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REVIEW ARTICLE

A State of the Art on Simulation and Modelling Methods in Machining: Future Prospects and Challenges

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Abstract

Simulation modelling methods have gained dramatic acceleration in the last years among academic environments and industry-driven enterprises. Primary reason is that such models have great potential in predicting of machining process parameters. Therefore, tis study evaluates the place and capability of these models in fundamental machining operations. In this direction, Finite Element Modelling Methods are discussed by questioning their contributions to the process performance. Despite numerous positive aspects, development of a successful model is highly difficult owing to the complexity of machining environment with variation of thermo-mechanical effect, tribological conditions, interaction of process variables and high deformation rate of materials etc. Therefore, a critical assessment of the merits and drawbacks of each method associating with their basic phenomena has been investigated. Predictive models basically aim to estimate the machinability characteristics such as stress–stain rates, cutting forces and temperatures etc. Nevertheless, practical applications require correlations between these characteristics and performance outcomes such as surface integrity of part, tool wear index, chip morphology, dimensional accuracy etc. In the end, the molecular dynamics and smoothed particle hydrodynamics have been discussed. Thus, this paper is expected to contribute to up-to-date studies by criticizing the key findings of the predictive models in machining processes.

1 Introduction

Machining is one of the highly used process in modern-day industrial applications with increasing demands from customers in all over the world such as transportation, medical, surgery, automotive, space, aeronautics etc. [1, 2]. To meet the demands of customers, extraordinary labor need to be given by considering the long supply and manufacturing chain which requires hypervelocity, accuracy, reliability and compensability [3]. On the other hand, mentioned processes have potential risks due to the complexity of such operations and developing events in the small area of metal cutting and hard-to-observe nature of cutting tool, machined part and created chips [4]. There are sophisticated connections between the changing material behaviors, deformation, tribological conditions and energies i.e. forces, temperature, vibration etc. [5, 6]. Each of them may cause an unexpected development at short notice that will change the ordinary progress of the operation [7, 8]. Actually, metal cutting zone is already convenient for brief alterations as a consequence of high cutting temperatures plus its effect on the microstructural as well as mechanical characteristics concerning the materials [9]. With an additional impact sorted previously, some challenging problems may occur; (i) rapidly development of tool wear, (ii) uncontrolled chip removing, (iii) poor part surface quality [10, 11]. Moreover, it should be noted that such quality reductions may result in low efficiency, unnecessary time loss, extra costs and waste of labor [12–14]. Since engineering materials are expensive and being hard and costly recycling procedures, researchers focuses on the recovery precautions before the destructive impressions emerge [15–17]. One of the prominent ways of protecting the loss of money and time for industries is using the simulation and modeling approaches [18–20]. Basically, it allows to observe the possible findings from any experimental work that may be highly costly [11]. Thus, it is helpful to achieve these results without consuming material and

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effort [21]. Mainly, all of the models and simulation based algorithms provide an approach including fundamental process parameters and responses to be predicted. The correlation between the modeling parameters and variables are developed through various calculations and the success of the model could be compared with the physical results [22, 23]. Simulation and modeling have a long history from the beginning of the 1990s in the machining world. Such methods cannot provide guarantee to obtain the exact results; however their main intend is to approach the actual findings [24]. When the developments in this field is considered, impressive results have been noticed which pushes the authors to work on this topic. It is expected that this review will be beneficial to the researchers and industrialists in the machining sector. This study includes literature overview for a wide range of materials processed by the analytical methods and their comparative results with actual experiments. In this perspective, the paper provides new visions for the future studies and gives an idea for the applicability and obtained results of several modeling approaches to the academicians for the same materials to be used. FEM, analytical model and statistical modeling approaches will be discussed in the context of this paper.

