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Original Article

Hot ultrasonic assisted machining modelling of Ti6Al4V in terms of power consumption

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ABSTRACT

Ultrasonic assisted machining is a manufacturing method which creates intermittent cutting mechanism using ultrasonic vibration. Hot machining is another technique which uses external heat source before or during machining operations. These methods help to machine difficult to cut materials such as titanium, nickel, composite materials and improve surface machining characteristics (low cutting force, stress level, etc.). Hot ultrasonic-assisted machining is a novel machining technique that combines Ultrasonic Assisted machining (UAT) and hot machining operations. In the present study, Hot Ultrasonic Assisted Turning (HUAT) of Ti6Al4V alloy was studied numerically via DEFORM-2D software. Cutting speed, feed rate, vibrational parameters, and preheating temperatures were chosen as cutting parameters for the simulation study. Cutting forces, maximum effective stresses, and cutting temperatures were calculated with respect to these parameters. This process has also been investigated in terms of its effect on the environment and energy consumption. Cutting speed, feed rate and preheating temperatures affect machining characteristics while vibrational parameters do not affect significantly. Decrease in cutting speed and feed rate leads to lower power consumption. Also, power consumption changes with the increase in heating temperature and vibration frequency/amplitude.

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INTRODUCTION

Titanium alloys are chosen in aerospace, automotive, biomedical and petrochemical industries because of their mechanical properties. The materials have superior strength and remarkable corrosion resistance at high temperatures. In addition, the low density of titanium helps to reduce weights in mechanical structures [1]. However, machining of titanium is still difficult due to high hardness, deep chemical affinity and reduced thermal conductivity [2]. Recent investigations have been carried out by using several manufacturing techniques to improve machinability.

Ultrasonic Assisted Turning (UAT) is a periodic machining operation which uses external vibrations produced by an ultrasonic setup. Better surface finish, reduced cutting forces and residual stresses were obtained for workpieces [3–9]. UAT uses high frequency (15–25 kHz) and low amplitude (5–30 µm) vibration during machining [10–13]. In literature, different studies have been

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performed to observe the UAT method. Several studies suggested models for predicting workpiece surface roughness [14–17] and surface texture based on vibration characteristics [18–23]. Also, different analytical-numerical studies were carried out [24, 25]. In order to minimize cutting forces, an ultrasonic-based vibrational machining system was used [26]. It was obtained that vibrational cutting reduces the cutting forces in machining operations. Dynamic recrystallization grain size at the workpiece surface was studied for UAT operation [27]. According to some studies about HUAT, the method contributes a further decrease in cutting forces compared to UAT technique due to the thermal softening. Also, the smoother chip flow was observed on the cutting tool [13, 28–32].

A novel hybrid method, namely hot vibration-assisted machining, was emerged in recent investigations. This technique takes advantage of intermitted cutting through vibration assistance and thermal softening through heat assistance in material removal of aerospace alloys. The first investigations were carried out by a research team from Loughborough University in 2011 [33]. In hot vibration-assisted machining, material removal mechanism is relieved due to intermitted cutting motion in addition to reduced flow stresses by the effect of thermal softening. This leads to a prolonging tool life because harsh cutting conditions are suppressed in material removal. Moreover, a significant improvement is obtained in surface finish due to facilitated machining process. Muhammad et al. [34] designed a hot vibration assisted turning operation. In this work, an ingot of titanium alloy (Ti15V3Cr3Al3Sn) was heated to 300 °C by using a tunnel furnace and then ultrasonic based vibrational cutting was carried out for the workpiece. A cemented carbide cutting tool with a cutting speed of 10 m/min was used in the experiments. Based on the results, hot vibration assisted turning method provided the lowest cutting forces amongst the investigated operations Farahnakian et al. [13] investigated the same concept. However, they improved the heating process by using a plasma torch for a much controllable temperature distribution on workpiece. For this reason, heating could be accumulated on a local area prior to material removal. A 27 kHz frequency ultrasonic system was adapted to turning operation to produce vibrations having an amplitude of 10 µm on cutting tool. A CBN insert was used for the turning operation of AISI 4140 alloy with a hardness of 50 HRC. By enabling plasma heating, workpiece temperature increased to 330 °C. In hot vibration assisted turning, cutting forces were within a band of 60–90 N, whereas cutting forces were around 100 N in vibration-assisted turning. In conventional turning, cutting forces reached 120 N. This novel cutting technique was also applied to most common aerospace alloys, Ti-6Al-4V and Hastelloy-X [28–30].

In this study, HUAT method was numerically investigated to find out appropriate cutting parameters. Parametric research was carried out. Ti6Al4V was selected to machine. Cutting speed, feed rate, preheating temperatures, and vibrational parameters were used as cutting parameters in the simulations. An experimental research was conducted to validate the developed model. Cutting tool temperatures were used to compare the results. The research gives an in-depth understanding of HUAT, which can be an alternative for conventional machining. To the best of our knowledge, hot ultrasonic turning simulation of Ti6Al4V has not been performed with respect to different cutting parameters before. Also, this process has not been previously investigated in terms of its energy consumption and its effect on the environment. The aim of this paper is to investigate HUAT in terms of different cutting parameters and energy consumption using a simulation study. In the second part, the numerical details of the model were given. In the next section, numerical results were presented and discussed. Then, an experimental research was performed to validate the suggested model. In the last part, conclusions were given.

MATERIAL AND METHODS

2D FE model was created using DEFORM-2D program. Lagrange FE formulation was used. Dry machining condition was used. Ti6Al4V was used as the workpiece. A snapshot of the program is given in Figure 1. In the Figure, y shows feed direction and x shows cutting direction.

