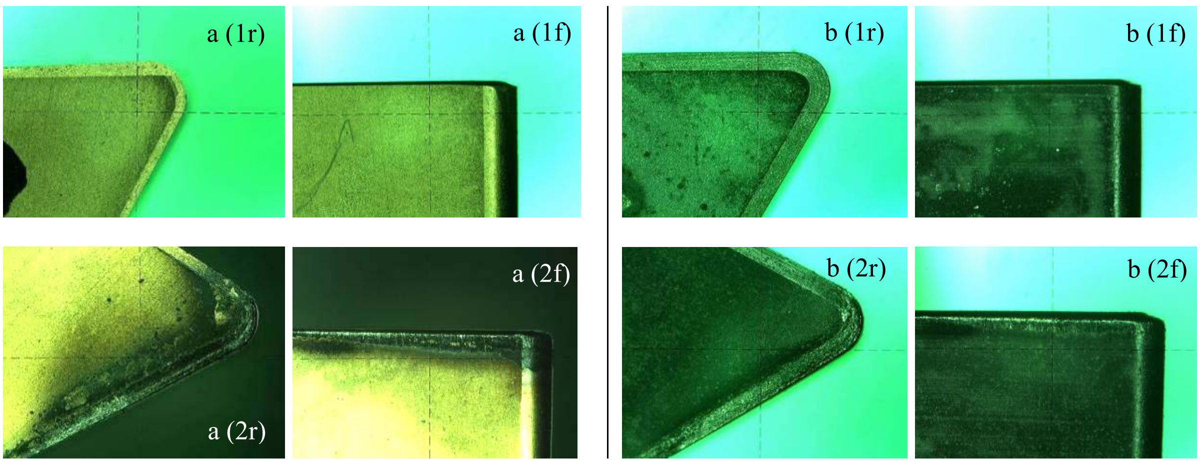


Figure 11: Comparison of T6B tool wears (1 – new, 2 – at end of tool life), on rake (r) and flake (f) face for two different tool manufacturer (a – M_b, b – M_a).

From this results rapidly increasing of wear can be obtained at the beginning and after that, area of steady linear wear increasing state can be recognized. There is also recognized high thermal influence

especially on M_b tools, which are coated. But this tool coating disappears after 20 machined workpieces. After 100 (for M_a) and 140 (for M_b) machined workpieces the burr was recognized by machine operating surgeon and tool edge had to be changed.
So a criterion for tool life is burr appearance and so not directly a flank wear. Flank wear defines the cutting edge retreat and has a significant influence on the workpiece dimensional accuracy. Therefore, these criteria have been the first used to measure the tool wear rate and also to classify wear of different cutting tools according to tool manufacturer. The tool wear is the loss of the cutting material chosen to measure the tool damage. Thus, the flank wear VB value is only a geometric dimension and it does not show the tool wear rate, but it is possible to obtain the volume of tool material removed as a function of VB, which lead to length of the workpiece rubbing.
As a tool wear measurement, figure 12 - left shows the flank wear VB as a function of machined workpieces for two compared tools, which are from different manufacturers and the integration of length along the cutting edge, which gives the surface of the workpiece rubbed with flank surface of the tool.
From these results shown in figure 12 - left, a criterion for tool life can be classified into two distinct groups according to the place of cutting. The first group represents *T6B* tool, where tool wear VB is not critical, but the burr appearance is criterion for tool or cutting edge elimination. The second group represents cutting tools *T1A* and *T2A*, where burr is not presented. So the tool life criterion is tool flank wear, which is connected with machined surface quality.
The burr on a workpiece edge appear after about 100 – 140 of machined workpieces. It is not big difference between tool makers. M_b tool behaviour is a little better, but this is due different tool geometry (Figure 9); M_b tools have smaller cutting edge chamfering. Consequence, the tool flank wear at cutting edge elimination is VB=180 μm.