2 Simulation and Modelling Methods

The simulation and modelling methods, first proposed by Merchant in 1944, outlined the modeling of the vertical shear process [25]. Using the finite element method, researchers have been able to simulate their findings more quickly as computer technology has advanced [26–28]. Finite element analysis is considered as a numerical calculation technique which permits complicated constructions to be separated into elements into perfect forms as well as resolved mathematically. The particular finite aspect technique includes systematic processes for derivatives regarding finite elements, which can be subdomains of estimation functions. Numerical remedies for variables from special points are known as nodes of each and every aspect and usually are applied in determining finite solutions regarding the whole angles in figuring out the particular solution in the trouble. Finite element analysis is beneficial because it offers solutions to issues that are difficult or impossible to address analytically. The initial stage in finite element model is to discretize the geometry, which is done by dividing the geometry into finite elements. Then, relying on the qualities necessary for analysis, several types of elements are utilized, such as triangular and rectangular for 2D, prismatic, tetrahedral, pyramidal and hexahedral for 3D. Describing the resistivity format, the meaning of loading conditions such as force, pressure, and speed in addition to the limit conditions at the specific connection follows. To specify element attributes, a stiffness structure is employed. Ultimately, the manifestation of the component, employed loads, combined with limit requirements are modified to the matrix development. Determined calculations are deciphered mathematically at undetermined principles. Strain, stress, along with additional characteristics of attention could be specified differing on the node dislocation consequence [29]. Symmetry calculations concerning common linear or even nonlinear stationary challenges of FE evaluation could be conveyed in this manner.

$$\{F\} = [K] * \{U\} \tag{1}$$

F is the element's force vector matrix, K denotes the stiffness matrix, and U denotes the calculated node displacement vector. It does, however, need a dynamic analytic form for time-independent dynamical issues.

$$\{F(t)\} = [K]\{U\} + \left[M^1\right]\left\{\dot{U}\right\} + \left[M^2\right]\left\{\ddot{U}\right\} \tag{2}$$

K is the stiffness matrix, U is the node movement vector refreshed with time shift, M^1 represents the vibration matrix, $\dot{U}$ node speed (initial integral of node dislocation), M^2 is the mass matrix, while $\ddot{U}$ is the node accelerating, are all used in this equation (second node displacement derivative) [29].

With in construction of finite elements, Eulerian, Lagrangian, as well as Arbitrary Lagrangian–Eulerian meshing forms are frequently developed. When such mesh structures are evaluated, they are discovered to have discrepancies [30]. The finite element mesh remains constant during the material flow in the Eulerian mesh structure; only the points are moved. The Eulerian mesh structure has the advantage that the form of the components does not vary over time, hence there is no distortion. Nevertheless, the chip's free surface must be presumed to be its initial shape, and the chip creation process cannot be described. In the Lagrangian technique, on the other hand, there is movement in the roof. The mesh is attached to the material and travels along with it. However, changing the geometry of the components during the material flow is challenging. Consequently, the crooked mesh might have to be swapped with the mesh once more. Therefore, mesh or adaptive meshing rezoning is necessary during the purpose of such mesh structuresas in Fig. 1. In addition, chip separation criteria are needed to shape the chip [31].

Into the Arbitrary Lagrangian–Eulerian (ALE) meshing, the surface points are neither attached to the substance nor the region, they change randomly. In additional phrases, the substance flow is separate of these points. ALE mesh as shown in Fig. 2, on the other hand, provides improved outcomes when matched to mutually mesh constructions [32].

Only Lagrangian or Eulerian meshing systems are utilized into several software programs applied concerning machining nowadays. Perhaps, it is utilized in programs like Third