Johnson-Cook material model was used to model the workpiece. The equations of the model are shown below (Eqs. 1, 2). Table 1 presents the value of coefficients for this model. The parameters of the cutting tool are shown in Table 2.

$$\sigma = \left(A + B\varepsilon^n\right)\left(1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)\left(1 - T^*\right)^m \quad (1)$$

$$T^* = \frac{\left(T - T_{room}\right)}{\left(T_{melt} - T_{room}\right)} \quad (2)$$

$\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)$:Plastic strain rate/reference plastic strain rate (dimensionless strain rate).

n: Sensitivity of strain rate for the material.
T_{room}: Room temperature.
T_{melt}: Melting temperature of the material.
A,B,C,m: The constants of the material.

Friction models, friction zones, and coefficients were obtained using different trials and a literature study [35]. Hybrid friction model (shear and coulomb friction) was used and coefficients were taken 0.7 according to different trials. Also, material properties for Ti6Al4V have been de-

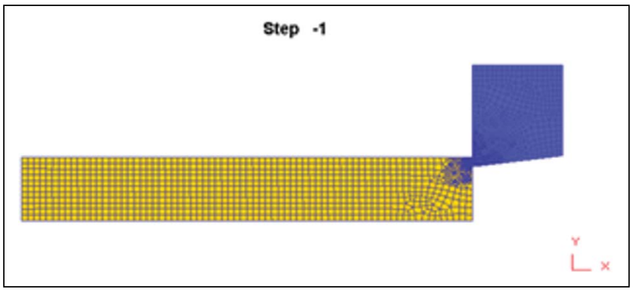

Figure 1. The snapshot of the DEFORM-2D program.

Table 1. The coefficients of the Johnson-Cook model [31]

Material	A(MPa)	B(MPa)	C	n	m	$\dot{\varepsilon}_0$
Ti6Al4V	724.7	683.1	0.035	0.47	1	2000

Table 2. The parameters of the cutting tool

The material of the cutting tool	WC + TiAlN
The rake angle	0°
The clearance angle	7°
Edge radius	0.02 mm

Table 3. Mechanical/thermal properties of Ti6Al4V

Mechanical/Thermal properties	Ti6Al4V
Elasticity module (MPa)	0.7412 T+113375
Thermal expansion (mm.mm^{-1} °C^{-1})	3×10^{-9}T $+7\times10^{-6}$
Thermal conductivity (watt. m^{-1} °C^{-1})	$7.039\times10^{0.0011T}$
Emissivity coefficient	0.7
Poisson ratio	0.31

Table 4. Parameter table

Parameters	Levels of parameters
Cutting speed (m/min.)	10, 20, 30, 40
Feed rate (mm/rev)	0.03, 0.1, 0.2
Preheating temperature of the workpiece (°C)	100, 200, 300, 500
Vibration frequency (Hz)	17,19,20,24
Vibration amplitude (micron)	2,8,10,15,20

termined using the literature [35] (Table 3). All input values (friction models, coefficients, material coefficient etc.) were determined according to experimental results which is given in in the experimental study title.

The parameter table is given in Table 4. The selection of the parameters and their levels has been benefited from literature studies [33–34, 36]. Preheating temperature is the initial temperature of the workpiece. It was set to different temperatures using workpiece settings. The ultrasonic vibration was given as a function and it was applied in the cutting direction. The cutting tool vibrates harmonically in the direction of cutting speed (Eqs. 3, 4).

Table 5. Mean cutting forces, max. effective stress and max. cutting temperatures at different

Cutting speed (m/min)	F_x (N)	F_y (N)	Max. effective stress (MPa)	Max. cutting temperature (°C)
10	103.5	36.4	1230	340
20	105.0	35.1	1562	445
30	120.7	44.4	1871	512
40	125.1	45.3	2150	617

Table 6. Mean cutting forces with respect to different feed rates

Feed rate (mm/rev)	F_x (N)	F_y (N)	Max. effective stress	Max. cutting temperature (°C)
0.20	193.5	66.2	2080	665
0.10	125.1	45.3	1782	512
0.03	102.2	37.2	1630	496

U_x= -acosωt (3)

U_y=0 (4)

where ω=2πf, f and a show frequency and amplitude of the vibration, respectively.

RESULTS AND DISCUSSION

The Results of the Simulation Study

Different trials were performed to find the optimum number of mesh. After the trials, in the simulations, 1062 elements were used for the cutting tool, and 5152 elements were determined for the workpiece. The results didn't change significantly when the elements were increased. The vibration was applied in the cutting direction. Table 5 gives the mean cutting forces with respect to various cutting speeds. The other parameters of the study were kept constant (Workpiece preheating temperature=100 °C, feed rate=0.1 mm/rev, vibration frequency/amplitude=20 kHz/20 microns).

When the cutting speed is increased from 10 m/min to 40 m/min, the mean cutting forces (F_x, F_y), max. effective stress and max. cutting temperatures are increased. The main reason of high cutting forces in UAT is that the tool separation in one complete cycle vanished at high cutting speed. Max. cutting temperature is nearly 617 °C at 40 m/min. An increase in temperature is obtained as cutting speed increases, as expected. The results of the study are consistent with the literature [36]. Figure 2 shows F_x cutting forces at 10 m/min cutting speed. Figure 3 gives F_y cutting forces in terms of time.

