Graph-based Analysis of Metal Cutting Parameters

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ABSTRACT

In this work, the interdependencies of different metal cutting parameters are examined. In order to ensure competitiveness in the field of manufacturing, the quality, productivity and costs of the work must be in optimal balance. The parameters affecting the end result of a metal cutting process form a complex web of interdependencies. In this work, graph-based modularity analysis is applied in order to impose a structure on the network of parameters. This allows the identification of the parameters that are to be used in more thorough examination of the individual cases. Combined with an understanding of the graph topology such as parameterized relationships between different factors, this enables powerful heuristic tools such as expert systems to be created.

1. INTRODUCTION

This study makes a proposal and then presents the information required to describe the machine and device resources in a machining environment. This information is needed for the development of an analytical method for automated and highly productive production. The description of the product and device resources and their interconnectedness is the starting point for method comparison [1], the development of expenses [2], production planning [3, 4] and performing optimization [5]. According to Newness [2], budgeting during the design phase requires the presentation of factors relating to production and the product itself, as does process optimization. The manufacturing methods cannot be optimized unless the environmental variables and their interdependences are known. Furthermore, it is impossible to create an optimal technological design, as indicated by Wang [6], unless the characteristics of the processes are known.

There are at least two points of view on cost-effectiveness in the manufacturing context, namely a cost-effective total product and cost-effective manufacturing. The concept of a cost-effective total product contains the idea of the financial control of the product's life cycle, including the main levels of this cycle: design, manufacture, marketing, use, maintenance, service and recycling or materials recovery. [7] When examining the concept of cost-effective manufacturing, we have to note that economically efficient manufacturing costs form a part of life cycle management and thus of the product's all-in price, but they do not influence the product directly as much as they do the actual manufacturer. The manufacturer must receive a yield from the manufacturing activities, making their chances of profitable operations smaller than those of the bearer of the actual product or product rights. A product is made more cost-effective when as little energy as possible is used in its production. In addition to this, the product's cycle in production must be organized in such a way that no energy is wasted on unnecessary stages of operation, warehousing or transport. [7]

The product and its production should be ecological, regardless of the point of view of cost-effectiveness. Therefore it is required to commit to an ever-increasing degree to manufacturability, as well as all other activities and events during a product's life cycle. In order for this to be possible, the informational parts of each process related to the product should be under control and the relationships of the factors affecting them should be understood. [7]

One technical development trend which research and development is currently turning towards may be the integration of master production scheduling and detailed capacity planning of separate design functions, such as drafting, operation, mechanics or production design, under one overall system in order to improve future profitability. However, whatever the development trend, it is almost certain that the portion of automatic and semi-intelligent

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systems will inevitably grow. The development of smarter systems requires several separate functions, practices and disciplines to be gone through in order to prepare systems that are able to present the information people need at the right time and with suitable accuracy.

When a product is designed in such a way that the capabilities and machine properties of production are taken into account throughout, a significantly higher degree of value added can be produced in a product than by acting in a traditional way, where the focus is first on functional structure and only then are the manufacturing possibilities charted [7]. Today, manufacturing companies must be agile under conditions of global competition in order to do business successfully. In western countries, one typical response to decreasing cost-effectiveness is to transfer or outsource the non-core-competence actions to a lower-cost location and concentrate on the most-value-adding actions, in which production efficiency also plays a major role. Such a contrast could be discerned between manufacturing bulk products and assembling low-volume mass-customized products.

2. METHODS

Cutting is one of the most complex physical problems in industry. In order to improve the performance of a cutting system, changes must be made to the cutting parameters. However, changing one parameter has multiple outcomes; for example, increasing the cutting speed leads to a higher output of products but it can lead to lower profit as a result of an increased rate of tool wear. This makes optimizing cutting parameters difficult. Optimizing cutting on the basis of a limited set of parameters can achieve good results, but may have unexpected side-effects. Optimizing the cutting speed and tool wear on the basis of income can lead to bad product quality and therefore loss of profit as a result of rejected products. Understanding a cutting system requires an advanced level of expertise in the subject, which is a relatively rare and thus expensive commodity in the industry. In this paper, the proposal is to build a knowledge base with a network analysis tool in order to empower decision makers to analyze different outcomes of parameter adjustment.