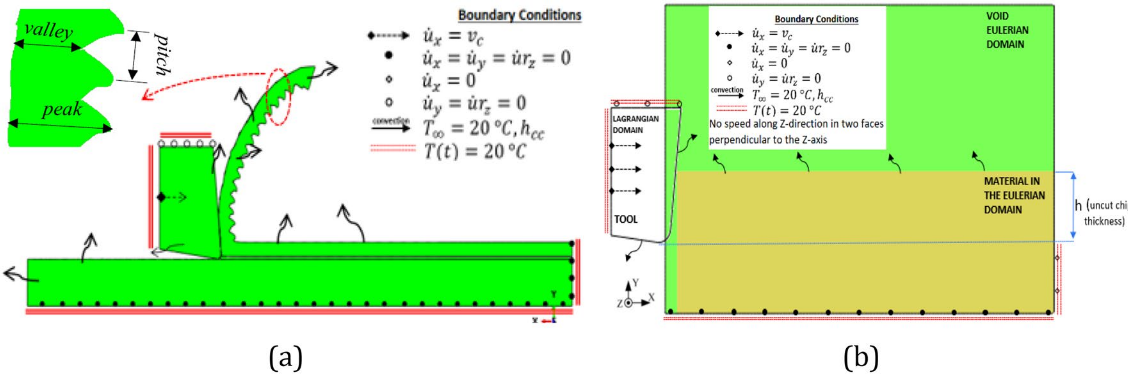

Fig. 1 Mesh structures of **a** Lagrangian and **b** coupled Eulerian–Lagrangian [31]

Wave AdvantEdge, MARC, DEFORM, ABAQUS, ANSYS LS-DYNA working with Johnson–Cook [33], Chaboche [34], Fields-Backofen [35], Rusinek-Klepaczko [36], Johnson–Cook [37] constitutive models, respectively after that optimistic findings are obtained. The remeshing technique employed in several of these programs raises the understanding and precision of the analysis. Most FE softwares use a 2D Lagrangian mesh formulation and has an automatic remeshing process. The breaking of nodes and the formation of a new surface during the remeshing process are presented in Fig. 3 [38].

In order to utilize the FE technique regarding the evaluation of chip development during metal cutting, some assumptions are required. These assumptions help identify the restrictions as well as loading situations in use to resolve the difficulty. The orthogonal metal cutting standard requires a coordinate three-dimensional structure in addition to time to fully define the problem. In demand to create the mentioned model, the subsequent assumptions (boundary restrictions) should be made.

- Cutting velocity is steady.
- The cutting width (cutting depth) is greater than the feed plus they are together steady.
- Chip is continuous for ductile materials.
- The cutting velocity trajectory is perpendicular against the cutting corner.
- The sample substance is a polycrystalline uniform, incompressible solid plus isotropous.
- The specimen reference temperature remains usually at room warmth.
- Cutting stands usually accomplished by air-cooled, not fluid.
- No tool wear.
- The cutting tool is rigid (not deformed).
- Steady-state cutting is achieved during the process.

It is feasible to simulate chip formation by picking the right modeling approach and modeling the material by applying these assumptions, establishing the material's deformation rate, and knowing how the workpiece material will react during plastic deformation. The strain rate and thermal effects of the constitutive equations must be chosen in order to describe the model's dynamic behavior. Metals stress varies depending on strain, rate of strain, and temperature.

Zerill-Armstorng [39], a modified version of the JC model [40], and the JC model [33] are the FE models as indicated in Eqs. 3–5, respectively. Among the phenomenological models, these models have been used to portray the complex flow behavior of a variety of materials, as they have a high degree of accuracy with a limited number of material constants. Nevertheless, phenomenological models do not account for the micro-mechanics of material deformation, rather they assess only the effect of macro-deformation factors (deformation temperature, strain rate, and strain) on flow stress. Consequently, all types of models have their own benefits and are suitable for various materials. When deciding which constitutive model is appropriate for a particular

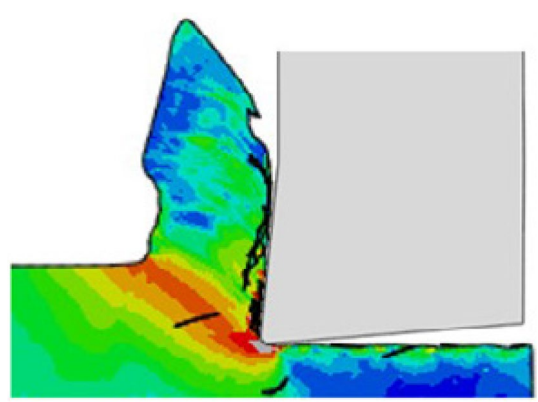

Fig. 2 ALE mesh structure [32]