Table 6 displays the change of cutting forces at various feed rates. The other parameters of the work were kept

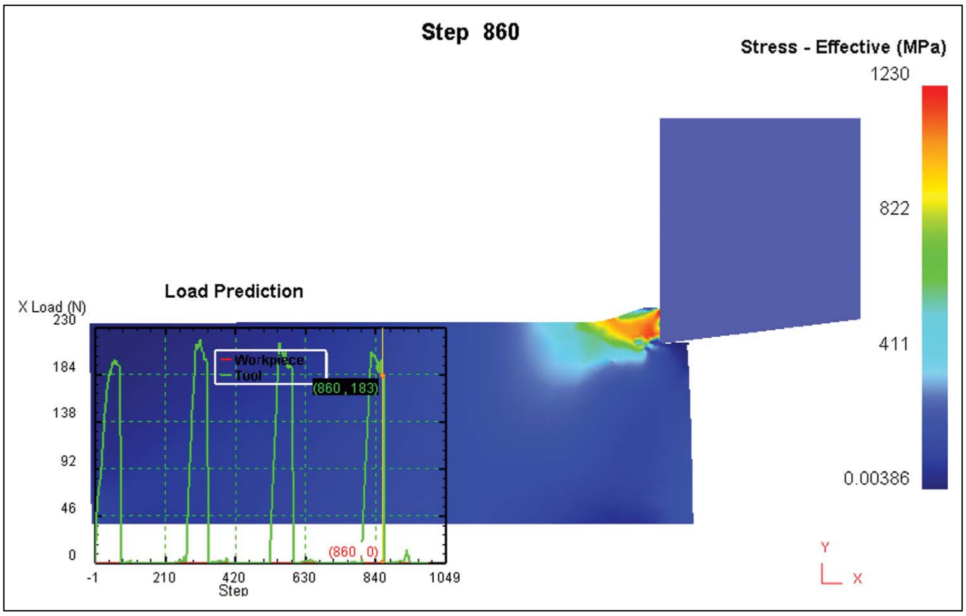

Figure 2. F_x forces at 10 m/min cutting speed.

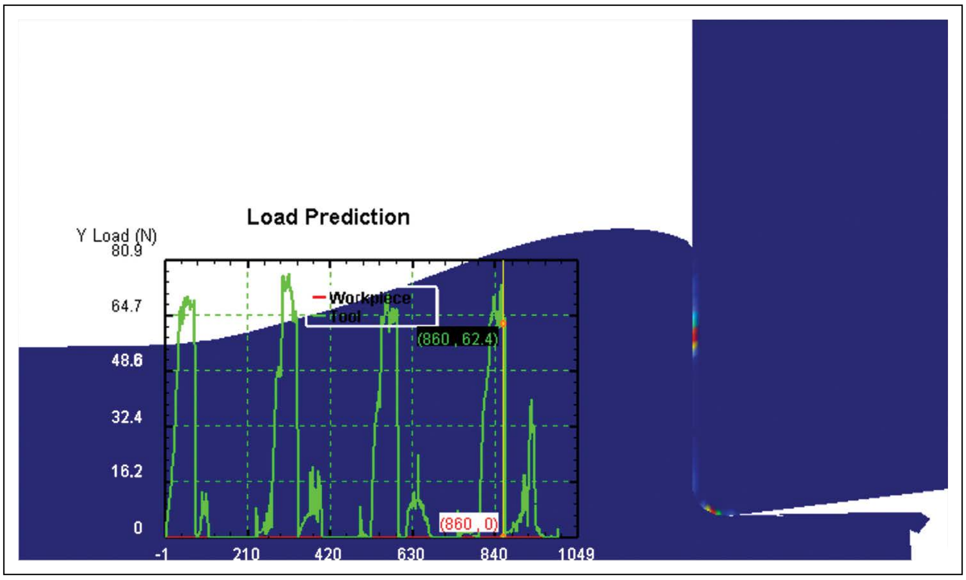

Figure 3. F_y forces at 10 m/min cutting speed.

constant (cutting speed=40 m/min, workpiece preheating temperature=100 °C, vibration frequency/amplitude=20 kHz/20 microns). As the feed rate decreases, the mean resultant cutting forces decrease. The cutting forces increase as the amount of the removed chips increases at high feed rates. The maximum effective stresses and max. cutting temperature varies between 1630–2080 MPa and 496–665 °C at feed rates of 0.03–0.2 mm/rev. An increase in the temperature of the cutting zone is seen when the feed rate increase.

Table 7 gives the mean cutting forces, maximum effective stresses and maximum cutting temperatures with respect to different preheating temperatures. The other pa-

Table 7. Mean cutting forces, maximum effective stresses and maximum cutting temperatures at different preheating temperatures

Preheating temperatures (°C)	F_x (N)	F_y (N)	Max. effective stress (MPa)	Max. cutting temperature (°C)
100	125.1	45.3	2030	617
200	99.5	34.7	1783	710
300	92.2	32.2	1567	752
500	87.0	28.3	1400	851

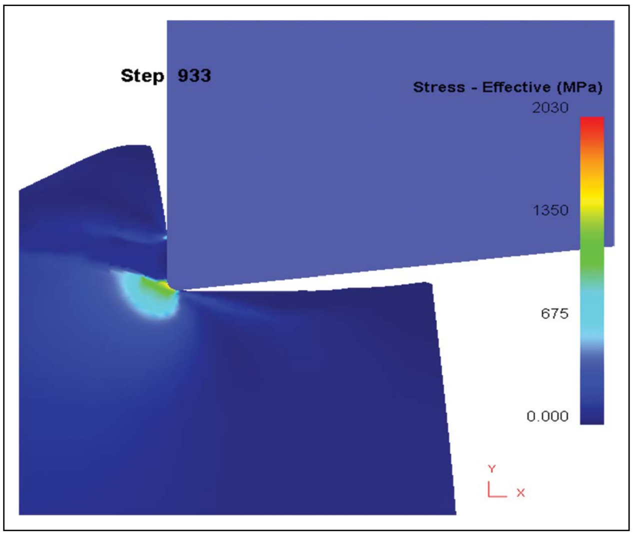

Figure 4. Distribution of effective stresses for the initial temperature of 100 °C.