The data for this research are collected from multiple research papers considering machining problems. The data are simplified into the form of a binary matrix that indicates the relationships between different parameters. The Gephi network analysis software[*] is used to automatically rearrange the network of parameters to visualize the weight of different parameters and to group the parameters. [8] Data for Gephi are prepared in human-readable form in Microsoft Excel using the NodeXL extension[†] [9]. Both pieces of software are published with an open source license and are freely available. Modularity analysis conducted with Gephi demonstrates how different parameters are connected and what kind of groups they form. This makes it possible to measure how well a network decomposes into modular communities. [10]

Several approaches have been used for the optimal cutting parameter value selection problem in cutting. If the model is known, there are several solvers that are available commercially, such as LINGO for linear programming problems. Well-known algorithms can be implemented for a customized solution. In addition, there are expert systems that were developed to find a suitable tool and cutting parameters [11, 12, 13]. For black-box models (where the objective space surface is not known) genetic algorithms and neural networks are very popular, such as in [14], though particle swarm optimization (PSO) methods have also been used [15]. Some cutting parameters may also be adjusted while the machining process is under way [16, 17, 18, 19]. The methods applied prior to machining may take considerable amounts of time, depending on the complexity of the problem or the exact configuration of the solver, but the methods used while the machining is under way must understandably be very computationally cheap. However, in order to achieve the required accuracy for the model to be optimized, it is crucial that the effects between different factors are understood and the most relevant parameters are identified.

3. RESEARCH

The cutting speed is the relative motion between the cutting tool and the workpiece. The cutting speed affects the magnitude of the cutting force, as well as the cutting temperature. The cutting temperature has been widely studied but because the connection between the cutting speed and temperature is highly case-sensitive, no generic models exist. [20] The effect of the cutting speed on tool wear rate is one of the most traditional research topics in machining. Usually, tool wear rate increases with increasing cutting speed. Though the field is well established, there are many new studies considering wear because nearly all tool-workpiece material couples require tool life testing since no universal

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[*] Available from https://gephi.org/

[†] Available from http://nodex1.codeplex.com/

model exists. [21] The cutting speed affects the power consumption of a machine tool; generally, at higher speeds power consumption is higher. In addition, higher cutting speeds lead to a better surface quality, except some examples such as specific stainless steels. [22, 23] The effect of the cutting speed on the cutting time is obvious but the effects on residual stresses and tolerances are more difficult to determine. In some cases there is a clear effect on tolerances, for example when the velocity of mass deforms a workpiece moving at high speed, causing inaccuracies in the intended geometry. The cutting speed has a clear effect on residual stresses, as demonstrated by numerous studies, but the trends are highly case-sensitive. [24]

The cutting feed is the speed at which the cutting tool advances through the workpiece. The cutting feed has an almost linear effect on the cutting force, as the area of the tool-chip contact area increases with increasing feed. This has been concluded in numerous studies, such as Kienzle and Victor's commonly referenced study [25].The cutting feed has an impact on the cutting temperature, as presented in Bacci and Wallbank's review [26]. The impact of the cutting feed on tool wear and the tool wear rate has been investigated by researchers such as Astakhov [27]; it is concluded that the effect of the feed is dependent on other variables, such as the cutting temperature and cutting speed. The cutting feed has only a minor effect on the power consumption. [10, 28] The effect of the cutting feed on surface roughness is case-sensitive but clearly exists [10, 29, 30]. The cutting feed has an inverse linear relation to the cutting time. The feed has an effect on residual stresses, as reported in [21] and affects tolerances, at least through increased amounts of tool deflection at high feeds. [31]

The cutting depth is a set value that defines the depth of the cut. Since the tool-chip contact area is determined by the cutting depth and feed, the cutting depth has a similar nearly linear relation to cutting forces as the cutting feed. [32] The temperature of the tool-chip contact surface increases slightly with an increase in the depth of the cut. [33] The cutting depth is linear to the cutting volume, which directly increases tool wear, but if the machining is carried out under the optimum cutting regime an increase in the depth of the cut should not change the tool wear rate. [9, 24] The power consumption increases with an increase in the depth of the cut. [25] The cutting depth affects the number of passes needed to finish a workpiece, and therefore the cutting time decreases with an increase in the depth of the cut. Tensile residual stresses are increased with increasing tool-chip contact surface; when low tensile stress values at the surface of the workpiece are desired, the cutting depth should be small. [21] The depth of the cut affects the forces acting on the tool and therefore the tool deflection; this has an effect on the tolerances of the workpiece. [27]