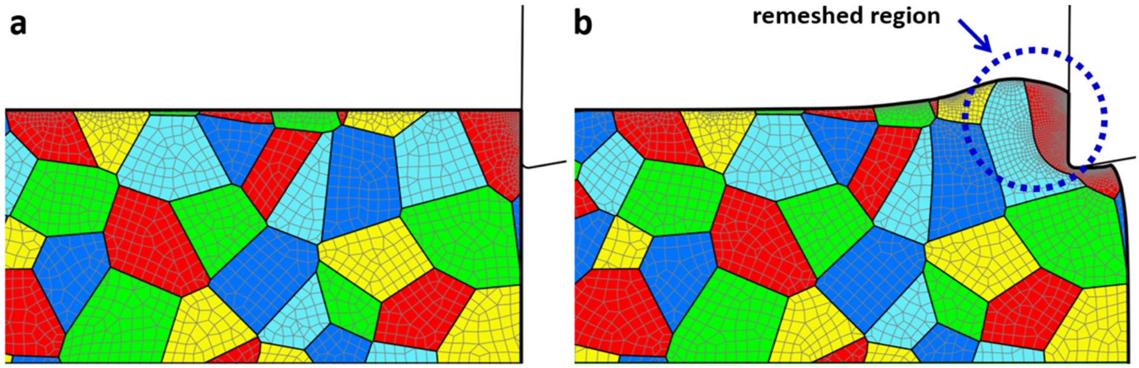

Fig. 3 Node breakage and new surface formation in the remeshing process [38]

material, it is necessary to compare the accuracy and adaptability of several models .

$$\sigma = c_0 + B_0\epsilon^{0.5}\exp(-\beta_0 T + -\beta_1 T\ln\dot{\epsilon}) \quad (3)$$

determine the mechanical boundary stress (MTS) and J–C material model of AISI 4340 steel tempered at different temperatures. At a given strain and temperature range, the yield stresses estimated by J–C and MTS were compared. MTS model parameters were easier to get than J–C model parameters, although MTS simulations took 1.5 times longer than J–C simulations, according to them. The authors stressed that the J–C material model is more effective numerically than the MTS model, and that numerous steel plates, such as AISI 4340, may be employed more in machining simulations [26]. Majzoobi et al. [27] combined experimental, numerical, and optimization techniques to determine the J–C material model. Experiments were simulated at small as well as elevated strain rates via applying specimens of the same geometry on standard testing machines. The authors stated that a decent deal among the investigational along with numerical estimation of the J–C material models, which they determined with the help of quasi-static combined with dynamic assessments [27]. Tan et al. [28] performed dynamic uniaxial tensile and quasi-static examinations at various strain levels to investigate the effects of 7050-T7451 aluminum alloy on the flow behavior. The authors argued that these tests are appropriate methods for determining the corrected J–C constitutive model. The J–C model, established by the experiments, was compared with the unique J–C model plus the Kahn-Liu standard. As a result of these tests presented at various strain levels, they observed that the corrected J–C material model was predicted with higher accuracy than the other two models [28]. Zhang et al. [29] accomplished dynamic experiments with a Split Hopkinson Pressure Bar experimental setup to determine the dynamic performance concerning 7075-T6 aluminum metal at different strain rates. The results revealed that the

$$\sigma^0 = \left(A_1 + B_1\epsilon + B_2\epsilon^2\right)\left(1 + C_1\ln\left(\frac{\dot{\epsilon}^p}{\dot{\epsilon}_0}\right)\right)\exp\left[\left(\lambda_1 + \lambda_2\ln\left(\frac{\dot{\epsilon}^p}{\dot{\epsilon}_0}\right)\right)\left(T - T_{ref}\right)\right] \quad (4)$$

One of the first constitutive equations including strain and heat effects is the Johnson–Cook (J–C) equation as mentioned above. Of course, constitutive models like rigid plastic, thermo-elastic plastic, elastic plastic, as well as thermo visco plastic are built utilizing these equations [29]. The preparation of Johnson and Cook's fundamental equivalence utilized with Deform 2D and 3D is represented below [33].

$$\sigma^0 = \left(A + B(\epsilon^p)^n\right)\left(1 + C\ln\left(\frac{\dot{\epsilon}^p}{\dot{\epsilon}_0}\right)\right)\left(1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m\right) \quad (5)$$

Here, σ^0 denotes the flow stress, ε represents the plastic strain, $\dot{\epsilon}$ strain rate, $\dot{\epsilon}_0$ reference strain rate, T (°C) instantaneous temperature, T_{melt} melting temperature of specimen, T_r (24 °C) room temperature. "A" parameter is the yield stress (MPa), "B" is the hardening module (MPa), "C" is the coefficient of strain rate sensitivity, "n" is the hardening coefficient in addition to "m" which is the coefficient of thermal softening.

