TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 66, Issue Special II, October, 2023

SIMULATION AND PRACTICAL INVESTIGATIONS OF INDUCTIVELY ASSISTED MACHINING USING THE EXAMPLE OF TURNING OPERATIONS

Frank ARNOLD, Niranjan MANUR KRISHNAMURTHY, Johannes PRASSE, Lars PENTER, Steffen IHLENFELDT

Abstract: *Due to the increasing use of hard-to-cut materials, machining processes face the challenge of overcoming technologically determined limits of machinability. Hybrid manufacturing processes combine different mechanisms of action into one process and are a promising approach to shift the limits of the individual processes. One approach for improving efficiency through hybrid manufacturing processes is thermally assisted machining. By softening the material in the heated area, machining forces can be reduced and surface quality can be improved. In comparison to other heating methods, induction is an easy-to-use and highly efficient option. Currently, there is no consistent method for simulating this process. The paper shows approaches for the Finite Element Method simulation and implementation of induction-assisted turning. The simulation model developed by the authors predicted temperatures and cutting forces with the validation and reduction of forces are proven by the practical tests.*
Key words: *hybrid machining, thermal assisted machining, induction assisted turning, induction, Smooth Particle Hydrodynamics, Finite Element Method*

1. INTRODUCTION

The increasing use of new and difficult-to-machine materials, driven by the constantly growing component requirements, serves as a catalyst for the further development of conventional machining processes. However, machining of difficult-to-machine materials is often associated with significant difficulties due to poor machinability and requires machining technologies adapted to the task. Hybrid machining is becoming more and more the focus of development efforts. It combines several working mechanisms or processes at the point of operation, thereby leveraging the advantages of each mechanisms and mitigating their drawbacks. Hybrid manufacturing can extend or shift technological process limits to more favorable areas [1, 2]. Furthermore, increased process performance, better machining results, reduced process forces and longer tool life are just some of the possible benefits of hybrid-assisted processes. [3, 4]. The prospect of easier machining of difficult-to-machine materials as well as the reduction of process force in the machining of conventional materials continues to drive research and development [5, 6]. Adding thermal energy has a positive influence in machining these materials. In particular, processes with heat input are a promising approach to improving cutting conditions. Introducing heat into the material reduces its tensile strength, making it much easier to machine difficult-to-machine materials by reducing cutting forces and increasing of tool life [7]. Current research focusses on laser and plasma assisted processes [8, 9].

2. INDUCTIVE ASSISTED TURNING

Stationary induction heat treatment involves no relative motion between the coil and the inductor [10]. In contrast, induction-assisted turning involves a relative movement between the induction coil and the workpiece. The specific area of the workpiece to be machined is heated to a higher temperature and is then machined by the cutting tool. This process allows for greater control of the temperature distribution and can significantly reduce the cutting forces required for machining, resulting in improved surface quality and reduced tool wear. It has been demonstrated in [11, 12] that inductive assisted machining is a promising method for machining difficult-to-cut materials such as titanium and Inconel 718.

Induction heating is a highly non-linear and complex process in nature, involving the interplay of multiple physical phenomena, including electromagnetic and thermal effects [11, 12]. Due to the continuous variation of magnetic flux linkage and temperature, the corresponding magnetic and thermal properties of the material also exhibit non-linear behavior [13, 14]. Extensive research has been conducted over the years to develop numerical models and simulations for induction heating processes. Researchers used finite element methods to investigate the complex and highly coupled magneto-thermal interactions involved in moving induction heating processes.

Wang et al. [15] developed a model utilizing a finite element approach with a re-mesh scheme for moving induction heat treatment. Shokouhmand [10] performed a nonlinear and transient magneto-thermal coupled temperature analysis of a moving induction process. Cho [16] developed a model that accounts for all non-linearities in the coupled electromagnetic and thermal systems for both 1D and 2D stationary billet induction heating. In addition, Li et al. [17] developed a model to investigate the mechanism of moving induction heating with a magnetic flux concentrator.

Jain [18] developed an electromagnetic-thermal model based on the finite element method to simulate induction heating of a moving wire. These studies have provided valuable insights into the complex and coupled nature of the electromagnetic and thermal interactions involved in moving induction heating processes.

A major focus of machining research has been the optimization of processes through a better understanding of the relationship between input and output variables. These variables include tool geometry, material characteristics, temperature, tool wear, and surface finish.

Computer-aided modeling and simulation has proven to be a valuable tool in understanding these parameters and optimizing machining processes.

Most of these models rely heavily on the Finite Element Method (FEM). However, limitations associated with FEM, such as the modeling of high deformation, material separation, and contact phenomena during machining, have led to the prevalence of two-dimensional (2D) models employing plain strain assumption.

The Smooth Particle Hydrodynamics (SPH) method, which is emerging as a promising alternative to FEM, uses a particle-based approach to discretize the domain, thereby, eliminating the necessity for explicit physical contact among particles.

Limido et al. [12] presented a 2D orthogonal machining model that employed the Johnson-Cook constitutive model to simulate material behavior. The study concluded that the SPH method for machining models offers advantages such as its meshless nature, natural separation of chips without the need for re-meshing. Fauerholdt [19] conducted a sensitivity analysis to investigate the influence of numerical parameters in the SPH method. Cherukuri [20] performed parametric studies focusing on the smoothing length, particle density, and stress distribution in SPH.