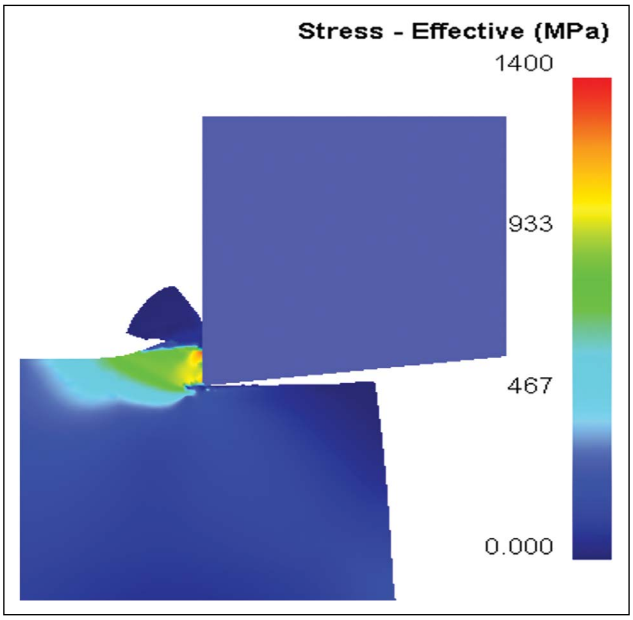

Figure 5. Distribution of effective stresses for the initial temperature of 500 °C.

rameters of the study were kept constant (cutting speed=40 m/min, feed rate=0.1 mm/rev, vibration frequency/amplitude=20 kHz/20 microns).

Preheating of workpiece reduces cutting forces and maximum effective stresses. When the heating temperature increases, the bond strength of the workpiece decreases and the internal stresses of the workpiece decreases accordingly. When the preheating temperature of the workpiece rises from 100 °C to 500 °C, the mean resultant cutting forces (F_x and F_y) are reduced by approximately 30% and 37%. While the workpiece temperature rises from 100 °C to 500 °C, the maximum effective stress drops. Considering the cost of high temperatures of titanium, it is advised that machining above 200 °C cannot provide significant benefits in terms of cutting forces because the forces cannot change significantly (nearly 20% between 100 °C and 200 °C whereas 13% between 200 °C and 500 °C). The reason for lower cutting forces and lower effective stresses is the thermal softening of the workpiece at high temperatures. Max. cutting temperature increases because of the increase in the preheating temperature of the workpiece. The results of the study seem to be compatible with the literature [36]. Figures 4, 5 show the distributions of effective stresses for 100 °C and 500 °C, respectively.

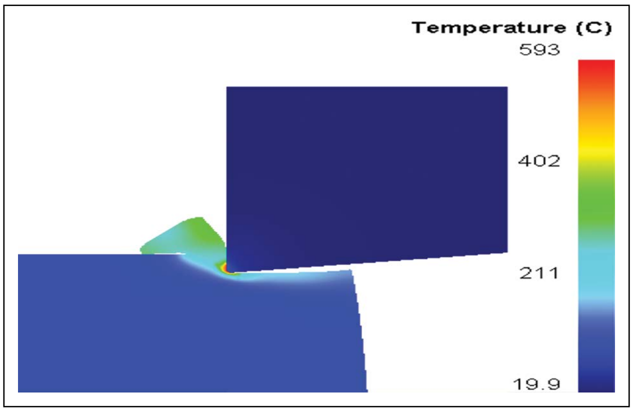

Figure 6. Cutting temperature distribution for 17 kHz vibration.

Table 8. Mean cutting forces, maximum effective stresses and maximum cutting temperatures with respect to the different vibration amplitudes

Amplitude (micron)	F_x (N)	F_y (N)	Max. effective stress (MPa)	Max. cutting temperature (°C)
15	97.5	33.0	1930	652
10	101.0	34.5	1902	649
8	102.0	36.8	1881	601
2	107.5	40.3	1830	580

Table 9. Mean cutting forces, maximum effective stresses and maximum cutting temperatures with respect to the different vibration frequency

Frequency (kHz)	Fx (N)	Fy (N)	Max. effective stress (MPa)	Max. cutting temperature (°C)
24	104.7	38.3	1930	730
19	107.5	39.5	1783	631
17	111.2	46.8	1630	593