It was commonly mentioned that the JC model is frequently used in FE analysis software, especially for machining simulations. In order to develop the JC material model, dynamic investigations, as well as quasi-static studies and studies conducted at high temperatures, are required. Conducting these experiments enables one to determine the material constitutive parameters, especially the JC model parameters. In order to develop the machining models, some boundary conditions in terms of J–C parameters are required. Banerjee et al. [26] tried to strain hardening coefficient is important and the improved J–C model, which was created by correcting this coefficient, demonstrated great deal with the investigational outcomes. They stated that model constraints can be used according to the high similarity between the numerical simulations made applying the J–C model along with the investigational findings [29]. Lin et al. [30] carried out high-temperature compression tests at two distinct strain levels in addition to two various temperatures to investigate the elevated-temperature deformation performance concerning the Al–Zn–Mg–Cu metal and to find the J–C model. Investigational findings showed that the found J–C standard was insufficient. Therefore, they developed a new structural equation contemplating the collective consequences of strain rate, strain, along with temperature factors. Numerical simulations with the developed model showed a high similarity with the experiments and the usability of the model was proven [30]. Huh et al. [41] accomplished tensile experiments at high strain levels with a Partitioned Hopkinson Pressure Bar experimental setup specially designed for sheet metals. Numerical simulations were made with the FE process using the J–C constitutive model, which was created with the investigational conclusions obtained from the dynamic assessments and quasi-static. The authors emphasized that this model used for sheet metal is highly suitable and can be used in high-speed vehicle collision analysis [41]. Gambirasio and Rizzi developed a modern strength prototype called the discrete J–C. Such model was created with a simplification suitable regarding the J–C original model. The model aimed to improve the original J–C model to reduce the problems caused by the combined effect of the resultant strain, strain rate, in addition to temperature factors, which are completely separate of each other, on the yielding stress. The stress-strain curves obtained with the SJC model showed that it was more efficient than the original J–C model when associated with the investigational results [42]. Buzyurkin et al. [43] plotted the real stress-strain graphs of different titanium alloys under dynamic load. Then, with the assistance of dynamic tests, the J–C material model required to use the alloys in numerical simulations was obtained. In addition, the authors who performed experiments on these alloys compared the experimental and numerical results and found that they were very similar. This demonstrated the usability of the J–C material model found concerning the tested titanium alloys [43]. Banerjee et al. [44] determined the J–C structural equation constants and fracture damage parameters of the armor steel material by four different uniaxial tensile tests. Then, the dynamic strain rate of armor steel, high triaxiality, and finite element analysis at high temperatures was performed in ABAQUS software. The similarity of the model and investigational outcomes demonstrated the accuracy as well as usability of the J–C structural equation constants found for the specified armor steel material. Slais et al. [45] examined the impact of strain rate factor on the mechanical behavior regarding the Ti–6Al–4V titanium metal and formed the J–C material model. Concerning the model, firstly, they started the experiments with static loading tests, and then they performed dynamic experiments at elevated strain levels with the help of the Taylor anvil test device. The findings of the FE assessment presented in ANSYS LS-DYNA 3D software showed a high similarity with the experiments. The researchers stated that the obtained J–C model could be used for numerical simulations in future studies. Guzman et al. [46] determined the J–C structural equation parameters of Al6082 aluminum alloy by assessing the heat increasing with the plastic strain via a Basma Hopkinson test device. It has been emphasized that the parameters can be used by stating that the investigational outcomes are comparable to the numerical analysis findings performed on the same material and using J–C parameters [46]. Dorogoy and Rittel determined the J–C material parameters of Ti6Al4V titanium alloy using a shear compression sample (SCS). After performing quasi-static tests using the thermal softening effect, dynamic tests were performed considering the strain rate hardening effect. Since the obtained J–C parameters are similar to the literature, the validity of the test methods applied in this study and the shear compression specimen was emphasized [47]. Hokka et al. [48] aimed to determine the J–C material parameters concerning T-6246 titanium alloy as well as a nickel-established superalloy comparable to Inconel 625 with quasi-static and dynamic tests and transfer them to a simulation program. Tests were conducted across a broad variety of strain rates and temperatures. Then, vertical cutting was performed both experimentally and as a simulation in software working with a finite element infrastructure. Experimental and numerical results are similar for titanium-6246 material, but not for nickel-based superalloy. The authors reduced the strain hardening coefficient at high deformation by adding the strain-softening coefficient to improve the model valid for the nickel-based superalloy. After this addition, it occurred that the investigational and mathematical outcomes for the nickel-based alloy were similar [48]. Ma et al. [49] aimed to obtain the J–C material model of SCM440H alloy steel and insert it into the ABAQUS software. In the first stage, they subjected the SCM440H steel to the milling process under certain cutting parameters. Then, numerical analyzes were performed for the same material, thanks to the J–C parameters placed in the software. It has been found that there is a difference of about 15% between experiments and simulations where cutting forces are measured as a machining output. In the light of this result, it has been stated that the J–C