Xi et al. [21] presented a coupled SPH-FEM machining model to study thermal assisted machining of Ti6Al4V. The workpiece was discretized using SPH particles in the high deformation zone (tool-workpiece interaction zone) and FE mesh in the low deformation zone. Similarly, Song et al. [22] used a coupled SPH and FEM model to investigate laser-assisted machining of fused silica and predict cutting forces. However, these models tend to significantly underpredict feed forces. Limited research [23, 24] has been conducted to incorporate realistic three-dimensional (3D) machining models, where only a section of the workpiece is modeled.

Ojal et al. [25] introduced a comprehensive 3D model of turning operations using a combined SPH and FEM approach. The advantages of each method were exploited to develop a highly accurate coupled SPH-FEM machining model. By applying this approach to 3D models, a 17% difference was achieved between the total simulated force and the experimentally measured force for Al 6061.

In conclusion, one of the shortcomings of the current state of the art in the field of moving induction heating is the lack of a consistent simulation approach that includes all non-linear parameters and their variations. This research paper addresses this gap. It presents a comprehensive 3D multiphysics FEM simulation model of induction heating in motion. The model integrates electromagnetic and thermal solvers in real-time using Ansys® software. In addition, this study draws on the knowledge provided by the work of Ojal's et al. [25] to develop a three-dimensional machining model. A systematic methodology is employed to create a complete workflow procedure for both induction heating and turning processes. Emphasize is place on the reduction of cutting forces and the performance of the model is evaluated by comparison with experimental data.

3. DEVELOPMENT OF SIMULATION MODEL

3.1 Software

This study employs the Ansys® FE code for induction heating and LS-Dyna® for turning simulations. Ansys® provides multiphysics two-way coupling with the ability to include all non-linear factors for comprehensive analysis. The induction heating simulations in this study is performed by coupling Ansys® electronics (Maxwell 3D) and Ansys® Fluent. The 3D turning simulation model is developed in LS-Dyna® using a coupled SPH and FEM. The inductor's CAD files were generated using SolidWorks®.

3.2 Model setup

The initial simulation setup of the inductor workpiece model is shown in Fig.1**Error! Reference source not found.**. In this setup, the workpiece undergoes a controlled upward motion, while the inductor remains in a fixed position.

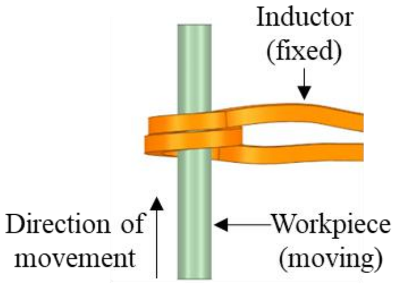

Fig.1. Induction heating in Maxwell 3D

Structural steel (1.0038) was selected for the workpiece and copper for the inductor.

Due to the non-linear nature of the induction heating process, temperature-dependent properties such as relative magnetic permeability, thermal conductivity, specific heat etc. are defined consistently in both the solvers. The mesh generated for the electromagnetic simulation consists of tetrahedral elements (workpiece) and triangular elements (inductor). Thermal simulations use the unstructured tetrahedral meshing method within Fluent for the workpiece. This approach ensures an accurate representation of the thermal behavior and better data mapping to and from Maxwell.

System coupling files are generated separately from both solvers, enabling the execution of a co-simulation. Ansys® system coupling integrates both solvers and facilitates a coupled simulation with tight integration and real-time data transfer Fig.2.

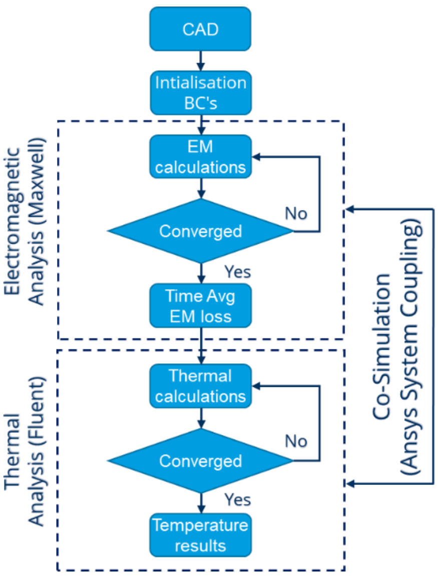

Fig.2. Coupled simulation for induction heating

Co-simulation incorporates a moving mesh technique that allows the mesh to move with the workpiece. This ensures that the system's behavior is accurately captured, while effectively managing computing resources.

The 3D machining model developed is shown in the Fig.3. Specifically, SPH particles (shown in green) are used in areas of high deformation and in contact with the cutting tool, while the FE mesh (shown in pink) is used in areas of lower deformation. To transfer properties, they are coupled at the interface using node-to-surface constraint algorithm [26]. Additionally, the tool is discretized using an FE mesh and brought into contact with the SPH particles during the simulation using a nodes-to-surface contact algorithm.