The cutting force is the reaction to the cutting action. The force equals the energy required to remove material from the workpiece. The cutting force acts on the cutting tool. It can be viewed as resulting from three force components. These components point in the radial and tangential directions in relation to the machined surface and the opposite direction to the feed. Therefore, the cutting force directly affects the choice of tool. The cutting force also affects the tool wear mechanism and tool wear rate. [34] The cutting force is the primary contributor to power consumption. The cutting force can affect surface quality by changing the contact conditions at the tool-chip interface but no general trends have been discovered. [27, 35] The cutting force indicates the amount of friction and plastic deformation in the cutting zone and therefore the level of residual stresses generated.

The power consumption of a machine tool is the amount of energy the machine needs to perform cutting operations. The maximum power of a machine tool is a limiting criterion when selecting the cutting speed, feed and depth; therefore, its also affects the maximum allowable cutting force. Electricity is getting more expensive and the excessive use of power is seen as bad PR in view of the prevailing green philosophy policies. A simplified equation for calculating power requirements is

$$P = R\,v \tag{1}$$

where P is the power consumption, R is the resultant cutting force and v is the cutting speed.

Tolerances are the accepted range of dimensions of the ready workpiece. Machine tools and the tolerances achievable by them must be considered when choosing requirements for tolerance and quality in the design phase. As already noted, the tolerances of the workpiece are affected by the cutting force through tool and workpiece deflection.

A cutting tool is a geometrically defined shape that is strong and hard enough to mechanically remove material from a workpiece. A cutting tool has a major effect on the maximum applicable cutting speed, feed and depth. These values are provided by the tool manufacturers for each type of workpiece material. The recommended optimal cutting parameters for a 15-minute tool life are usually found in the catalogs of the tool manufacturers. Cutting tool performance is determined by the mechanical, tribological and thermal properties of the tool material. The performance is often measured by the tool life, maximum achievable material removal rate and cost of the tool. The geometry of the cutting tool has a major impact on cutting forces, cutting temperature, surface quality and tolerances. [10, 20, 21]

Tool wear is the flow of material away from the cutting tool as a result of adhesion, abrasion, plastic deformation and electrochemical phenomena. Tool wear obviously affects the cutting tool and its costs and performance, which is reflected in increased cutting forces. [36] Tool wear has an effect on the surface quality; the flank wear profile in particular is seen on the surface of the workpiece. [37] Tool wear and the cutting temperature have a strong omnidirectional effect on each other and the cause-effect relationship should be investigated experimentally more thoroughly. [38] The tool wear rate is the speed at which the tool wears. The wear rate affects how long one tool can be used continuously and therefore the cutting time is affected. Tolerances are critical with regard to tool wear rate because if the wear is fast, then the tool compensation changes quickly and is inaccurate, therefore leading to poor tolerances.

Cutting fluid is a lubricant and its major functions are removing cutting waste and chips, cooling the tool and workpiece and lubrication. The lubricating properties of cutting fluids have been questioned because there are indicators that the cutting fluid cannot access the tool-chip contact surface as a result of the high pressure in that area. The cutting fluid has an effect on surface quality and tool wear, as presented, for example, in Xavior and Adithan's work [39]. The cooling properties of cutting fluids are evident and strongly correlated by the thermal properties of the fluid. [40]

The cutting temperature is generated from the friction and adhesion between the tool and the workpiece and from the plastic deformation of the workpiece material. The cutting temperature has a significant effect on the cutting tool wear rate. [41] Thermal softening and thermal elongation of the workpiece and tool also affect the cutting forces and tolerances. Residual stresses are caused by the joint effect of elastic and plastic deformation and changes in temperature. [42]

The cutting time is the time needed for the cutting action. The cutting time affects the choice of cutting tool and the cumulative temperature generated and conducted to the workpiece and tool. The cutting time is the primary measurement for tool life and therefore tool wear should be considered. The cutting time affects the total power consumption of the process, labor costs and machine costs.

