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Mechanical behavior of materials in metal cutting operations, a review

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Abstract

Material properties of the machined parts are changed in metal cutting operations due to generated heat and friction in chip formation process. Temperature distributions in cutting zone can be analyzed to prevent the cutting tool failure in machining operations. Stress and strain rate in metal cutting condition, residual stress in the machined parts can be predicted and analyzed in virtual environments in order to increase performances of produced parts in actual working conditions. Material removal rate can be increased due to Simulation and analysis of the friction, flow stress and chip formation process in metal cutting operations. To prevent the workpiece deformation as well as tool deflection error in machining operation, cutting forces can be predicted and analyzed. To increase accuracy in process of part production using machining operation, deformation of workpiece due to applied forces can be analyzed and decreased. Machining operations of hard to cut materials is investigated in order to increase surface roughness of produced parts and cutting tool life in machining operations. In this paper, a review in mechanical behavior of materials during machining operations is presented and future research works are also suggested. It has been observed that the research filed can be moved forward by reviewing and analyzing recent achievements in the published papers.

Keywords: Workpiece Materials; Machining Operations

1. Introduction

In the metal cutting operation, material properties of machined parts are changed due to generated forces and heat in the cutting zone. The process of chip formation in the machining operations is under the coupled effect of strain, strain rate and temperature on the flow stress of the material. The study and analysis of the chip formation, generated heat, temperature distributions in cutting zone, friction in the cutting zone, and residual stresses in metal cutting operation is important in modification of the machining operations. As a result, advanced models of cutting tools can be designed and produced in order to decrease time and cost of accurate production using machining operations. Heat generation and temperature prediction in metal cutting is reviewed by Abukhshim et al. [1] to present the main requirements for the modelling of high speed metal machining processes. A review on the type of material models used in the modeling of metal forming and machining is presented by Dixit et al. [2] to analyze the used method of martial modeling and suggest the directions for further research in this area. Interaction of the cutting tools and the ceramic-reinforced metal matrix composites during micro-machining is reviewed by Liu et al. [3] to simulate and analyze the chip formation mechanism considering different dominant effects, such as materials strengthening mechanisms, micro-structural effect, size effect and minimum chip thickness effect. To provide a broad and in-depth vision of the methods suitable for tissue and bone cutting simulations, a review of cutting mechanics and modeling techniques for biological materials is presented by Takabi and Tai [4]. Prediction and measurement methods of cutting temperature is reviewed by Silva and Wallbank [5] to show the effects of cutting parameters, such as cutting speed and feed rate. Application of sustainable techniques in metal cutting for enhanced machinability is reviewed by Ghosh Rao [6] to enhanced cutting tool life with minimum cutting temperatures and cutting forces.

In this paper, a review in mechanical behavior of materials during machining operations is presented categorized to provide a useful study for the researchers in the interesting field. As a result, new ideas in mechanical behavior analysis of materials and gaps in the existing literature are obtained and future research works are also suggested in order to push forward this interesting research field.

Simulation of chip formation process, simulation of temperature distributions in cutting zone, simulation of flow stress in metal cutting process, simulation of friction in the cutting zone, prediction of the residual stresses, prediction of stress and strain rate in metal cutting condition, prediction of cutting forces in metal cutting operations, prediction of cutting tool wear and surface roughness in machining operations, viscoplastic analysis of metal cutting operations, deformation analysis of workpiece in machining operations and machining operations of hard to cut materials are categorized as different issues of research works in mechanical behavior of materials during machining operations.

Section 2 presents a review from research works in mechanical behavior of materials during machining operations. In the section 3, research works are classified according to the different topics in issue and future research works in mechanical behavior of materials during machining operations systems are suggested.

2. Review of research works in mechanical behavior of materials during machining operations

The research works in mechanical behavior of materials during machining operations is recently developed in different topics of mechanical properties of produced parts to increase quality as well as efficiency in the part production using machining operations. The different topics of research works are classified in this section in order to review their achievements in the research field.

2.1. Simulation of chip formation process

The process of chip formation in the machining operations is with heat generation in order to create plastic deformation in the cutting zone of machined parts. The chip formation process can be analyzed and investigated in order to increase machining abilities in part manufacturing process using machine tools.