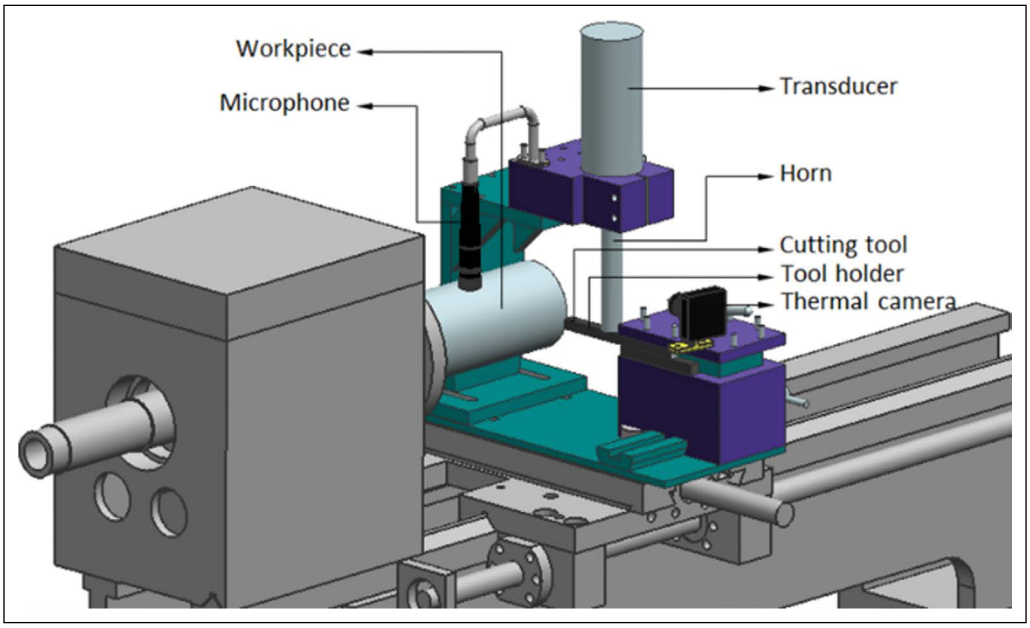

Figure 7. Ultrasonic assisted turning setup (schematic).

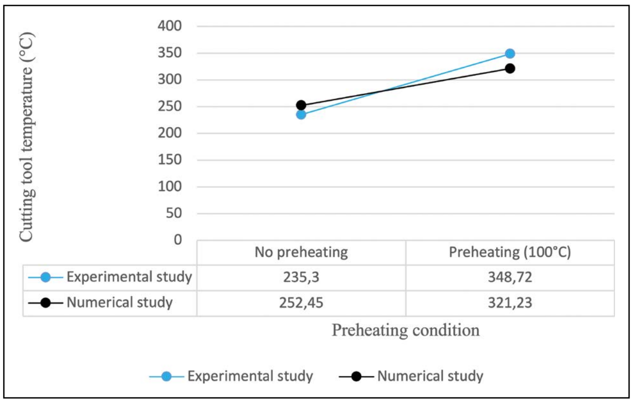

Figure 8. Comparison of experimental and simulation studies.

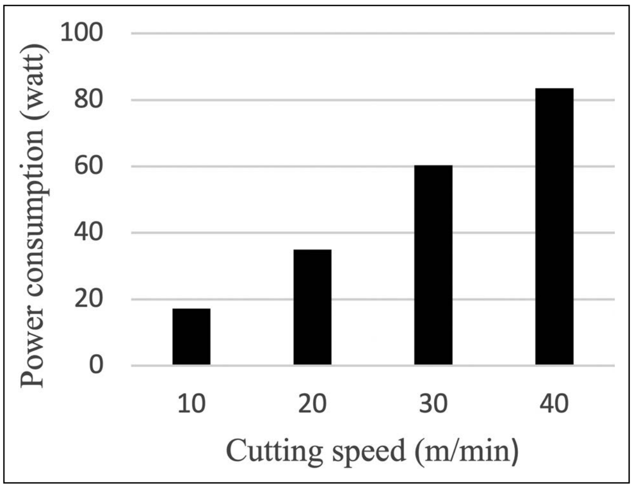

Figure 9. Power consumption in terms of cutting speed.

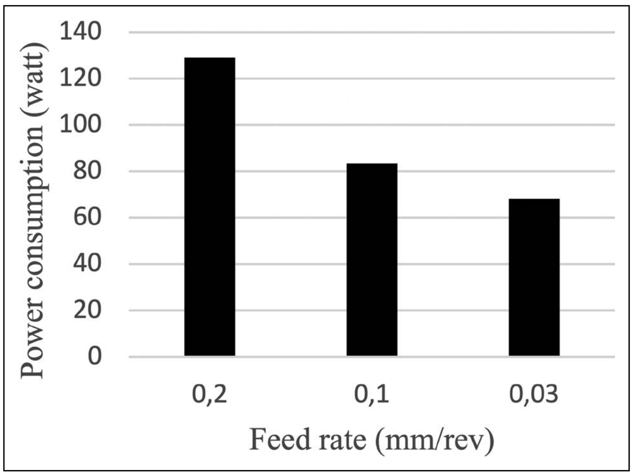

Figure 10. Power consumption in terms of feed rate.

Tables 8, 9 give the mean cutting forces and maximum effective stresses for different vibration amplitudes and vibration frequency. The other parameters were kept constant (preheating temperature 100 °C, Cutting speed=40 m/min, Feed rate=0.1 mm/rev). Figure 6 shows the cutting temperature distribution for 17 kHz vibration.

Cutting forces, max. effective stresses and max. cutting temperature do not change significantly when the vibrational amplitude or frequency changes. When the vibration amplitude increases, the extent of separation between cutting tool/workpiece in one cycle increases, which causes a higher force decrease in HUAT. It was obtained that the higher vibration amplitude causes an increases the force reduction. At lower frequency, the cutting tool separation is slow in HUAT. Increasing vibration frequency and amplitude causes higher cutting temperatures.