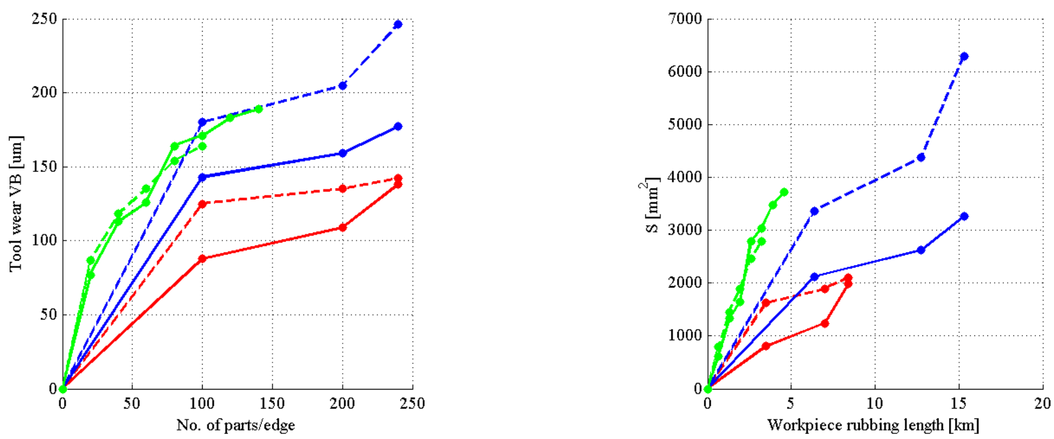


Figure 12: Flank wear (left) and rubbing length (right) for different cutting tool (– – M_a, – M_b) in three different cutting operations (– T1A, – T2A, – T6B).

In second group two cutting tools are used one after another, *T1A* is for roughing and *T2A* is for finishing. Because of separated operations, the decrease in tool flank wear was expected. After 240 machined workpieces the tool flank wear was not critical. Tool wear of cutting tool *T1A* after 240 machined workpieces was 142 μm for M_a and 138 μm for M_b. Tool wear of cutting tool *T2A* after 240 machined workpieces was 246 μm for M_a and 177 μm for M_b. Also here, the difference between different tool makers is because smaller tool edge chamfering. Smaller tool edge chamfer is recognized as better behave tool geometry, what is expected because of relatively soft grey cast iron.
Second presented results (Figure 12 - right) show the cutting tool material removal rate in relationship with rubbing length. Each of this curves can be represent with straight line. Thus, each flank wear can be defined by one parameter that is the straight line slope. Higher is that slope, greater the tool wear rate is. Also from these rates, it can be seen that the most critical cutting tool is *T6B*. Differences in tool makers are the same as introduced above.

The surface of the tool rake and flank plane with cutting edges shows many wear mechanisms that can be observed with the optical microscope. Picture of tool wears comparison between new tool and cutting tool at alternation are shown on figure 11. On this figures it was shown only cutting tool *T6B*, which is critical.
At early stage of cutting, initial breakdown in cutting edge with the edge rounding is observed with only a flank wear which increased rapidly. Then the flank wear becomes or it is going to be stable. From result figure 11 it is possible to see grooves, which are formed in the cutting speed direction. Those grooves seem to be the result of extensive abrasion wear. The grooves on the flank surface appear at the beginning of machining and they never disappear.
On rake face can also be seen slight crater wear. Crater wear is usually cause of hard workpiece material particles and high cutting speed but in this case is cause of high cutting speed with present of BUE. Increase in cutting speed with presence of BUE leads to an increase in cutting temperature which contributes to acceleration of tool wear.
This rapid tool wear show the presence of free ferrite. Free ferrite content of the grey cast iron is an important factor when machining with CBN. The free ferrite content must be below 10 % in order to achieve optimum performance [6, 7]. So this workpiece material local has to high free ferrite content. Iron with free ferrite contents above 10 % lead to chemical attack of the CBN, which in turn will result in greatly reduced tool life. Examination of the flank wear on the used tool and the presence of vertical striations on the wear scar is an indication of chemical wear as a result of free ferrite contact [8].
Another cause of rapidly tool wear at critical tool *T6B* is to small feed rate. Because of difference in feed rate between tools *T2A* (*f*=0.2 mm/rev) and *T6B* (*f*=0.08 mm/rev), which are geometrically practically identical, is tool wear at *T6B* tool extremely more critical. Practically the feed rate is smaller than the tool chamfering length (0.2 or 0.1 mm), so the tool rake angle is even more negative –26°. It is known that increasing in the feed rate increase the tool life [9]. Cause of this may be instability or absence of BUE (build up edge) [10, 11].

5. DISCUSSION

From experiments above, it is possible to conclude that the main reason of low productability is to high tool wear rate. There is no escaping the fact that in one respect, tools for high production technology are just like all others. They wear out. Crater and flank wear develop during the working life of all high production technology tools. Knowing how wears and very important burr arises and the effect will nevertheless help maximise the productivity benefits of finish turning case – grey cast iron surfaces. To increase machinability of used grey cast iron can be implemented three improvements: (1) Tool geometry, (2) cutting parameters and (3) cutting tool path.