The influence of thermo-mechanical behavior in chip formation during hard turning of 100Cr6 bearing steel is simulated by Poulachon et al. [7]. Flow stress, work hardening, thermal softening, and strain-rate sensitivity in machining of 100Cr6 (AISI 52100) bearing steel are analyzed in the study to predict the thermo-mechanical behavior in chip formation processes. FEM simulation of orthogonal metal cutting process is presented by Gang and Pan [8] to obtain the chip formation, temperature distribution, cutting force variable and residual stress in cutting operations. Modified material constitutive models for serrated chip formation simulations and experimental validation in machining of titanium alloy Ti–6Al–4V is presented by Sima and Özel [9] to calculate temperature-dependent flow softening parameters in chip formation process. The influence of cutting edge geometry and cutting speed on the chip removal process is studied by Movahhedy et al. [10] to predict the chip formation process in machining operations.

Simulation of mechanical cutting using a physical based material model is studied by Kalhori et al. [11] to predict orthogonal cutting of stainless steel Sanmac 316L. The chip morphology and the cutting forces are predicted in the study to obtain the material behaviour such as strain hardening and shear localization at the process zone. Finite element analysis of adiabatic shear band formation during orthogonal metal cutting is investigated by Rhim et al. [12] to predict the serrated chip formation in the cutting process. To predict chip formation and temperature distribution in high speed dry machining of biomedical magnesium–calcium alloy, simulation of cutting mechanics using internal state variable plasticity model is developed by Salahshoor and Guo [13].

The effect of cutting speed on chip formation under orthogonal machining is investigated by Lee [14] to examine the chip formation process in machining operations of 6061-T6 aluminum, 4340 steel, and Ti-6A1-4V titanium. To investigate the shear angle evolution during the chip formation process in cutting of AISI-1045 steel, a coupled magnetic–mechanical approach is developed by Mkaddem et al. [15]. So, the plastic shear, resulting in modification of the chip formation mechanisms can be simulated and analyzed to enhance the material flow along the secondary shear zone. To predict the mechanism of chip formation in cutting processes of AISI 1045 steel, 2D-FEM simulation of the orthogonal high speed cutting process is developed by Klocke et al. [16]. Finite element simulation of chip formation is presented by Mamalis et al. [17] to predict the cutting forces in orthogonal metal cutting operations. Simulation of chip formation during high-speed cutting is presented by Hortig and Svendsen [18] to analyze the cutting forces in the machining operations. Finite element simulation of chip flow in metal machining is developed by Dirikolu et al. [19] to predict and analyze the chip formation in turning operations.

2.2. Simulation of temperature distributions in cutting zone

The generated heat in the cutting zone of machined parts can be analyzed in order to be decreased. As a result, the amount of coolant in the machining operations can be decreased to decrease cost of machining operations. Also, cutting tool life can be increased due to analyzing and decreasing the generated heat in the cutting process.

The plasticity models of Johnson–Cook is used by Guo [20] to characterize material behavior of titanium Ti-6Al-4V, AISI 52100 steel (62 HRc), and aluminum 6061-T6 such as different temperatures, strains, and strain rate in machining operations. Mechanical characterization and modelling of Inconel 718 material behavior for machining process assessment is presented by Iturbe et al. [21] to describe the particular behavior of nickel based alloys at elevated temperatures and high strain rates. To predict the elevated-temperature deformation behavior in high strength aluminum alloy AA7075-T6, constitutive flow stress formulation, model validation and FE cutting simulation is investigated by Paturi et al. [22]. The modified-Johnson Cook (m-JC) and modified-Zerilli–Armstrong (m-ZA) models are applied to predict the combined effects of strain, strain rate and temperature on flow stress in machining operations.

To predict chip geometry, chip compression ratio, forces, plastic deformation and temperature distributions in Ti-6Al-4 V orthogonal cutting operations, numerical models using the Johnson-cook Constitutive model is investigated by Zhang et al. [23]. Metal cutting simulation of 4340 steel using an accurate mechanical description of material strength and fracture is presented by Maudlin and Stout [24] to obtain the temperature distribution, heat conduction and friction at the toolwork-piece interface. Effect of cutting conditions on temperature generated in drilling process using the FEA simulation is developed by Muhammad et al. [25] to simulated and analyze the cutting process. Measurements and simulations of temperature and deformation fields in transient metal cutting is presented by Potdar and Zehnder [26] to predict and analyze the temperature distributions in the cutting zone. Finite element simulation of machining operation is investigated by Karpat [27] to predict the temperature distribution in the machining operations. Effects of friction modeling at the tool–chip–workpiece interfaces on chip formation process is investigated by Arrazola and Özel [28] in order to predict forces, temperatures and other field variables such as normal stress and shear stress on the tool by using advanced finite element (FE) simulation techniques. Simulated temperature fields by using the FE model with Lagrangian boundaries is shown on the figure 1 [28].

