On the mechanics of chip formation in Ti–6Al–4V turning with spindle speed variation

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International Journal of Machine Tools and Manufacture, Volume 77, February 2014, Pages 16–26

Abstract

Titanium alloys are hard-to-cut materials and need to be machined at relatively low cutting speeds with obvious negative consequences on the profitability of machining.
In order to enhance material removal rate (MRR), a strategy that relies on higher depths of cut could be chosen if vibrational issues due to regenerative chatter did not occur.
A lot of research was done to suppress regenerative chatter without detrimental effects on productivity. One of the most interesting chatter suppression methods, mainly due to its flexibility and relative ease of implementation, is spindle speed variation (SSV), which consists in a continuous modulation of the nominal cutting speed. Sinusoidal spindle speed variation (SSSV) is a specific technique that exploits a sinusoidal law to modulate the cutting speed.
The vast scientific literature on SSV was mainly focused on cutting process stability issues fully neglecting the study of the mechanics of chip formation in SSV machining. The aim of this work is to fill this gap: thus, finite element method (FEM) models of Ti–6Al–4V turning were setup to simulate both SSSV and constant speed machining (CSM). The models consider both the micro-geometry of the insert and the coating. Numerical results were experimentally validated on dry turning tests of titanium tubes exploiting the experimental assessment of cutting forces, cutting temperatures and chip morphology. Tool–chip contact pressure, tool engagement mechanism and the thermal distribution in the insert are some of the analysed numerical outputs because they cannot be easily assessed by experimental procedures. These quantities were useful to compare thermo-mechanical loads of the insert both in CSM and SSSV machining: it was observed that the loads significantly differ. Compared to CSM, the modulation of the cutting speed involves a higher tool–chip contact pressure peak, a higher maximum temperature and higher temperature gradients that could foster the main tool wear mechanisms.

Riferimenti bibliografici

[1] M. Kayhan, E. Budak, An experimental investigation of chatter effects on tool life, Proc. Inst. Mech. Eng., Part B: J. Eng. Manuf., 223 (2009) 1455-1463.
[2] J. Tlusty, M. Polacek, The stability of machine tools against self excited vibrations in machining, Proc. Int. Res. Prod. Eng. Conf., (1963) 465-474.
[3] S.A. Tobias, W. Fishwick, The chatter of lathe tools under orthogonal cutting conditions, Trans. ASME, 80 (1958) 1079-1088.
[4] M. Weck, E. Verhaag, M. Gather, Adaptive control for face-milling operations with strategies for avoiding chatter vibrations and for automatic cut distribution, Ann. CIRP, 24 (1975) 405-409.
[5] G. Quintana, J. Ciurana, Chatter in machining processes: A review, Int. J. Mach. Tools Manuf, 51 (2011) 363-376.
[6] P. Albertelli, S. Musletti, M. Leonesio, G. Bianchi, M. Monno, Spindle speed variation in turning: technological effectiveness and applicability to real industrial cases, Int. J. Adv. Manuf. Technol., 62 (2012) 59-67.
[7] M. Siddhpura, R. Paurobally, A review of chatter vibration research in turning, Int. J. Mach. Tools Manuf, 61 (2012) 27-47.
[8] G.M. Pittalà, M. Monno, Flow stress determination in orthogonal cutting process combining the primary and the secondary shear zones, Int. J. Mater. Form., 3 (2010) 483-486.
[9] G.M. Pittalà, M. Monno, 3D finite element modeling of face milling of continuous chip material, Int. J. Adv. Manuf. Technol., 47 (2010) 543-555.
[10] L. Filice, F. Micari, S. Rizzuti, D. Umbrello, A critical analysis on the friction modelling in orthogonal machining, Int. J. Mach. Tools Manuf, 47 (2007) 709-714.

[11] G.R. Johnson, W.H. Cook, A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures, Proc. 7th Int. Symp. Ballist., (1983) 541-547.
[12] D. Umbrello, Finite element simulation of conventional and high speed machining of Ti6Al4V alloy, J. Mater. Process. Technol., 196 (2008) 79-87.
[13] M. Calamaz, D. Coupard, F. Girot, A new material model for 2D numerical simulation of serrated chip formation when machining titanium alloy Ti–6Al–4V, Int. J. Mach. Tools Manuf, 48 (2008) 275-288.
[14] Y. Karpat, Temperature dependent flow softening of titanium alloy Ti6Al4V: An investigation using finite element simulation of machining, J. Mater. Process. Technol., 211 (2011) 737-749.
[15] M.G. Cockroft, D.J. Latham, Ductility and workability of metals, J. Inst. Met., 96 (1968).
[16] T. Özel, The influence of friction models on finite element simulations of machining, Int. J. Mach. Tools Manuf, 46 (2006) 518-530.
[17] R. Alvarez, R. Domingo, M.A. Sebastián, Comparison of predicted forces in 2D and 3D FEM orthogonal cutting simulations of UNS A92024 and Ti6Al4V alloys, 12th CIRP Conf. Model. Mach. Oper., 1 (2009) 83-90.
[18] Y. Karpat, Finite element modeling of machining titanium alloy Ti-6Al-4V using a modified material model, 12th CIRP Conf. Model. Mach. Oper., 1 (2009) 107-114.
[19] Y. Burhanuddin, C.H.C. Haron, J.A. Ghani, Effects of edge geometry on the performance of CBN tools when cutting titanium 6Al-4V : experimental and simulation, 12th CIRP Conf. Model. Mach. Oper., 1 (2009) 211-217.
[20] D. Umbrello, L. Filice, S. Rizzuti, F. Micari, L. Settineri, On the effectiveness of Finite Element simulation of orthogonal cutting with particular reference to temperature prediction, J. Mater. Process. Technol., 189 (2007) 284-291.
[21] M. Cotterell, G. Byrne, Characterisation of chip formation during orthogonal cutting of titanium alloy Ti–6Al–4V, CIRP J. Manuf. Sci. Technol., 1 (2008) 81-85.
[22] L. Xinhua, B. Balachandran, Stability of Up-milling and Down-milling Operations with Variable Spindle Speed, J. Vib. Control, 16 (2010) 1151-1168.
[23] E. Chiappini, S. Tirelli, P. Albertelli, M. Strano, M. Monno, FEM simulation of Ti6Al4V turning with SSSV, AITeM Conf. Proc., S. Benedetto del Tronto (Italy), (2013).
[24] L. Filice, D. Umbrello, S. Beccari, F. Micari, On the FE codes capability for tool temperature calculation in machining processes, J. Mater. Process. Technol., 174 (2006) 286-292.