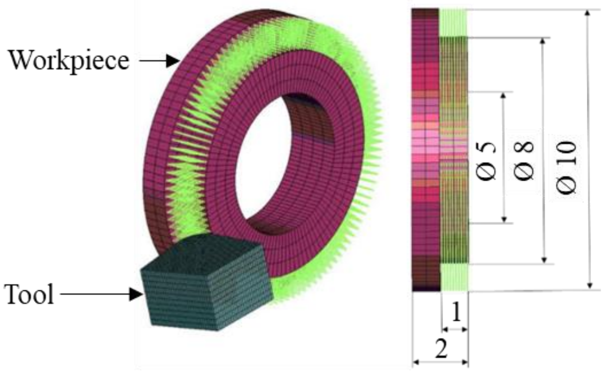

Fig.3. Coupled SPH-FEM model for turning

To streamline the model and reduce computational complexity, the tool is assumed to be a rigid entity. The Johnson-Cook material and damage model is utilized to accurately replicate the behavior of the workpiece and simulate fracture.

4. PRACTICAL TESTS

Practical tests were carried out on a lathe to verify of the simulation results. The machine was equipped with an inductor holder for heating in front of the tool cutting edge. Two different water-cooled inductors were used for the tests. Inductor 1 was a fully enclosed inductor with an internal diameter of 16mm, while inductor 2 was designed with a curved surface with a radius of 24 mm to allow one-sided heating with a variable coupling distance to be included in the tests Fig.4.

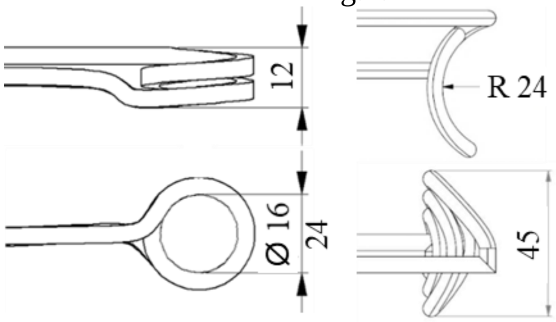

Fig.4. Inductor 1 (left) and 2 (right)

An "eldec HFG 3" generator with a total output of 3 kW was used as the induction unit. A "PCLNR 2020K12" tool holder with a "CNMG08 04 12 - HB7035" indexable insert of the type was used as the turning tool. The process forces during both conventional and induction-assisted machining were measured using a “Kistler 9527B” dynamometer Fig.5.

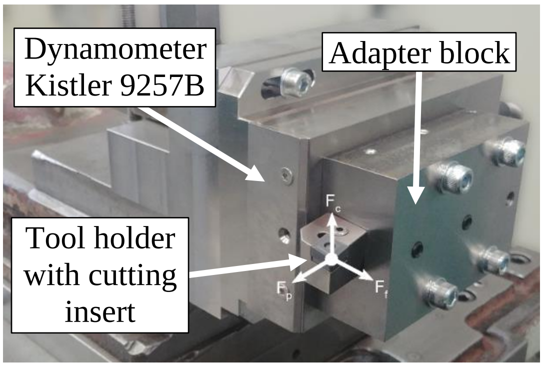

Fig.5. Position of the tool attached to the Dynamometer

A “CT Laser LT CF1” pyrometer was used to record the temperatures generated on the surface of the workpiece in the cutting zone. It was mounted on the support of the lathe and moved together with the inductor and the tool, remaining focused on the cutting zone Fig. 6.

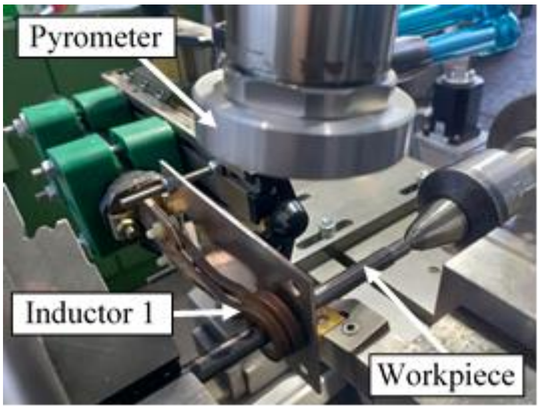

Fig. 6. Setup of pyrometer

5. RESULTS

The results of both simulations and practical tests for moving induction heating and conventional turning processes are presented. The influence of parameters such as cutting depth, current, feed and coupling distance are investigated. The main objective is to reduce the cutting forces due to induction heating. The simulation results are validated with data from practical tests to ensure their accuracy and reliability.

5.1 Cutting depth

To predict the cutting forces and select suitable cutting depth for inductive assisted turning process, simulations of conventional turning is performed initially. A workpiece of 10mm diameter is used for this study. Cutting depths of 0.25mm and 0.50mm were chosen for the simulation.

The workpiece rotated at a constant angular velocity of 710rpm. According to the study by [25], increasing the cutting speed up to 10x in the simulation has no significant effect on the cutting forces, but reduces the computation time significantly. The cutting speed in all subsequent simulations is 5x (actual cutting speed).