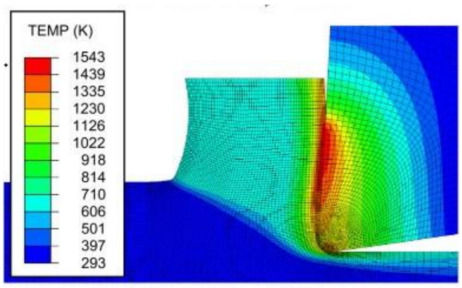

Figure 1. Simulated temperature fields by using the FE model with Lagrangian boundaries [28].

2.3. Simulation of flow stress in metal cutting process

To analyze the material removal rate in machining operation, flow stress in metal cutting process can be analyzed. As a result, efficiency in part production process using machining operation can be increased. Flow stress in the primary shear zone is studied by Jaspers and Dautzenberg [29] to predict and analyze the material behavior in metal cutting operations. Material flow stress and failure in multiscale machining titanium alloy Ti-6Al-4V is investigated by Sun and Guo [30] to predict the flow stress characteristics of strain hardening and thermal softening using the Johnson–Cook model coupled with the adiabatic condition. The determination of ploughing force and its influence on material properties in metal cutting is investigated by Guo and Chou [31] to predict the material flow stress in metal cutting operations. To approximate flow stress in machining analysis and simulations, dynamic material behaviour modelling using internal state variable plasticity and its application in hard machining simulations is investigated by Guo et al. [32]. A new quantitative sensitivity analysis of the flow stress of 18 engineering materials in machining operation is investigated by Fang [33] to analyze the effective parameters of flow stress such as strain hardening and thermal softening. Determination of flow stress for metal cutting simulation is presented by Sartkulvanich et al. [34] to determine material properties through orthogonal slot milling experiments. A new flow stress model based on some assumptions on large deformation process with very high speed and high temperature during cutting process is developed by Rhim and Oh [35] to predict chip formation in metal cutting process with new flow stress model for AISI 1045 steel. The development of a hardness-based flow stress and fracture models for machining AISI H13 tool steel is presented by Umbrello et al. [36] to simulate the influence of work material hardness on the chip formation process. Determination of workpiece flow stress and friction at the chip–tool contact for high-speed cutting is presented by Özel and Altan [37] to analyze and optimize the effective parameters in flow stress and friction models.

2.4. Simulation of friction in the cutting zone

The friction between cutting tool and workpiece is a challenge of machining operation which can generate heat in cutting zone and decrease cutting tool life. Moreover, quality of surface roughness is under influence of friction in the cutting zone. So, the friction in the cutting zone as an effective parameter in quality of produced parts should be analyzed in order to be managed.

To calibrate the friction model in metal cutting operations, experimental investigation for workpiece materials AISI 1045, AISI 4140 and Inconel 718 is presented by Puls et al. [38]. Contact interface caused by frictional heat generation and plastic deformation are investigated in the study to analyze friction phenomena within the tool–chip interface in metal cutting. Analytical and experimental investigation of rake contact and friction behavior in metal cutting is presented by Ozlu et al. [39] to understand and model the friction in metal cutting operations.

To predict and analyze friction characteristics, chip formation, temperature and stress distributions in orthogonal cutting operations of AISI 1045 steel, Özel and Zeren [40] presented application of the finite element method simulation by using Lagrangian Eulerian method. Wear behavior of alumina based ceramic cutting tools on machining operations of stainless steel-grade 410 and EN 24 steel work pieces is investigated by Kumar et al. [41] to model friction and predict the flank wear, crater wear and notch wear of the cutting tool in actual cutting operations. Finite element modeling of stresses induced by high speed machining with round edge cutting tools is developed by Özel and Zeren [42] to present a detailed friction modeling at the tool-chip and tool-work interfaces in machining processes.

Friction model for tool/work material contact is developed by Denguir et al. [43] to predict surface integrity in orthogonal cutting operations. In order to identify the friction coefficient and the heat partition between OFHC copper and tungsten carbide, series of tribology tests combined with numerical simulations of the contact process are implemented under different sliding speeds and contact pressures. Inverse identification of flow stress in metal cutting process using response surface methodology is studied by Malakizadi et al. [44] to determine optimum frictional boundary conditions and the constitutive parameters for wide range of materials including Inconel 718 in aged condition, AISI 1080 plain carbon steel and AA6082-T6 aluminium alloy. The simulated temperature distribution at inner side of the chips at cutting conditions; FACE1 (a), FACE2 (b), FACE3 (c), FACE4 (d), is shown in the figure 2 [44].