The surface quality is the topology of the already-machined surface layer of the workpiece. The surface quality affects the tolerances if the surface average roughness value Ra is high. The quality and tolerance requirements are also affected by a bad surface or very high costs of reaching good surface quality. Residual stresses are the remaining stresses in the workpiece after the cutting is done. The surface quality and tolerances can change if the residual stresses are released and therefore distort the workpiece. Quality and tolerance requirements are engineering-driven qualities that are critical for the workpiece to function properly in its intended surroundings. The requirements for the product also have a major impact on product costs, because if the requirements are unnecessarily high, then producing over quality in the sense of surface roughness, and the tolerances, tool, labor and machine costs are higher. Additionally, if the tolerance requirements are high, this requires the surface roughness requirements to be high too.

Tool costs mainly comprise the retail price of tool bits. If tool costs are critical in the cost structure of the product, this can affect the choice of cutting tool. Labor costs are calculated from the time the machinist must attend to the machine tool for each workpiece. Machine costs include maintenance and down payments.

Table 1 and Figure 1 present the relationships between different variables in the cutting process.

Table 1: Connections between different cutting variables

	Cutting Speed	Cutting Feed	Cutting Depth	Cutting Fluid	Cutting Tool	Cutting Force	Cutting Temperature	Tool Wear	Tool Wear Rate	Power Consumption	Surface Quality	Cutting Time	Residual Stresses	Tolerances	Tool Costs	Labor Costs	Machine Costs	Quality Requirements	Tolerance Requirements
Cutting Speed	0	0	0	0	0	1	1	0	1	1	1	1	1	1	0	0	0	0	0
Cutting Feed	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Cutting Depth	0	0	0	0	0	1	1	1	0	1	0	1	1	1	0	0	0	0	0
Cutting Fluid	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
Cutting Tool	1	1	1	0	0	1	1	1	0	0	1	0	1	1	1	0	0	0	0
Cutting Force	0	0	0	0	1	0	0	1	1	1	1	0	1	1	0	0	0	0	0
Cutting Temperature	0	0	0	0	1	1	0	0	1	0	0	0	1	1	0	0	0	0	0
Tool Wear	0	0	0	0	1	1	1	0	0	0	1	0	0	0	1	0	0	0	0
Tool Wear Rate	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0
Power Consumption	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Surface Quality	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
Cutting Time	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	1	1	0	0
Residual Stresses	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Tolerances	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Tool Costs	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labor Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Machine Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quality Requirements	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1
Tolerance Requirements	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	0