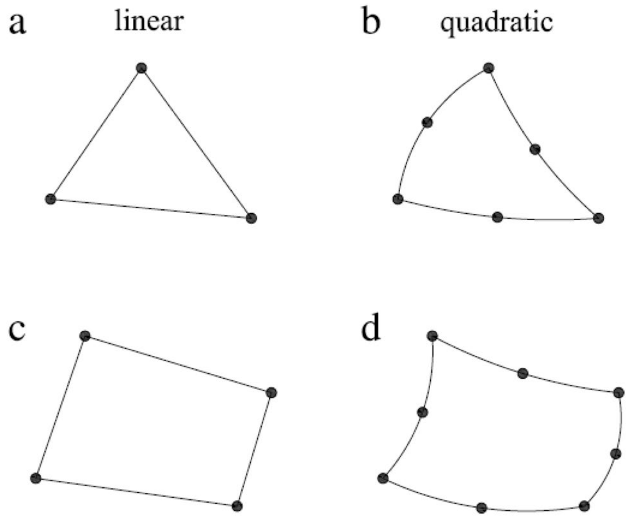

Fig. 4 Mesh structure for 2D processes, **a** 3-node, **b** 6-node, **c** 4-node, **d** 8-node [51]

parameters of the material are suitable and can be used in future studies [49]. Sekar et al. [50] carried out an optimization study concerning the Ti–6Al–4V titanium metal alloy with the Taguchi L16 vertical array using the J–C parameters previously found by four different researchers. A high degree of similarity was observed between the simulation study and experimental studies performed with these parameters obtained as a result of the optimization, and the usability of the model parameters was emphasized [50].

In many FE softwares, the use of 3-node triangular element, 6-node triangular element, 4-node quadrilateral element and 8-node quadrilateral element is preferred (Fig. 4). The common geometric sturcture concerning FE assessment is illustrated in Fig. 5.

In DEFORM 2D, Cockroft along with Latham's standards can be utilized to estimate the tensile stress in the chip sections in vertical cutting. This criterion is expressed by the following equation (Eq. 6) [44].

$$\int_0^{\dot{\epsilon}_f} \sigma_1 d\bar{\epsilon} = D \tag{6}$$

Here, ε is the actual strain, σ1 is the highest primary stress, along with D which is the constitutive constant. In the DEFORM 2D program, the critical damage value is calculated by the program at each step-time of each element under deformation.

The numerical evaluation regarding machining is clearly linked to the good creation of the constitutive model. Therefore, the success of the developing model is feasible by means of establishing the relevant characteristics fairly in addition to entering them as feedback [53]. Table 1 summarizes the applied methods and models to enhance the machining processes.