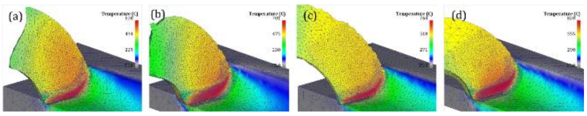

Figure 2. The simulated temperature distribution at inner side of the chips at cutting conditions; FACE1 (a), FACE2 (b), FACE3 (c), FACE4 (d) [44].

The influence of friction models on finite element simulations of machining operations is presented by Özel [45] to analysis of orthogonal cutting process. So, flow stress behavior of the material can be predicted in order to improve the material removal rate in orthogonal cutting process. A finite element study of the effect of friction in orthogonal metal cutting is investigated by Shi et al. [46] to obtain the maximum temperature, the contact length, the shear angle, and the cutting force in machining operations.

2.5. Prediction of the residual stresses

To increase performances of produced parts in actual working condition, residual stress of the machined parts can be predicted in order to be decreased. To predict cutting forces, temperature distributions and residual stresses in machining operations of AISI 316L steel, Umbrello et al. [47] presented the influence of Johnson–Cook material constants using finite element simulation. Numerical investigating is presented by Mohammadpour et al. [48] to predict the effect of machining parameters such as cutting speed and feed rate on residual stresses induced after orthogonal cutting operations. 4. Surface and subsurface residual strain profile in the cutting (circumferential) direction is shown in the Figure 3 [48].

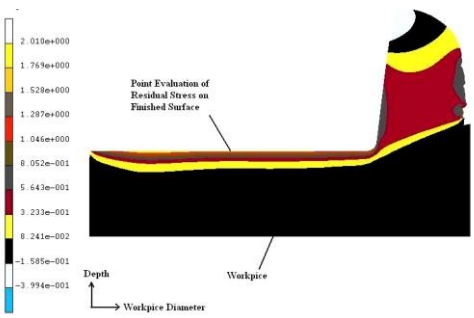

Figure 3. Surface and subsurface residual strain profile in the cutting (circumferential) direction [48].

To predict the cutting tool forces, distribution of stresses and temperatures, estimation of tool wear and residual stresses on machined surfaces, determination of mechanical behavior of aa5083 alloy under machining conditions, applicable in metal cutting simulation is investigated by Davoodi et al. [49]. Residual stresses and strains in orthogonal metal cutting is developed by Shet and Deng [50] to simulate and analyze the orthogonal metal cutting process under plane strain conditions. Analytical elasto-plastic model and a relaxation procedure is developed by Ulutan et al. [51] to calculate the thermal and mechanical loads and residual stress in machining operations. To predict the residual stress in orthogonal cutting operations, Liang and Su [52] developed a rolling/sliding contact algorithm. Hybrid model for the prediction of residual stresses induced by 15-5PH steel turning is presented by Mondelin et al. [53] to increase performances of machined parts by decreeing the final residual stress state. An enhanced analytical model for residual stress prediction in machining operations is developed by Lazoglu et al. [54] to increase safety of machined parts by decreasing the total amount of residual stress. In order to predict and decrease the residual stress in hard machining of AISI 52100 steel, Umbrello et al. [55] developed a numerical model in the study. Finite element modeling of residual stresses in machining operation using a tool with finite edge radius is developed by Ee et al. [56] to study the influence of sequential cuts, cutting conditions on the residual stress of machined parts. Prediction of residual stress distribution after turning operations of turbine disks is investigated by Salio et al. [57] to predict all the relevant variables, like stresses, strains, temperatures, chip shape and residual stresses, wide range of cutting conditions. Prediction of machining induced residual stresses in turning of titanium and nickel based alloys with experiments and finite element simulations is presented by Özel and Ulutan [58] to be analyzed and decreased.

2.6. Prediction of stress and strain rate in metal cutting condition

Work hardening and strain rate hardening response in the metal cutting process is investigated by Stevenson [59] to predict mechanical behavior of produced parts using machining operations. Study on related techniques for the finite element method simulation in metal cutting using the FEM simulation is investigated by Zhigang et al. [60].

Constitutive material model parameters for high-strain rate metal cutting conditions using evolutionary computational algorithms is studied by Özel and Karpat et al. [61] to predict and analyze the forces, temperatures, and stresses generated in metal cutting operations. The applications of finite element analysis (FEA) in metal cutting process are reviewed by Wenjun et al. [62] to predict the mechanical properties of material such as stress and strain rate in cutting processes. Modelling of high strain rate phenomena in metal cutting simulation is studied by Wedberg et al. [63] to simulate orthogonal metal cutting of AISI 316L stainless steel. Mechanical properties of hardened AISI 52100 steel in hard machining processes is studied by Guo and Liu [64] to estimate mechanical properties of the work material for both elastic and plastic deformations in a broad range of strain, strain rate in machining operations. Evaluation of present numerical models for predicting metal cutting performance and residual stresses is presented by Outeiro et al. [65] in order to increase efficiency of machining operations by using the optimized cutting parameters. Prediction of residual stress distribution after turning in turbine disks is presented by Salio et al. [57] to increase quality of machined turbine disks by analyzing and decreasing the residual stress. Equivalent plastic strain plot in reference conditions is shown in the figure 4 [57].