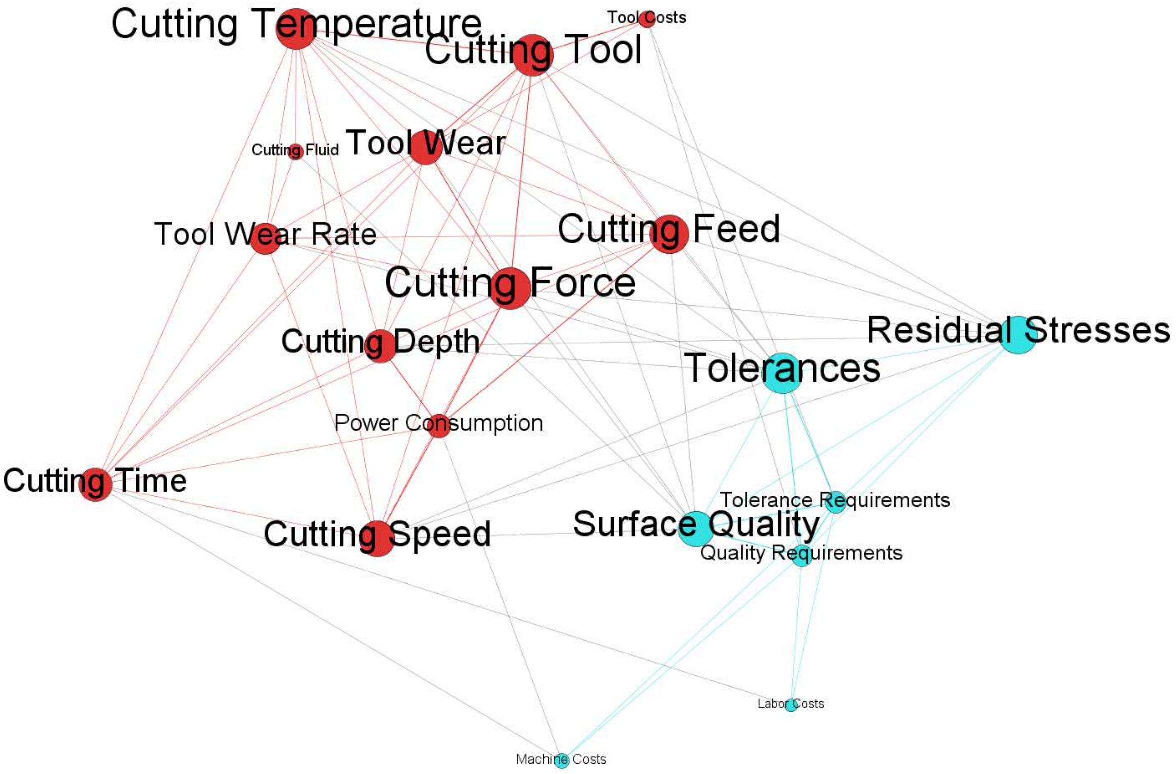

Figure 1: Relationships between factors affecting the metal cutting process

4. CONCLUSIONS

Optimizing workpiece quality, machining costs and productivity is essential for competitive manufacturing. In order to optimize cutting processes, different parameters are adjusted to achieve desirable outcomes. However, as a result of the complex nature of the cutting process and the various coupled effects of different parameters, it is difficult to predict different outcomes resulting from a parameter change. This research was conducted to inspect a graph-based approach to the creation of an expert system for assessing the outcomes of different cutting parameter changes. This is done by applying a simplified model based solely on known relationships between different parameters in cutting.

The analysis shows that cutting parameters are divided into two groups, namely “machine parameters” and “design parameters”. The division is based on Gephi modularity analysis. First, it is interesting to note that the modularity analysis led to sensible groups. Additionally, it seems to be sensible to use the network approach in order to visualize such a practical problem. Depending on the case to be optimized, different parameter loops can be identified and thus taken into account during the design of the machining routine. This approach does not give automatic optimization solutions for these cases, but helps to identify the parameters that are to be used in more thorough analysis. This kind of an expert system can be upgraded by inducing topology in the form of functions between different parameters. However, because of the high level of variation in the materials used for tools and workpieces, universal models of cutting parameters have not been created. This makes it difficult to formulate such functions. Regardless of this, the observation of two distinctive parameter groups (design and machine parameters) eases the design of the machining process through the creation of a clearer distinction between objectives and means.

REFERENCES

[1] *D. Lutters, E. ten Brinke, A.H. Streppel, and H.J.J. Kals: "Computer aided process planning for sheet metal based on information management", Journal of Materials Processing Technology, vol. 103, pp. 120-127, 2000.*

[2] *L.B. Newness, A.R. Mileham, and H. Hosseini-Nasab: "On-screen real-time cost estimating", International Journal of Production Research, vol. 45, no. 7, pp. 1577-1594, 2007.*

[3] *J. Cuirana, I. Ferrer, and J.X. Gao: "Activity model and computer aided system for defining sheet metal process planning", Journal of Materials Processing Technology, vol. 173, pp. 213-222, 2006.*

[4] *C. Hayes: "P3 : A process planner for manufacturability analysis", IEEE Transactions of Robotics and Automation, vol. 12, no. 2, 1996.*

[5] *D.K.J. Singh and C. Jebara: "Feature-based design for process planning of machining processes with optimisation using genetic algorithms", International Journal of Production Research, vol. 43, no. 18, pp. 3855-3887, 2005.*

[6] *G.G. Wang and S.Q. Xie: "Optimal process planning for a combined punch-and-laser cutting machine using ant colony optimization", International Journal of Production Research, vol. 43, no. 11, pp. 2195-2216, 2005.*

[7] *M. Lohtander: On the development of object functions and restrictions for shapes made with a turret punch press, Lappeenranta University of Technology, 2010.*

[8] *M. Bastian, S. Heymann, and M. Jacomy: "Gephi: An Open Source Software for Exploring and Manipulating Networks", 3rd International AAAI Conference on Weblogs and Social Media, San Jose, CA, USA, 2009.*