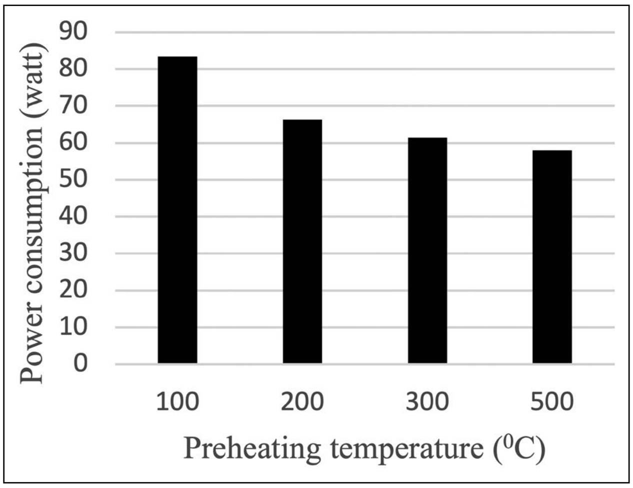

Figure 11. Power consumption in terms of preheating temperature.

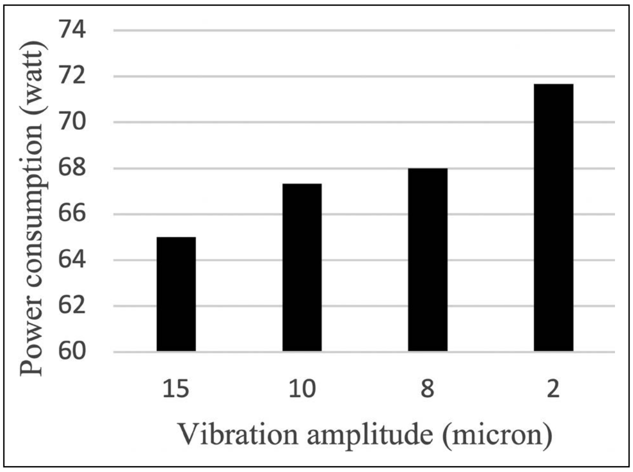

Figure 12. Power consumption in terms of vibration amplitude.

Experimental Study

In the experimental research, a universal lathe was used and an ultrasonic system (SONIKEL) was adapted. It is shown in Figure 7. The frequency of the ultrasonic system was 20 kHz, and the amplitude was measured as 20 µm using a dial indicator. The vibration was applied in the cutting direction. A thermal camera (OPTRIS PI 400) was used to measure the temperatures. Ultrasonic horn is a metal bar that augments the displacement amplitude provided by an ultrasonic transducer. Devices that generate or sense ultrasound energy are known as ultrasonic transducers.

The validation experiments were performed at 20 °C and 100 °C for UAT. A tunnel furnace was used to heat the workpiece before machining. The cutting speed was 40 m/min and the feed rate was 0.1 mm/rev. The turning operation was performed using orthogonal cutting conditions. The same cutting tool was used in the experiments. Experimental and simulation studies were compared in terms of cutting tool temperatures. Figure 8 displays the results. It

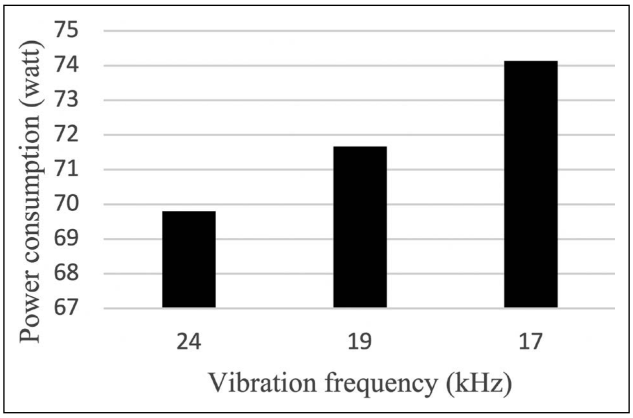

Figure 13. Power consumption in terms of vibration frequency.

was obtained that the experimental results are consistent with the simulation studies.

Power Consumption and Environmental Effect of the Process

The power consumption value is calculated by multiplying the cutting force by the cutting speed. Figures 9–13 show power consumption values with respect to different cutting parameters. When cutting speed and feed rate decrease, cutting forces decrease and this causes lower power consumption. In addition, power consumption decreases as the heating temperature and vibration frequency/amplitude increase. The power of ultrasonic equipment is 2000 watt, and the power of the preheating furnace is 1500 watt. These values should be taken into consideration with a constant power of turning lathe. Ultrasonic machining technology is an environmentally-friendly technology and does not harm the environment. In addition, no cooling-lubrication is required. Considering that the low preheating temperatures for the workpiece have a positive effect on the cutting forces, it is predicted that the energy consumption can be controlled at the appropriate values.

CONCLUSION

HUAT is a novel machining technique that combines UAT and hot turning operations. The method helps to machine difficult to machine materials and improve surface machining characteristics (low cutting force, stress level, etc.). In this research, a simulation study was performed for this method (Hot ultrasonic assisted turning). Ti6Al4V alloy was used as workpiece material. Cutting speed, feed rate, preheating temperature and vibration frequency/amplitude were used as inputs. Cutting speed, feed rate and preheating temperatures affect machining characteristics, whereas vibrational parameters do not affect significantly. Decrease in cutting speed and feed rate leads to lower power consumption. In addition, power consumption changes with the increase in heating temperature and vibration frequency/amplitude. Hot ultrasonic-assisted machining is a method that does not harm the environment. The proposed study is useful to understand the effects of HUAT. In future studies, different cutting parameters (tool geometry, etc.) might be investigated. Also, various materials can be studied in the simulation studies.

Data Availability Statement

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

Author's Contributions

M. Alper Sofuoğlu: Carrying out experiments and simulations.

Melih Cemal Kuşhan: Performing simulations, Analyzing results.