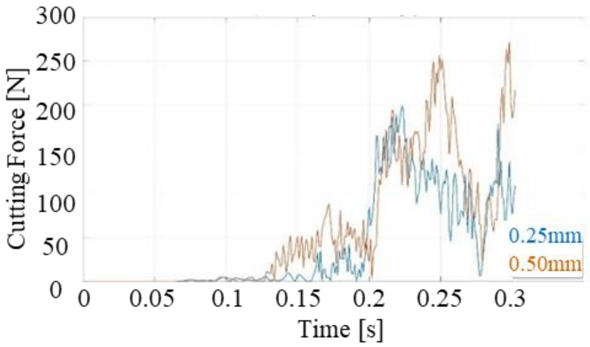

Fig.7. Simul. of cutting forces, different cutting depths

According to [27], an increase in depth of cut leads to an increase in cutting forces. Fig.7 shows the cutting forces from the simulations for the two speeds. When the cutting depth was doubled, the cutting forces increased by 36%.

The performance of the developed machining model is validated with the experimental data. The validation results are presented in Fig.8 and Fig.9.

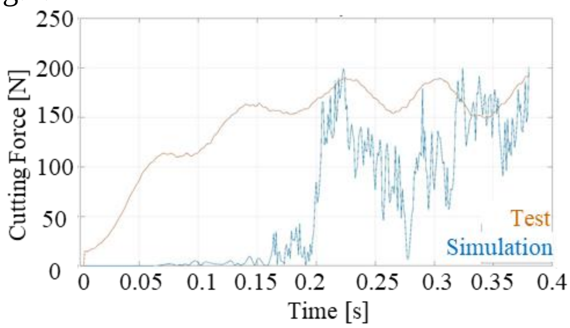

Fig.8. Cutting forces, cutting depth 0.25mm

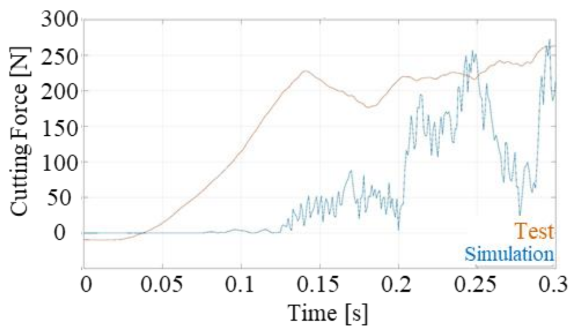

Fig.9. Cutting forces, cutting dept 0.50mm

The forces predicted by the simulation model are within an acceptable range when compared to the experimental data for both cutting depths. However, it is worth noting that the predictions of the simulation model underestimated the cutting forces by 20% and 26% for cutting depths of 0.25mm and 0.50mm, respectively.

Various factors such as the values of the material model parameters (J-C model), coarse mesh resulting in the discontinuities in the prediction of the cutting forces, variations in the coefficient of friction, and the uncertainties introduced during the measurements may have contributed to the divergence.

5.2 Influence of current

A 10mm diameter workpiece with inductor 1 was used to study the influence of current. The input excitation currents for the simulations are chosen to be 225A, 500A, and 750A, while the frequency is kept constant at 280kHz. The initial feed is set to a constant value of 0.27mm/rev in practical tests, the length of the workpiece is 75mm with a constant speed of 710rpm.

Fig.10 shows the temperature profile of a moving workpiece after 25s of heating. The highest temperature of approximately 885°C is obtained for the input current of 750A.

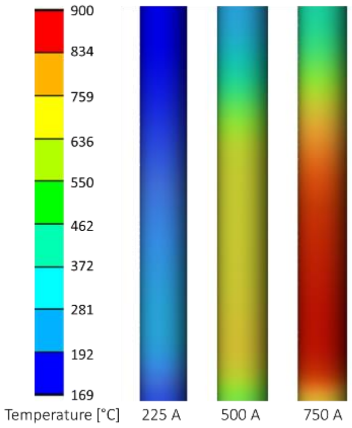

Fig.10. Temperature profiles for 280kHz at 25s

The comparison of the simulated temperatures with the experimental values are depicted in Fig.11, Fig.12 and Fig.13.