5.1. Tool geometry

From the properties (Figure 8) of used grey cast iron can be seen, that the content of free ferrite is above 10%. The hardness of free ferrite is about 90 HBN, so in this case we have to deal with relatively (very) soft grey cast iron and the need of high tool toughness is not necessary and rake angle can be increased and chamfer angle of tool edge can be decreased.
Virtually all high production technology inserts have a chamfer, which is essential for controlling their performance. In addition, a chamfered edge is less sensitive to chipping and generally performs more consistently (Figure 13).

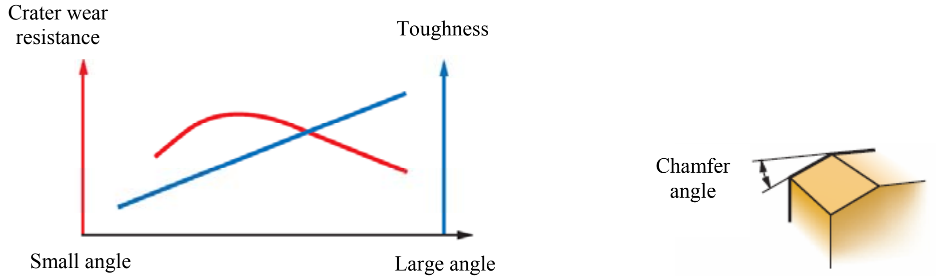


Figure 13: Influence of chamfer angle on tool wear and tool toughness [13].

From [12, 13], the honed tool giving a low resultant force as compared to the chamfered tool; Cutting direction stresses are higher at the tool tip and on the chip surface for the chamfered tool due to greater workpiece–tool contact area. Also the compressive stresses are distributed over a wide range due to larger chip–tool contact length.
Increasing of cutting rake angle, thereby increase the cutting edge shear angle and improve chip flow over the insert. This lead to lower cutting forces and thus lower levels of transferred energy. The result is lower temperature level in the cutting zone. Improvement in tool life released trough reduced flank wear, due to lower temperature and load. Reductions in both cutting temperature and load lead to a reduction in chemical attack of the cutting edge, thereby increasing tool life. In addition also the improvement in surface finish due to the improved chip flow can be expected. Improved cutting tool is shown in figure 14. Also in economical view it is possible to manufacture positive tool geometry with grinding. Such tool configuration combines the advantage of an increased shear angle and cutting edge with economics of a multi–cutting edge solid CBN insert.

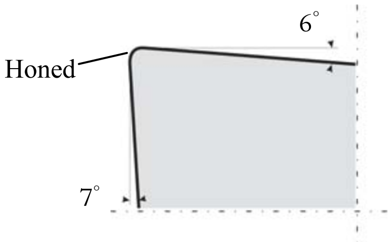


Figure 14: Improved cutting tool geometry.

5.2. Cutting parameters

Second improvement in machinability could be done with improved cutting parameters. Course of high wear rate of critical cutting tool *T6B* is because to low feed rate (f=0.08 mm/rev). From the tool manufacturer the recommended feed rate cutting depths form 0.5–4 mm are between 0.2 to 0.8 mm/rev [6]. Increasing of feed rate will not just increase tool life, but also decrease burr formation possibility on workpiece edge, because it is known that higher the feed rate is, smaller is the possibility for plastically deformation of material.

5.3. Tool path

And the third addition is to improve cutting strategy, to increase machinability due to reduce the probability of burr appearance. In cutting process planning of part, designers need to pay attention to burr formation potential on part's edges. Burr at certain location on the edges can affect part's performance drastically. To the minimum, designer should be aware of the impact of edge finish on the part's performance. The critical edge where burr formation is not allowed must be clearly specified (not as subjective filling). In above presented technology, after some tool wear on workpiece edge burr appears. This burr has very low high (about 5 μm) and is shown on figure 15.

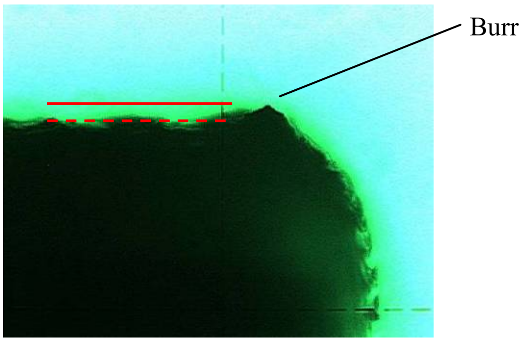


Figure 15: Burr appearance on workpiece edge.