[9] *M. Smith, B. Schneiderman, N. Milic-Frayling, E.M. Rodrigues, V. Barash, C. Dunne, T. Capone, A. Perer, and E. Gleave: "Analyzing (Social Media) Networks with NodeXL", Proceedings of the Fourth International Conference on Communities and Technologies, State College, PA, USA, 2009.*

[10] *V. D. Blondel, J.-L. Guillaume, R. Lambiotte, and E. Lefebvre: "Fast unfolding of communities in large networks", Journal of Statistical Mechanics: Theory and Experiment 2008, no. 10, p. 1000, 2008.*

[11] *N.R. Abburi and U.S. Dixit: "A knowledge-based system for the prediction of surface roughness in turning process", Robotics and Computer-Integrated Manufacturing, vol. 22, no. 4, pp. 363-372, 2006.*

[12] *K. Huh and C. Pak: "Unmanned Turning Force Control with Selecting Cutting Conditions", IEEE, American Control Conference, Denver, CO, USA, 2003.*

[13] *D. Karayel: "Prediction and control of surface roughness in CNC lathe using artificial neural network", Journal of Materials Processing Technology, vol. 209, pp. 3125-3137, 2009.*

[14] *Y.H. Peng: "On the performance enhancement of self-tuning adaptive control for time-varying machining processes", International Journal of Advanced Manufacturing Technology, vol. 24, pp. 395-403, 2004.*

[15] *J. Srinivas, R. Giri, R. and S.-H. Yang: "Optimization of multi-pass turning using particle swarm intelligence", International Journal of Advanced Manufacturing Technology, vol. 40, pp. 56-66, 2009.*

[16] *J. Ratava, M. Rikkonen, V. Ryynänen, J. Leppänen, T. Lindh, J. Varis, and I. Sihvo: "An adaptive fuzzy control system to maximize rough turning productivity and avoid the onset of instability", International Journal of Advanced Manufacturing Technology vol. 53, no. 1, pp. 71-79, 2012.*

[17] *V. Ryynänen, J. Ratava, T. Lindh, M. Rikkonen, I. Sihvo, J. Leppänen, and J. Varis: "Chip control system for monitoring the breaking of chips and elimination of continuous chips in rough turning", Mechanika vol. 4 no. 78, pp. 57-62, 2009.*

[18] *V.S. Sharma, S.K. Sharma, and A.K. Sharma: "Cutting tool wear estimation for turning", Journal of Intelligent Manufacturing, vol. 19, no. 1, pp. 99-108, 2006.*

[19] *O. Yilmaz, G. Görür, and T. Dereli: "Computer Aided Selection of Cutting Parameters by Using Fuzzy Logic", Proceedings of the International Conference, 7th Fuzzy Days on Computational Intelligence, Theory and Applications, Dortmund, Germany, 2001.*

[20] *H. Saglam, S. Yaldiz, and F. Unsacar: "The effect of tool geometry and cutting speed on main cutting force and tool tip temperature", Materials & Design, vol. 28, no. 1, pp. 101-111, 2007.*

[21] *X. Cui, J. Zhao, Y. Dong: "The effects of cutting parameters on tool life and wear mechanisms of CBN tool in high-speed face milling of hardened steel", International Journal of Advanced Manufacturing Technology, July 2012.*

[22] *A. Bhattacharya, S. Das, P. Majumder, A. Batish: "Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA," Production Engineering, vol. 3, no. 1, pp. 31-40, 2009.*

[23] *A. Hamdan, A.A.D. Sarhan, and M. Hamdi: "An optimization method of the machining parameters in high-speed machining of stainless steel using coated carbide tool for best surface finish," International Journal of Advanced Manufacturing Technology, vol. 58, no. 1-4, pp. 81-91, 2012.*

[24] *V.G. Navas, O. Gonzalo, and I. Bengoetxea: "Effect of cutting parameters in the surface residual stresses generated by turning in AISI 4340 steel", International Journal of Machine Tools and Manufacture, vol. 61, pp. 48-57, 2012.*

[25] *O. Kienzle and H. Victor: "Die Bestimmung von Kräften und Leistungen an spanenden Werkzeugmaschinen", VDI-Z, vol. 94, no. 11-12, pp. 155-171, 1952.*