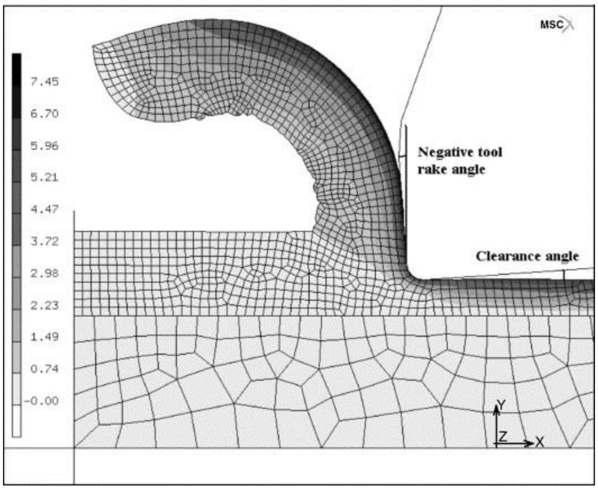

Figure 4. Equivalent plastic strain plot in reference conditions [57].

Prediction model of surface residual stress within a machined surface by combining two orthogonal plane models is presented by Sasahara et al. [66] to analyze and optimize the machining parameters such as size of the tool's corner radius and the feed rate affect residual stress.

2.7. Prediction of cutting forces in metal cutting operations

Cutting forces in machining operations can be predicted in order to be analyzed and decreased. Therefore, accuracy and efficiency in part production process can be increased by decreasing tool deflection error, workpiece deformation and cutting tool failure in machining operations.

Cutting force prediction in ball end milling of sculptured surface with Z-level contouring tool path operations is investigated by Wei et al. [67] to analyze and optimize the feed turning angle and cutter engagement in milling operations. Prediction of cutting forces in milling of circular corner profiles is presented by Zhang and Zheng [68] to analyze and modify the machining operations in terms of tool/workpiece geometry, cutting parameters and workpirece material property, as well as the relative position of the tool to workpiece. Cutting force and preheating-temperature prediction for laser-assisted milling of Inconel 718 and AISI 1045 steel is investigated by Kim and Lee [69] to increase machinability and machining efficiency in laser-assisted milling operations. Pramanik et al. [70] presented the prediction of cutting forces in machining of metal matrix composites in order to calculate different forces as the chip formation force, the ploughing force, and the particle fracture force in machining operations. To optimize the feed rate as well as cutting location data, cutting force prediction in milling operations is presented by Li et al. [71]. Cutting forces prediction using genetic algorithm in milling operations is developed by Kovacic et al. [72] to obtain the optimized machining parameters in milling operations. Analytical model using Griffith theory is developed by Sikder and Kishawy [73] to predict the cutting forces in machining operations of metal matrix composite. To optimize machining parameters and reduce machining damages, Wang et al. [74] presented the prediction of cutting forces in helical milling process based on the experimental tests. Prediction of cutting forces in helical end milling fiber reinforced polymers is presented by Kalla et al. [75] to decrease the cutting tool failure in machining operations. Development of cutting force prediction model for vibration-assisted slot milling of carbon fiber reinforced polymers is presented by Amin et al. [76] to analyse and decrease cutting forces in machining operations.

2.8. Prediction of cutting tool wear and surface roughness in machining operations

Cutting tool life is an important factor in cost of part production using machining operations. The wear of cutting tool in machining operation can be predicted and analyzed in order to increase cutting tool life in machining operations. Also, efficiency of part production can be increase by analyzing and increasing the surface quality of machined parts.

To predict the cutting tool wear and surface properties in machining operations, modeling of metal cutting and ball burnishing is investigated by Yung-Chang [77]. In-process tool wear prediction system based on machine learning techniques and force analysis is presented by Gouarir et al. [78] to monitor the progression of the tool flank wear and machine learning (ML) using a Convolutional Neural Network (CNN). FEM-based approach for tool wear estimation in machining operations is presented by Malakizadi et al. [79] to predict the rate of flank wear evolution for uncoated cemented carbide tools in longitudinal turning processes. Flowchart illustrating the steps of wear modelling algorithm is shown in the figure 5 [79].