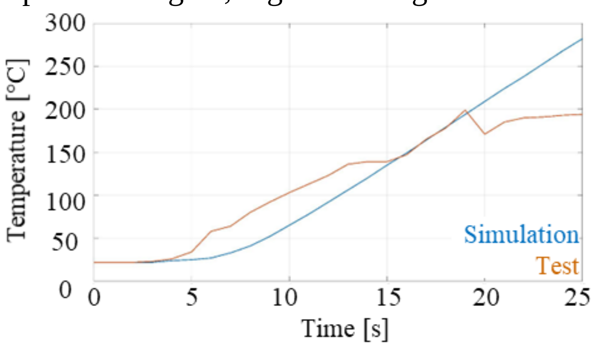

Fig.11. Validation of heating curve for 225A

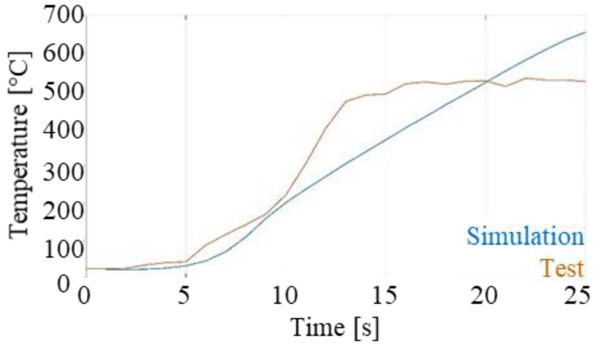

Fig.12. Validation of heating curve for 500A

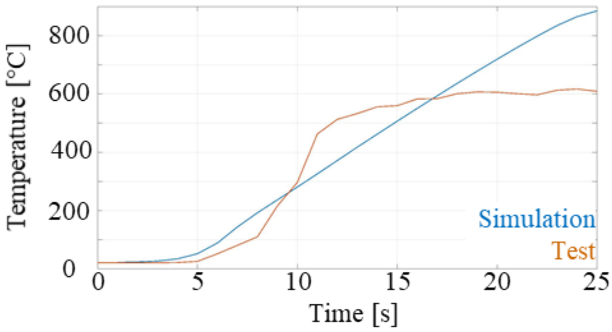

Fig.13. Validation of heating curve for 750A

Although there are some under and over-predictions at different time intervals, the overall nature of the heating curves is in good agreement with the experimental data. The average maximum difference between the total simulated temperatures and the experimental values is 13.83% for inductor 1 at 750A. Fig.14 illustrates a comparative analysis of the cutting forces between inductively assisted turning (225A, 500A, and 750A) and conventional turning. The greatest reduction in cutting force is obtained for 750A, due to the higher temperatures. Specifically, there was a reduction of 31.25% in cutting forces for 750A and the figures dropped to 25% and 6.25% for 500A and 225A respectively. This demonstrates the significant effect of induction heating on cutting forces during turning operations.

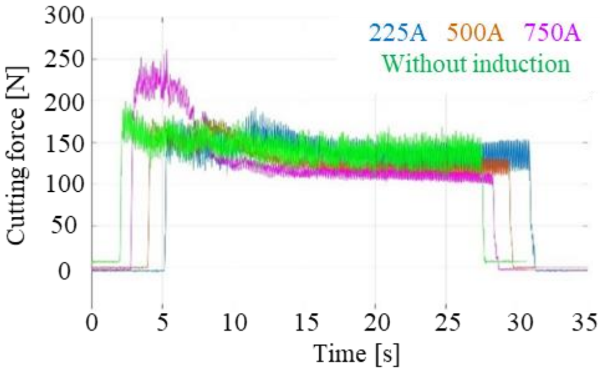

Fig.14. Reduction in cutting forces, different currents

5.3 Effect of feed

The effect of the velocity of the workpiece (feed rate) and the efficiency of the simulation model in predicting temperatures is studied with inductor 1. The input current and frequency are held constant at 500A and 280kHz. The temperatures generated for a feed of 0.17mm/rev and 0.27mm/rev for a 10mm diameter workpiece are shown in Fig.15 after 25s of heating.

Compared to a feed of 0.27mm/rev and with the same input parameters, a higher temperature is observed at 0.17mm/rev with a maximum of 706°C. The experimental values confirm the same where the lower feed produced higher temperatures and vice versa.

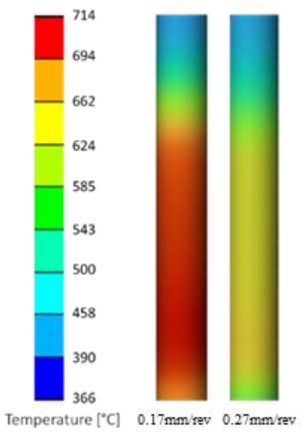

Fig.15. Temperature profiles at different feed

Fig.16**Error! Reference source not found.** shows the comparison of simulation and experimental results of temperatures for the feed of 0.17mm/rev. The simulation model can also predict the type of heating curve and temperature values for a different feed also with a maximum average deviation of 12.66%.

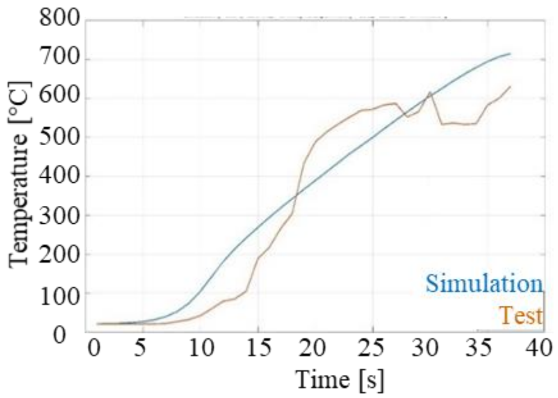

Fig.16. Validation of heating curves for feed of 0.17mm/rev

Fig.17 shows the cutting forces from the experiments for three different feed.