[26] *M.B. da Silva and J. Wallbank: "Cutting temperature: prediction and measurement methods - a review", Journal of Materials Processing Technology, vol. 88, no. 1-3, pp. 195-202, 1999.*

[27] *V.P. Astakhov: "Effects of the cutting feed, depth of cut, and workpiece (bore) diameter on the tool wear rate", International Journal of Advanced Manufacturing Technology, vol. 34, no. 7-8, pp. 631-640, 2007.*

[28] *R.K. Bhushan: "Optimization of cutting parameters for minimizing power consumption and maximizing tool life during machining of Al alloy SiC particle composites", Journal of Cleaner Production, vol. 39, pp. 242-254, 2013.*

[29] *N. S. Kumar, A. Shetty, A. Shetty, Ananth K, and H. Shetty: "Effect of Spindle Speed and Feed Rate on Surface Roughness of Carbon Steels in CNC Turning", Procedia Engineering, vol. 38, pp. 691-697, 2012.*

[30] *H. Aouici, M.A. Yallese, K. Chaoui, T. Mabrouki, and J.-F. Rigal: "Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization", Measurement, vol. 45, no. 3, pp 344-353, 2012.*

[31] *T.S. Ong and B.K. Hinds, "The application of tool deflection knowledge in process planning to meet geometric tolerances", International Journal of Machine Tools and Manufacture, volume 43, no. 7, pp. 731-737, 2003.*

[32] *V. Sivaraman, S. Sankaran, and L. Vijayaraghavan: "The Effect of Cutting Parameters on Cutting Force During Turning Multiphase Microalloyed Steel", Procedia CIRP, vol. 4, pp. 157-160, 2012.*

[33] *L.B.Abhang and M. Hameedullah: "Chip-Tool Interface Temperature Prediction Model for Turning Process", International Journal of Engineering Science and Technology, vol. 2, no. 4, 382-393, 2010.*

[34] *S.K Choudhury and K.K Kishore, "Tool wear measurement in turning using force ratio", International Journal of Machine Tools and Manufacture, vol. 40, no. 6, pp. 899-909, 2000.*

[35] *G. Bartarya and S.K. Choudhury: "Effect of Cutting Parameters on Cutting Force and Surface Roughness During Finish Hard Turning AISI52100 Grade Steel", Procedia CIRP, vol. 1, pp. 651-656, 2012.*

[36] *K.-M. Li and S.Y. Liang: "Modeling of cutting forces in near dry machining under tool wear effect", International Journal of Machine Tools and Manufacture, vol. 47, no. 7-8, pp. 1292-1301, 2007.*

[37] *R. Pavel, I. Marinescu, M. Deis, and J. Pillar, "Effect of tool wear on surface finish for a case of continuous and interrupted hard turning", Journal of Materials Processing Technology, vol. 170, no. 1-2, pp. 341-349, 2005.*

[38] *M.U. Ghani, N. A. Abukhshim, and M. A. Sheikh: "An investigation of heat partition and tool wear in hard turning of H13 tool steel with CBN cutting tools", International Journal of Advanced Manufacturing Technology, vol. 39, no. 9-10, pp 874-888, 2008.*

[39] *M.A. Xavior and M. Adithan: "Determining the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel", Journal of Materials Processing Technology, vol. 209, no. 2, pp. 900-909, 2009.*

[40] *J.M. Vieira, A.R. Machado, and E.O. Ezugwu: "Performance of cutting fluids during face milling of steels", Journal of Materials Processing Technology, vol. 116, no. 2-3, pp. 244-251, 2001.*

[41] *D. Jianxin, Z. Hui, W. Ze, L. Yunsong, X. Youqiang, and L. Shipeng: "Unlubricated friction and wear behaviors of Al2O3/TiC ceramic cutting tool materials from high temperature tribological tests", International Journal of Refractory Metals and Hard Materials, vol. 35, pp. 17-26, 2012.*

[42] *N. Guillemot, M. Winter, A. Souto-Lebel, C. Lartigue, and R. Billardon: "3D Heat Transfer Analysis for a Hybrid Approach to Predict Residual Stresses After Ball-End Milling", Procedia Engineering, vol. 19, pp. 125-131, 2011.*