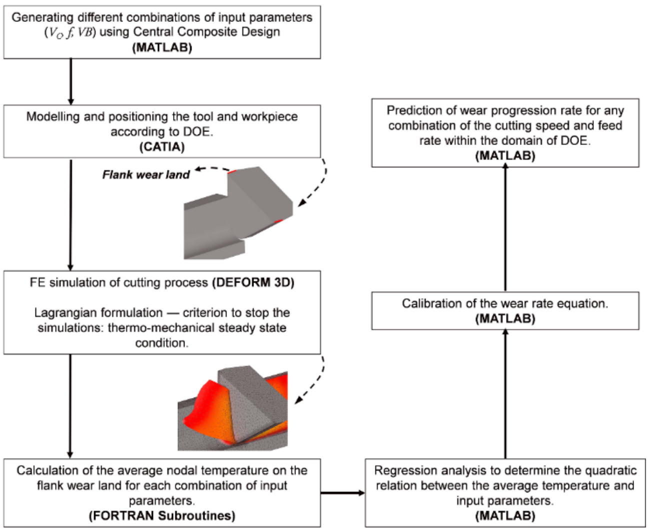

Figure 5. Flowchart illustrating the steps of wear modelling algorithm [79].

2.9. Viscoplastic analysis of metal cutting operations

To model and analyze the cutting process in machining operation, Behavior, Viscoplastic, Elasto-Viscoplastic and Thermo-Viscoplastic models can be considered. So, the simulated machining process can increase efficiency by analyzing the cutting forces, generated stress and heat in cutting zone.

Thermo-Viscoplastic Behavior of Ni-Based Superalloy Haynes 282 and its application to machining simulation is investigated by Rodríguez-Millán [86] to successfully model and analyze the orthogonal cutting operations. To analyze chip formation and segmentation or breaking in orthogonal metal cutting operations, 2D adaptive FE Simulations in Finite Thermo-Elasto-Viscoplasticity considering ductile damages is investigated by Saanouni et al. [87]. Prediction of polycrystalline materials texture evolution in machining via Viscoplastic Self-Consistent modeling is presented by Fergani et al. [88] to understand the forces and stresses generated by the cutting tool at each workpiece point. A new Thermo-viscoplastic material model for finite-element-analysis of the chip formation process is investigated by Warnecke and Oh [89] to express the complex flow behavior which depends on the local strain, strain rate and temperature. Prediction of machining induced surface integrity using elastic-viscoplastic simulations and temperature-dependent flow softening material models in titanium and nickel-based alloys is presented by Ulutan et al. [90]. Comparison of Viscoplastic and Elasto-Viscoplastic models in finite element simulation of micro-end milling titanium alloy is presented by Thepsonthi and Özel [91]. Behaviour of elasto/visco-plastic workpiece material during machining operations is presented by Chodor and Kukiełka [92] to characterize the flow behavior of the material in machining operations. Numerical simulation of machining Nickel-Based alloys is investigated by Del Prete et al. [93] to obtain the material flow stress and fracture in the machining operations. Analysis of the machining process using a Thermo-Elastic-Viscoplastic Finite Element Model is investigated by Balihodzic et al. [94] to simulate and analyze the effect of process parameters, tool geometry and edge preparation on the orthogonal machining operations.

2.10. Deformation analysis of workpiece in machining operations

To increase accuracy in machined parts, deformation of workpiece due to applied forces in machining operations can be analyzed and decreased.

Validation of a heat input model for the prediction of thermomechanical deformations during NC milling operations is presented by Joliet et al. [95] in order to be predicted and decreased. Machining deformation prediction for frame components considering multifactor coupling effects is presented by Tang et al. [96] to increase accuracy in process of part production using machining operations. Clamping force optimization for minimum deformation of workpiece by dynamic analysis of workpiece-fixture system is presented by Selvakumar et al. [97] to increase accuracy and efficiency in machining operations. Deformation control through fixture layout design and clamping force optimization is investigated by Chen et al. [98] to decrease the amount of workpiece deformation in machining operations. Study of cutting deformation in machining operations of nickel-based alloy Inconel 718 is presented by Dong et al. [99] to analyze the shear strain, shear strain rate and shear stress model in the cutting zone. Large strain deformation field in machining operations is investigated by Lee et al. [100] in order to be analyzed and decreased. Large strain deformation and ultra-fine grained materials by machining operations is studied by Swaminathan et al. [101] to increase accuracy in produced parts. Finite element simulation and analysis of deformation in machining of aeronautical aluminum alloy thin-walled workpiece by considering cutting force, dynamic loading and material removal rate is presented by Bi et al. [102]. Deformations of thin-walled plate due to static end milling force is investigated by Aijun and Zhanqiang [103] in order to predict and decrease deformation error in thin-walled plate with low rigidity. To improve machining accuracy in milling thin-walled parts, Chen et al. [104] presented deformation prediction and error compensation in multilayer milling processes for thin-walled parts. FEM-Modelling of the thermal workpiece deformation in dry turning operations is presented by Klocke et al. [105] to analyze and decrease the geometrical deviations of the machined part.