Sezan Orak: Performing simulations, Analyzing results.

Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics

There are no ethical issues with the publication of this manuscript.

Financial Disclosure

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REFERENCES

[1] Niknam, S. A., Khettabi, R., & Songmene, V. (2014). Machinability and Machining of Titanium Alloys: A Review, in Machining of Titanium Alloys. In J. P. Davim (Ed.), Materials Forming, Machining and Tribology (pp. 1–30). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-43902-9_1 [CrossRef]

[2] Singh, P., Pungotra, H., & Kalsi, N.S. (2016). On the Complexities in Machining Titanium Alloys, in D. K. Mandal and C. S. Syan, (Eds.), CAD/CAM, Robotics and Factories of the Future (pp. 499–507) Springer India. https://doi.org/10.1007/978-81-322-2740-3_49 [CrossRef]

[3] Amini, S., & Teimouri, R. (2016). Parametric study and multicharacteristic optimization of rotary turning process assisted by longitudinal ultrasonic vibration, *Proceedings of the Institution of Mechanical Engineers, Part E*, 231(5), 978-991. https://doi.org/10.1177/0954408916651894 [CrossRef]

[4] Babitsky, V., Kalashnikov, A., Meadows, A., & Wijesundara, A.A.H. (2003). Ultrasonically assisted turning of aviation materials. *Journal of Materials Processing Technology*, 132(1–3), 157–167. https://doi.org/10.1016/S0924-0136(02)00844-0 [CrossRef]

[5] Babitsky, V., Mitrofanov, A., & Silberschmidt, V.V. (2004). Ultrasonically assisted turning of aviation materials: simulations and experimental study. *Ultrasonics*, 42(1–9), 81–86. https://doi.org/10.1016/j.ultras.2004.02.001 [CrossRef]

[6] Jiao, F., Niu, Y., & Liu, X. (2015). Effect of ultrasonic vibration on surface white layer in ultrasonic aided turning of hardened GCr15 bearing steel. *Materials Research Innovations*, 19(8), S8–938–S8–942. https://doi.org/10.1179/1432891715Z.0000000001844 [CrossRef]

[7] Mitrofanov, A.V., Babitsky, V.I., & Silberschmidt, V.V. (2003). Finite element simulations of ultrasonically assisted turning. *Computational Materials Science*, 28(3–4), 645–653. https://doi.org/10.1016/j.commatsci.2003.08.020 [CrossRef]

[8] Nath, C., & Rahman, M. (2008). Effect of machining parameters in ultrasonic vibration cutting, *International Journal of Machine Tools and Manufacture*, 48(9), 965–974. https://doi.org/10.1016/j.ijmachtools.2008.01.013 [CrossRef]

[9] Zou, P., Xu, Y., He, Y., Chen, M., & Wu, H. (2015). Experimental investigation of ultrasonic vibration assisted turning of 304 austenitic stainless steel. *Shock Vibration*, 2015, Article 817598. https://doi.org/10.1155/2015/817598 [CrossRef]

[10] Patil, S., Joshi, S., Tewari, A., & Joshi, S.S. (2014). Modelling and simulation of effect of ultrasonic vibrations on machining of Ti6Al4V. *Ultrasonics*, 54 (2), 694–705. https://doi.org/10.1016/j.ultras.2013.09.010 [CrossRef]

[11] Sharma, V.S., Dogra, M., & Suri, N.M. (2008). Advances in the turning process for productivity improvement – a review. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 222(11), 1417–1442. https://doi.org/10.1243/09544054JEM1199 [CrossRef]

[12] Brehl, D.E., & Dow, T.A. (2008). Review of vibration-assisted machining. *Precision Engineering*, 32(3), 153–172. https://doi.org/10.1016/j.precisioneng.2007.08.003 [CrossRef]

[13] Farahnakian, M., & Razfar, M.R. (2014). Experimental study on hybrid ultrasonic and plasma aided turning of hardened steel AISI 4140. *Materials and Manufacturing Processes*, 29(5), 550–556. https://doi.org/10.1080/10426914.2014.892612 [CrossRef]

[14] Shamoto, E., Suzuki, N., & Hino, R. (2008). Analysis of 3D elliptical vibration cutting with thin shear plane model. *CIRP Annals Manufacturing Technology*, 57(1), 57–60. https://doi.org/10.1016/j.cirp.2008.03.073 [CrossRef]

[15] Shamoto, E., & Moriwaki, T. (1994). Study on elliptical vibration cutting. *CIRP Annals Manufacturing Technology*, 43(1), 35–38. https://doi.org/10.1016/S0007-8506(07)62158-1 [CrossRef]

[16] Cheung, C.F., & Lee, W.B. (2000). Modelling and simulation of surface topography in ultra-precision diamond turning. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 214(6), 463–480. https://doi.org/10.1243/0954405001517775 [CrossRef]

[17] Kim, D.S., Chang, I.C., & Kim, S.W. (2002). Microscopic topographical analysis of tool vibration effects on diamond turned optical surfaces. *Precision Engineering*, 26(2), 168–174. https://doi.org/10.1016/S0141-6359(01)00115-5 [CrossRef]

[18] Sajjady, S.A., Nouri Hossein Abadi, H., Amini, S., & Nosouhi, R. (2016). Analytical and experimental study of topography of surface texture in ultrasonic vibration assisted turning. *Materials & Design*, 93, 311–323. https://doi.org/10.1016/j.matdes.2015.12.119 [CrossRef]