This burr appears at entrance of cutting tool *T6B* (backward flow). To decrease the possibility presence of that burr, the cutting strategy can be changed. It is clear that whenever possible, the part's edge angle should be greater than 90°, especially when burr forming is critical (Figure 16). This same idea leads to the notation of pre chamfering part's edge to avoid burr formation in turning.

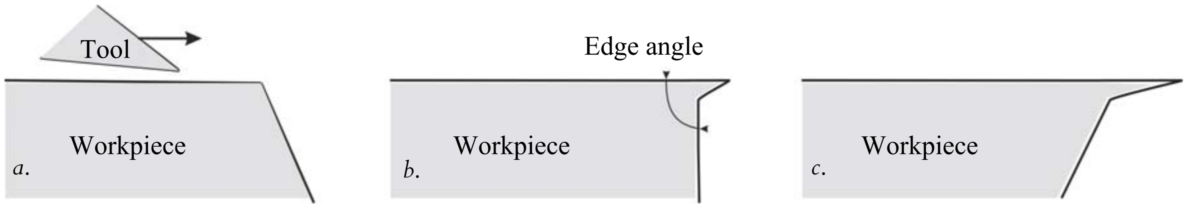


Figure 16: Effect of part's edge angle on burr formation: (a.) large edge angle – smaller burr, (b., c.) small edge angle – larger burr.

In case of that work, the improved technology to decrease the burr appearance possibility is shown in figure 17.

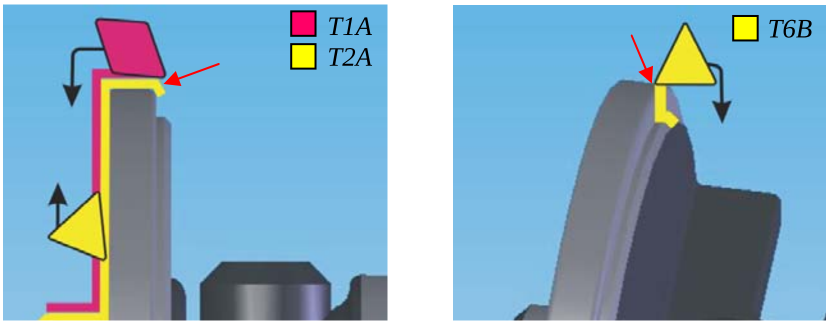


Figure 17: Improvement of cutting tool paths.

6. CONCLUSIONS

As one of the most important targets and solutions of HPM technology is the manifestation of an analysis approach, in which the whole value adding chain is taken into consideration. Thus, in the development process the manufacturing steps for row material have to be analysed in order to calculate costs and validate the manufacturing relevant parameters (dimensions, mechanical properties, microscopic material structure, manufacturing behaviour such as abrasive reaction characteristics in chipping process).

This means also that our resources and environment must be dealt with in product and process development issues. Applying this concept of sustainability to material and manufacturing process research, in addition to the economical scale, the following aspects will have to be taken into consideration in the HPM technology:

- contribution of materials to relieving the environment by special applications, especially in transport and energy technology,
- development of efficient products and production processes with low energy and material consumption,
- minimizing raw material input and emissions along the entire product chain,
- giving preference to closed cycles: consideration of the total life cycle from production through processing and application up to disposal/recycling (life cycle assessment)

Manufacturing based on cutting processes covers more than 60% of the value adding chain. Especially new cutting materials and tool technologies offer increased functionality to operate by higher speeds, tool life performance and process quality. Improvements in machine tool construction showing flexible concepts and mechanical properties with higher feed rate capabilities, stiffness and accuracy guide to innovative process application, such as high speed cutting, try machining or cutting of hard materials. Furthermore, materials research must furnish important contributions especially in the field of mechanical engineering technology for the assessment of operational strength and system reliability. Efficiency increase in mechanical engineering apart from lightweight construction aspects and the integration of information technology into mechanical engineering, this industry in terms of economic efficiency especially benefits from durable tool materials, low-cost manufacturing processes, innovative joining technologies and from so-called “intelligent materials”, which have a high potential for energy saving and performance increase in many fabrication processes.

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