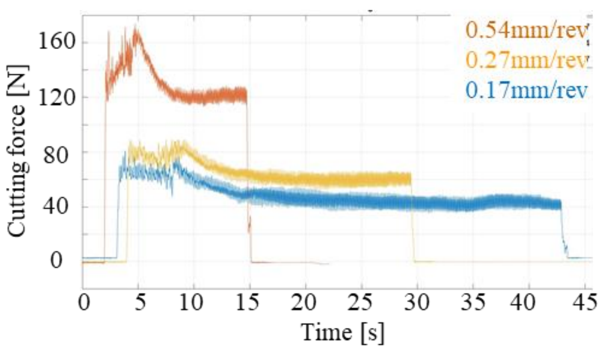

Fig.17. Reduction in cutting forces, different feed

Temperatures have an effect on the reduction of cutting forces. Lower feed result in higher temperatures and lower cutting forces.

According to [28], the increase in the temperature during the machining facilitates the gradual decrease in the cutting forces. The reduction in cutting forces for 1.0038 is evident with the introduction of thermal energy by induction. A reduction in cutting forces of 35%, 29%, and 21% is achieved for the feed of 0.17mm/rev, 0.27mm/rev and 0.54mm/rev respectively.

5.4 Influence of Coupling distance

Inductor 2 is employed for this study as it can by flexibly coupled as an external heating inductor to workpieces of various shapes and sizes. Three coupling distances of 1mm, 1.5mm and 2mm for a workpiece of 20mm diameter are simulated for temperatures. In all three cases the heating conditions and feed are kept constant at 500A, 175 kHz and 0.27mm/rev. Heating curves are obtained for three different coupling distances as shown in Fig.18**Error! Reference source not found.**.

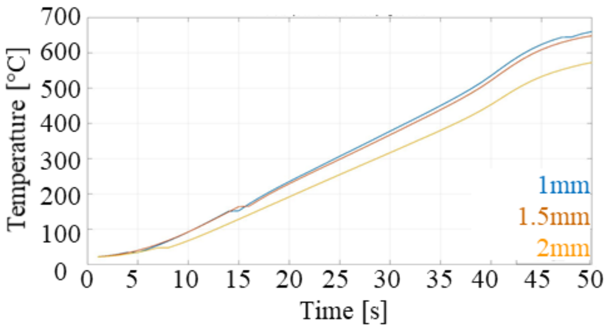

Fig.18. Different coupling distances, inductor 2

It shows that the heating is more pronounced when the coupling distance is 1mm and gradually decreases as the distance increases due to a decrease in energy transfer to the workpiece. A temperature drop of 2.72% and 13.2% is observed when comparing 1mm with 1.5mm and 2mm. The coupling distance of 1mm, which produced the highest temperature, was chosen selected for practical test. The comparison of temperature data from simulation and experimental analysis is shown in Fig.19.

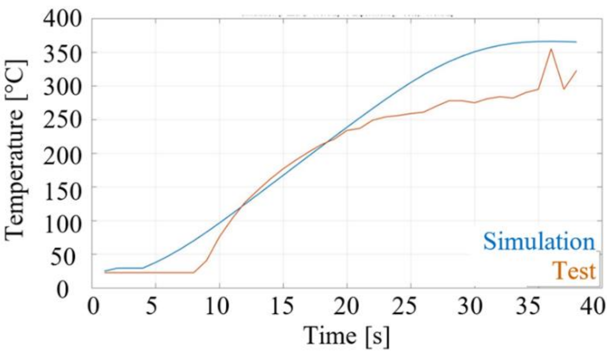

Fig.19. Heating curves for inductor 2, dist. 1mm

Although the nature of the heating curve shows a promising trend, the temperature was over predicted by the simulation model by 14.50%. Fig.20 shows a comparison of cutting forces between induction assisted turning and conventional turning processes for inductor 2. Due to the setup (Fig. 6) the tool starts with cutting unheated material for a short distance initially (gap between inductor and tool), which results in the same forces as the conventional machining in the beginning. As the tool starts cutting the heated material, the forces gradually start decreasing. The findings show an average 28% reduction in the cutting forces with induction heating.

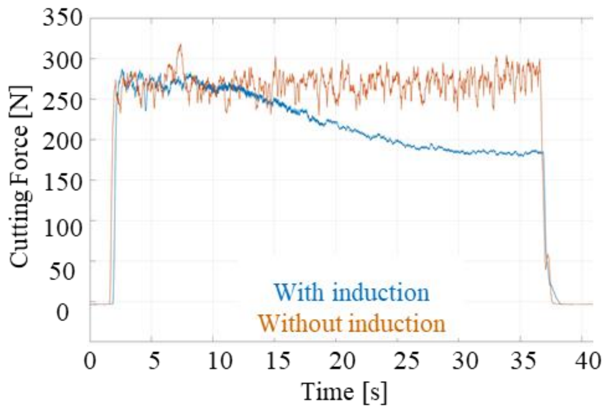

Fig.20. Cutting forces, inductor 2, dist. 1mm

6. CONCLUSION

The study shows that it is possible to represent the entire, inductively assisted machining by a combination of different simulation approaches. These include the simulation of the ohmic losses occurring during induction heating, the simulation of the resulting temperature rise in the workpiece, the application of the Johnson-Cook model and the combination of the SPH method with the FEM for machining.

The developed simulation model predicted temperatures for different input currents, feed and coupling distance. The results indicate that higher the input current, lower the feed and coupling distance higher temperatures are obtained. This has a substantial impact in reducing the cutting forces. The inductive assisted turning process with optimal parameters achieved a maximum reduction in cutting forces of 35% compared to conventional turning. The validated simulation models proved an accuracy of approximately 85% and 80% in predicting temperatures and cutting forces.