[19] Zhang, C., Ehmann, K., & Li, Y. (2015). Analysis of cutting forces in the ultrasonic elliptical vibration-assisted micro-groove turning process. The International Journal of *Advanced Manufacturing Technology*, 78(1–4), 139–152. https://doi.org/10.1007/s00170-014-6628-3 [CrossRef]

[20] Guo, P., & Ehmann, K.F. (2013). Development of a tertiary motion generator for elliptical vibration texturing. *Precision Engineering*, 37(2), 364–371. https://doi.org/10.1016/j.precisioneng.2012.10.005 [CrossRef]

[21] Zhang, C., Guo, P., Ehmann, K.F., & Li, Y. (2016). Effects of ultrasonic vibrations in micro-groove turning. *Ultrasonics*, 67, 30–40. https://doi.org/10.1016/j.ultras.2015.12.016 [CrossRef]

[22] Amini, S., Hosseinabadi, H.N., & Sajjady, S.A. (2016). Experimental study on effect of micro textured surfaces generated by ultrasonic vibration assisted face turning on friction and wear performance. *Applied Surface Science*, 390, 633–648. https://doi.org/10.1016/j.apsusc.2016.07.064 [CrossRef]

[23] Silberschmidt, V.V., Mahdy, S.M.A., Gouda, M.A., Naseer, A., Maurotto, A., & Roy, A. (2014). Surface-roughness improvement in ultrasonically assisted turning. *Procedia CIRP*, 13, 49–54. https://doi.org/10.1016/j.procir.2014.04.009 [CrossRef]

[24] Zhang, X., Senthil Kumar, A., Rahman, M., Nath, C., & Liu, K. (2012). An analytical force model for orthogonal elliptical vibration cutting technique. *Journal of Manufacturing Processes*, 14(3), 378–387. https://doi.org/10.1016/j.jmapro.2012.05.006 [CrossRef]

[25] Zhang, X., Kumar, A.S., Rahman, M., & Liu, K. (2013) Modeling of the effect of tool edge radius on surface generation in elliptical vibration cutting. *The International Journal of Advanced Manufacturing Technology*, 65(1–4), 35–42. https://doi.org/10.1007/s00170-012-4146-8 [CrossRef]

[26] Razavi, H., & Mirbagheri, M. (2016). Design and fabrication of a novel vibrational system for ultrasonic assisted oblique turning process. *Journal of Mechanical Science and Technology*, 30(2), 827–835. https://doi.org/10.1007/s12206-016-0137-2 [CrossRef]

[27] Bai, W., Sun, R., & Leopold, J. (2016). Numerical modelling of microstructure evolution in ti6al4v alloy by ultrasonic assisted cutting. *Procedia CIRP*, 46, 428–431. https://doi.org/10.1016/j.procir.2016.03.122 [CrossRef]

[28] Gürgen, S., Çakır, F.H., Sofuoğlu, M.A., Orak, S., Kuşhan, M.C., & Li, H. (2019). Multi-criteria decision-making analysis of different non-traditional machining operations of Ti6Al4V. *Soft Computing*, 23(13), 5259–5272. https://doi.org/10.1007/s00500-019-03959-8 [CrossRef]

[29] Sofuoğlu, M.A., Çakır, F.H., Gürgen, S., Orak, S., & Kuşhan, M.C. (2018). Experimental investigation of machining characteristics and chatter stability for Hastelloy-X with ultrasonic and hot turning. *The International Journal of Advanced Manufacturing Technology*, 95(1–4),83–97. https://doi.org/10.1007/s00170-017-1153-9 [CrossRef]

[30] Sofuoğlu, M.A., Çakır, F.H., Gürgen, S., Orak, S., & Kuşhan, M.C. (2018). Numerical investigation of hot ultrasonic assisted turning of aviation alloys. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 40(3), 112. https://doi.org/10.1007/s40430-018-1037-4 [CrossRef]

[31] Lee, W.S., & Lin, C.F. (1998). Plastic deformation and fracture behaviour of Ti–6Al–4V alloy loaded with high strain rate under various temperatures. *Materials Science and Engineering*: A, 241(1–2):48–59. https://doi.org/10.1016/S0921-5093(97)00471-1 [CrossRef]

[32] Çakır, F.H., Gürgen, S., Sofuoğlu, M.A., Çelik, O.N., & Kuşhan, M.C. (2015). Finite element modeling of ultrasonic assisted turning of Ti6Al4V alloy. *Procedia Social and Behavioral Sciences*, 195, 2839–2848. https://doi.org/10.1016/j.sbspro.2015.06.404 [CrossRef]

[33] Muhammad, R., Maurotto, A., Roy, A., & Silberschmidt, V.V. (2011). Analysis of forces in vibro-impact and hot vibro-impact turning of advanced alloys, *Applied Mechanics and Materials*, 70, 315–320. https://doi.org/10.4028/www.scientific.net/AMM.70.315 [CrossRef]

[34] Muhammad, R., Maurotto, A., Roy, A., & Silberschmidt, V.V. (2012). Hot ultrasonically assisted turning of β-ti alloy. *Procedia CIRP*, 1, 336–341. https://doi.org/10.1016/j.procir.2012.04.060 [CrossRef]

[35] Özel, T., Sima, M., & Srivastava, A.K. (2010). Finite element simulation of high speed machining Ti-6Al-4V alloy using modified material models. *Trans NAMRI/SME* 38, 49–56.

[36] Muhammad, R. (2013) *Hot ultrasonically assisted turning of Ti15V3Al3Cr3Sn: experimental and numerical analysis* (Doctoral dissertation). Loughborough University, UK.