2.11. Deformation analysis of workpiece in machining operations

Machining operations of part from nickel base and titanium alloys materials are with challenges due to their peculiar characteristics such as poor thermal conductivity, high strength at elevated temperature, resistance to wear and chemical degradation. To produce advanced parts using machining operations from hard to cut materials such as hardened steels and high temperature strong aerospace materials, the cutting operations should be analyzed and modified.

Design and performance of AlTiN and TiAlCrN PVD coatings for machining of hard to cut materials is investigated by Fox-Rabinovich et al. [106] to increase surface quality in produced parts. Impact of Al and Cr alloying in TiN-based PVD coatings on cutting performance during machining of hard to cut materials is investigated by Kovalev et al. [107] to decrease generated heat in the cutting zone. Investigation of tool temperature and surface quality in hot machining of hard-to-cut materials is presented by Davami and Zadshakoyan [108] to increase cutting tool life and surface roughness in machining operations. Cutting force and tool deflection predictions for high speed machining of hard to cut material is analyzed by Sheu et al. [109] to increase efficiency in manufacturing process using machining operations. Thermally enhanced machining of hard-to-machine materials is reviewed by Sun et al. [110] to increase machining abilities of the hard to cut materials. To increase productivity with a lower manufacturing cost and without adverse effect on the surface quality in machining operations, key improvements in the machining of difficult-

to-cut aerospace superalloys is presented by Ezugwu [111]. A review of developments towards dry and high speed machining of Inconel 718 alloy is presented by Dudzinski et al. [112] to reduce the use of coolants in order to decrease machining operation cost in part production process. Relationship between flank wear and cutting force on the machining of hard martensitis stainless steel by super hard tools is investigated by Thamizhmanii and Hasan [113] to increase dimensional accuracy by decreasing cutting forces in machining operations. Experimental investigation on the effect of the material microstructure on tool wear when machining hard titanium alloys such as Ti–6Al–4V and Ti-555 is presented by Nouari and Makich [114] to increase cutting tool life in machining operations.

To increase machining abilities in micro/nano machining of hard and brittle materials, design and development of PCD micro straight edge end mills is presented by Cheng et al. [115].

Recent development in study for mechanical behavior of materials during machining operations is presented in the Table 1.

Table1: Recent development in study for mechanical behavior of materials during machining operations.

Topic of research work	Papers	Finding/ Discoveries
Simulation of chip formation process	[8]	Chip formation, temperature distribution, cutting force variable and residual stress in Orthogonal Metal Cutting Process are calculated.
	[12]	Shear band formation and the serrated chip formation during orthogonal metal cutting are analyzed.
	[16]	To analyze the chip formation process, a two dimensional FEM model for high speed cutting operations is developed.
Simulation of temperature distributions in cutting zone	[21]	The temperature distribution in machining operations of Inconel 718 using Johnson–Cook model was analyzed.
	[23]	The Johnson- Cook fracture model is applied to simulate the temperature distributions of cutting zone in 4340 steel machining operation.
	[27]	Temperature distributions in cutting zone considering different rake angle of cutting tool for machining of titanium alloy Ti6Al4V is presented.
Simulation of flow stress in metal cutting process	[30]	Material flow stress in machining of Titanium Ti-6Al-4V alloy is studied to analyze the effects of failure strain to the pressure-stress ratio.
	[32]	The material constants for the developed models in the study are determined for AISI 52100 steel to analyze the flow stress in metal cutting process.