The results of the practical verification of the resulting temperatures and cutting forces compared to simulation results are within an acceptable range. The main reasons for the deviations are the often still insufficient availability of the electromagnetic material properties and the J-C model properties as a input for the simulation. Improving the accuracy of these parameters will significantly improve the quality of the simulation results. The use of induction heating significantly reduces the resulting cutting forces in a turning operation. This can increase the efficiency compared to conventional turning.

In addition, the reduction in the tensile strength of the material to be machined and the associated improvement in cutting conditions allows the process limits specified by the machine to be shifted.

Further work is underway to investigate the effects of the resulting temperatures on chip formation and the tool life in induction assisted machining.

7. REFERENCES

[1] Patz, M. "Innovationen in der Zerspantechnik: Technologien, Anwendungsbeispiele und Perspektiven," *Diamant Hochleistungswerkzeuge dihw Magazin*, no. 3, 2010.

[2] Brecher, C. *Integrative Produktionstechnik für Hochlohnländer: Hybride Produktionssysteme*. Berlin, Heidelberg: Springer Verlag, 2011.

[3] Brecher, C. *Advances in Production Technology*. Cham: Springer Verlag, 2015.

[4] Luo, X. and Qin, Y. *Hybrid Machining: Therory, Methods and Case Studies*. London: Academic Press Verlag, 2018.

[5] Emonts, M. *Hybride Produktionstechnik: Neue Entwicklungen von hybriden Verfahren und hybriden Werkzeugmaschinen.* [Online]. Available: https://silo.tips/download/hybride-produktionstechnik-neue-entwicklungen-von-hybriden-verfahren-und-hybride (accessed: Oct. 7 2021).

[6] Mescheder, U., Armbruster, C. *Forschungsbericht 2018/2019.* [Online]. Available: https://www.hs-furtwangen.de/fileadmin/Redaktion/Publikationen/Forschungsbericht_2018_2019.pdf (accessed: Oct. 16 2021).

[7] Baili, M. et all "An Experimental Investigation of Hot Machining with Induction to Improve Ti-5553 Machinability," *Applied Mechanics and Materials*, vol. 62, 2011.

[8] Jeon, Y., Park, H. W., Lee, C. M. "Current research trends in external energy assisted machining," *International Journal of Precision Engineering and Manufacturing*, vol. 14, no. 2, 2013.

[9] Abele, E., Hölscher, R. "Durch induktive Erwärmung gestützte Materialbearbeitung, insbesondere Zerspanen von Titanlegierungen oder Materialien mit vergleichbar geringem Wärmeleitfaktor," EP24180044A1, Deutschland, Feb 15, 2012.

[10] Shokouhmand, H., Ghaffari, S. "Thermal analysis of moving induction heating of a hollow cylinder with subsequent spray cooling: Effect of velocity, initial position of coil, and geometry," *Applied Mathematical Modelling*, vol. 36, no. 9, pp. 4304–4323, 2012, doi: 10.1016/j.apm.2011.11.058.

[11] Sun, J., Li, S., Qiu, C., Peng, Y. "Numerical and experimental investigation of induction heating process of heavy cylinder," *Applied Thermal Engineering*, vol. 134, pp. 341–352, 2018, doi: 10.1016/j.applthermaleng.2018.01.101.

[12] Limido, J. et all "SPH method applied to high speed cutting modelling," *International Journal of Mechanical Sciences*, vol. 49, no. 7, pp. 898–908, 2007, doi: 10.1016/j.ijmecsci.2006.11.005.

[13] Kagimoto, H. et all "Effect of Temperature Dependence of Magnetic Properties on Heating Characteristics of Induction Heater," *IEEE Trans. Magn.*, vol. 46, no. 8, pp. 3018–3021, 2010, doi: 10.1109/TMAG.2010.2046145.

[14] Totten, G.E., Howes, M., Inoue, T. *Handbook of Residual Stress and Deformation of Steel*, 2002. [Online]. Available: https://www.researchgate.net/publication/313175568_Handbook_of_Residual_Stress_and_Deformation_of_Steel

[15] Wang, K.F., Chandrasekar, S., Yang, H. T. Y. "Finite-element simulation of moving induction heat treatment," (in En;en), *JMEP*, vol. 4, no. 4, pp. 460–473, 1995, doi: 10.1007/BF02649308.

[16] Cho, K.-H. "Coupled electro-magneto-thermal model for induction heating process of a moving billet," *International Journal of Thermal Sciences*, vol. 60, pp. 195–204, 2012, 10.1016/j.ijthermalsci.2012.05.003.

[17] Li, F., Li, X., Zhu, T., Rong, Y. "Numerical Simulation of the Moving Induction Heating Process with Magnetic Flux Concentrator," *Advances in Mechanical Engineering*, vol. 5, p. 907295, 2013, doi: 10.1155/2013/907295.

[18] Jain, I. "Electromagnetic-Thermal Modeling of Induction Heating of Moving Wire," *Heat*

Trans. Asian Res., vol. 46, no. 2, pp. 111–133, 2017, doi: 10.1002/htj.21201.

[19] Villumsen, M., Torben, G. Fauerholdt, "Simulation of Metal Cutting using Smooth Particle Hydrodynamics," 2008. [Online]. Available: https://www.semanticscholar.org/paper/Simulation-of-Metal-Cutting-using-Smooth-Particle-Villumsen-Fauerholdt/7ca7564b730e9e445d04ac46d00f1e07b3906ca6

[20] Avachat, C.S., Cherukuri, H.P. "A Parametric Study of the Modeling of Orthogonal Machining Using the Smoothed Particle Hydrodynamics Method," *ASME 2015 International Mechanical Engineering Congress and Exposition*, 2016, doi: 10.1115/IMECE2015-53237.

[21] Xi, Y., et all "SPH/FE modeling of cutting force and chip formation during thermally assisted machining of Ti6Al4V alloy," *Computational Materials Science*, vol. 84, pp. 188–197, 2014, doi: 10.1016/j.commatsci.2013.12.018.

[22] Song, H. et all., "SPH/FEM modeling for laser-assisted machining of fused silica," (in En;en), *Int J Adv Manuf Technol*, vol. 106, 5-6, pp. 2049–2064, 2020, doi: 10.1007/s00170-019-04727-6.

[23] Llanos, I., Villar, J A., Urresti, I., Arrazola, J. "FINITE ELEMENT MODELING OF OBLIQUE MACHINING USING AN ARBITRARY LAGRANGIAN–EULERIAN FORMULATION," *Machining Science and Technology*, vol. 13, no. 3, pp. 385–406, 2009, doi: 10.1080/10910340903237921.

[24] Ozel, T., Llanos, I., Soriano, J., Arrazola, P.-J. "3D FINITE ELEMENT MODELLING OF CHIP FORMATION PROCESS FOR MACHINING INCONEL 718: COMPARISON OF FE SOFTWARE PREDICTIONS," *Machining Science and Technology*, vol. 15, no. 1, pp. 21–46, 2011, doi: 10.1080/10910344.2011.557950.

[25] Ojal, N., Copenhaver, R., Harish, P., Schmitz, L., Kyle, T. Devlugt and Adam W. Jaycox, "A Realistic Full-Scale 3D Modeling of Turning Using Coupled Smoothed Particle Hydrodynamics and Finite Element Method for Predicting Cutting Forces,"

[26] John, O. Hallquist, *LS-DYNA: Theory manual*. Livermore, Calif.: Livermore Software Technology Corp, 2006.

[27] Mruthunjaya, M., Yogesha, K.B. "A review on conventional and thermal assisted machining of titanium based alloy," *Materials Today: Proceedings*, vol. 46, no. 1, pp. 8466–8472, 2021, doi: 10.1016/j.matpr.2021.03.490.

[28] Wagner, V., Harzallah, M., Baili, M., Dessein, G., Lallement, D. "Experimental and numerical investigations of the heating influence on the Ti5553 titanium alloy machinability," *Journal of Manufacturing Processes*, vol. 58, pp. 606–614, 2020, doi: 10.1016/j.jmapro.2020.08.018.

Investigații și simulări practice ale prelucrărilor asistate inductiv

Datorită utilizării tot mai des a materialelor greu de tăiat, procesele de prelucrare se confruntă cu provocarea de a depăși limitele de prelucrabilitate determinate tehnologic. Procesele de fabricație hibride combină diferite mecanisme de acționare într-un singur proces și reprezintă o abordare promițătoare pentru a schimba limitele proceselor individuale. O abordare pentru îmbunătățirea eficienței prin procese hibride de fabricație este prelucrarea asistată termic. Prin înmuierea materialului în zona încălzită, forțele de prelucrare pot fi reduse și calitatea suprafeței poate fi îmbunătățită. În comparație cu alte metode de încălzire, inducția este o opțiune ușor de utilizat și foarte eficientă. În prezent, nu există o metodă consistentă pentru simularea procesului. Lucrarea prezintă abordări pentru simularea FEM și implementarea strunjirii asistate cu inducție. Modelul de simulare dezvoltat de autori a prezis temperaturile și forțele de tăiere cu validarea și reducerea forțelor prin intermediul testelor practice.

Frank ARNOLD, Dipl.-Ing., Research associate, TU Dresden - Chair of Machine Tools Development and Adaptive Controls, , Helmholtzstraße 7a, 01069 Dresden, frank.arnold@tu-dresden.de

Niranjan Manur KRISHNAMURTHY, MSc, mk.niranjan@outlook.com

Johannes PRASSE, Dipl.-Ing., johannes.prasse@googlemail.com

Lars PENTER, Dr.-Ing., Senior Engineer Research and Education, TU Dresden - Chair of Machine Tools Development and Adaptive Controls, Helmholtzstraße 7a, 01069 Dresden, lars.penter@tu-dresden.de

Steffen IHLENFELDT, Prof. Dr.-Ing., Head of Chair, TU Dresden - Chair of Machine Tools Development and Adaptive Controls, Helmholtzstraße 7a, 01069 Dresden, steffen.ihlenfeldt@tu-dresden.de