	[36]	A hardness-based flow stress model for machining operations of AISI H13 was developed and validated.
Simulation of friction in the cutting zone	[39]	An analytical model is developed to investigate the rake contact and friction behaviors in metal cutting operations.
	[42]	The Lagrangian Eulerian method is developed to simulate and analyze the friction in the cutting zone.
	[44]	The FE modelling of orthogonal cutting process is developed to analyze the friction in machining operations of Inconel 718, AISI 1080 plain carbon steel and AA6082-T6 aluminium alloy.
Prediction of the residual stresses	[47]	The Johnson–Cook's material model is applied to predict the residual stresses in machining operations of AISI 316L steel.
	[50]	Residual stresses and strains in orthogonal metal cutting is simulated to be analyzed and decreased.
	[54]	The developed model based on finite element methods is presented to predict the residual stresses in machining operations.
Prediction of stress and strain rate in metal cutting condition	[60]	The Finite Element Method Simulation in Metal Cutting is investigated to predict stress and strain rate in metal cutting operations.
	[63]	Stress and strain rate in metal cutting condition in metal cutting of AISI 316L stainless steel is simulated to be analyzed.
	[57]	Finite element model of orthogonal cutting is presented to predict the stress rate in turning operations of Inconel 718.
Prediction of cutting forces in metal cutting operations	[68]	Cutting forces in peripheral milling operations of circular corner profiles are predicted to be analyzed.
	[70]	A mechanics model is developed to predict the forces in machining aluminum alloy-based MMCs reinforced with ceramic particles.
	[74]	The prediction of cutting forces variations in helical milling process is developed to analysis the cutting parameters such as depth of cut, spindle speed and tool geometry.
Prediction of cutting tool wear in machining operations	[78]	In-process tool wear prediction system based on machine learning techniques and force analysis is presented.
	[81]	Prediction of cutting tool wear, surface roughness and vibration of work piece in boring of AISI 316 steel with artificial neural network is investigated.
	[83]	A comparative study on machine learning algorithms for smart manufacturing is presented.
Viscoplastic analysis of metal cutting operations	[86]	Thermo-Viscoplastic Behavior of Ni-Based Superalloy Haynes 282 and its application to machining simulation is investigated.
	[89]	A new Thermo-viscoplastic material model for finite-element-analysis of the chip formation process is investigated.
	[93]	Numerical simulation of machining Nickel-Based alloys is investigated.

Deformation analysis of workpiece in machining operations	[97]	Clamping force optimization for minimum deformation of workpiece by dynamic analysis of workpiece-fixture system is presented.
	[100]	Large strain deformation field in machining operations is investigated.
	[105]	FEM-Modelling of the thermal workpiece deformation in dry turning operations is presented.
Machining operations of hard to cut materials	[108]	Investigation of tool temperature and surface quality in hot machining of hard-to-cut materials is presented.
	[112]	A review of developments towards dry and high speed machining of Inconel 718 alloy is presented.
	[115]	Design and development of PCD micro straight edge end mills in micro/nano machining of hard and brittle materials is presented.

3. Conclusion

In the present research work, a review in mechanical behavior of materials in metal cutting is presented. Different topics in mechanical behavior analysis of materials in metal cutting is reviewed and discussed in order to provide a useful study for the researchers in the interesting field. Simulation of chip formation process is presented in order to obtain the effects of thermo-mechanical behavior, cutting edge geometry and cutting speed to the chip formation process in metal cutting operation. Temperature distributions in cutting zone is simulated to increase cutting tool life in the machining operations. Flow stress in metal cutting process is simulated to analyze the effective parameters of flow stress such as strain hardening and thermal softening in machining operations. Friction in the cutting zone is simulated and analysed to predict the flank wear, crater wear and notch wear of the cutting tool in actual cutting operations. Residual stresses in the machined parts can be predicted to predict the performances of produced parts in actual working conditions. Stress and strain rate in metal cutting condition can be predicted to analyze mechanical properties for both elastic and plastic deformations in a broad range of strain, strain rate in machining operations. Cutting forces in metal cutting operations can be predicted to prevent the workpiece deformation as well as tool deflection error in machining operation. Prediction of cutting tool wear in machining operations is studied in order to increase cutting tool life in machining operations. So, cost of machining operations can be decreased by reducing the cutting tool failure rate in machining operations. Viscoplastic analysis of metal cutting operations is investigated in order to be applied to the finite-element-analysis of metal cutting operations to obtain the chip formation, residual stress and temperature distributions in cutting zone. To increase accuracy in process of part production using machining operation, deformation of workpiece due to applied forces can be analyzed and decreased. Machining operations of hard to cut materials is analyzed in order to decrease distributed temperature in the cutting zone. Also, surface roughness as well as cutting tool life can be increase.

New alloys for cutting tool materials can be analyzed to predict the temperature distribution in the machining operation. Also, in the process of chip formation, different angles of cutting tools can be analyzed to introduce modified versions of cutting tools in machining operations. The effects of cutting zone temperatures as well as friction in the cutting zone on the cutting forces can be analysed in order to increase the material removal rate in the cutting operations. Moreover, the rate of cutting tool failure can be decreased in order to increase efficiency in machining operations. Residual stress in the assembled machined parts can be analyzed to increase performances of parts in actual working conditions.

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