2.1 Cutting Force and Cutting Temperature Models

Numerical modeling of the cutting process is used as an alternate solution approach since machining research is costly and time-consuming. Among the numerical approaches for modeling the cutting process, the finite element method is the most used. Chip removal mechanics have improved dramatically thanks to computer algorithms (ANSYS, ABAQUS, DEFORM, and others) that assist forecast cutting forces, temperature, and stress values throughout the chip creation process. As a result, cutting conditions in machining operations may be adjusted, and tooling costs can be reduced significantly, lowering manufacturing costs. In this regard, the finite element method has become a crucial tool for analyzing engineering designs and production processes. The results of the computer package programs used to simulate manufacturing procedures using finite elements and the results of the relevant plastic deformation process (force, temperature, etc.) must be same. In this case, it's critical to accurately simulate the materials in the simulation software. Several structural material models that can appropriately depict high strain behavior across a wide range of strain rates and temperatures have been developed. These

Fig. 5 General geometric structure for an orthogonal cutting process [52]

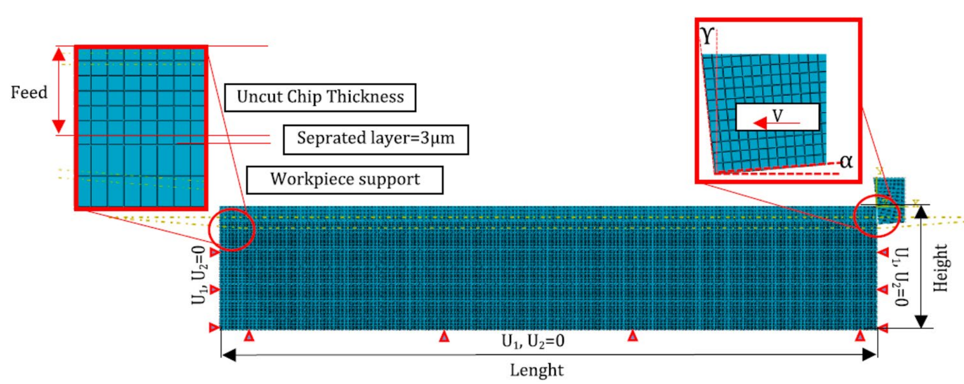

Table 1 Summarization of applied methods and models to enhance machining processes

References	Materials	Model/test	Results
[2]	AISI 4340 steel	Mechanical boundary stress (MTS) and J–C material simulation	The J–C material standard is further effective than the MTS standard
[27]	ST37 steel	J–C material model	Excellent deal among the investigational and mathematical estimation
[28]	7050-T7451 aluminum	Quasi-static as well as dynamic uniaxial tensile analyses compared with the original J–C model	The corrected J–C material model was predicted with higher accuracy
[29]	7075-T6 aluminum	Dynamic tests with a Split Hopkinson Pressure Bar experimental system	Findings demonstrated great deal with the investigational outcomes
[30]	Al–Zn–Mg–Cu	High-temperature compression tests and J–C model	Experimental results showed that the found J–C model was insufficient
[41]	Sheet metals	Tensile tests and J–C material model	The authors emphasized that this model used for sheet metal is highly suitable
[42]	A fundamental steel, natural metal combined with stainless steel	Developed a modern strength model called the discrete J–C (SJC)	The stress-strain curves obtained with the SJC model showed that it was more efficient than the original J–C model
[43]	Titanium alloys	Dynamic tests, the J–C constitutive model	The investigational and mathematical results found that they were very similar
[44]	Armor steel	Uniaxial tensile tests	The similarity of the model and investigational results demonstrated the accuracy and usability of the J–C structural equation constants
[46]	Al6082 aluminum	Temperature increasing with plastic strain tests	The investigational outcomes are comparable to the numerical analysis effects performed on the same material and using J–C parameters
[47]	Ti6Al4V titanium alloy	Quasi-static tests using the thermal softening effect, dynamic tests	The validity of the test methods applied in this study and the shear compression specimen was emphasized
[48]	Titanium-6246 titanium and Inconel 625	Quasi-static and dynamic tests	The experimental and numerical results for the nickel-based alloy were similar
[49]	SCM440H alloy steel	Milling process under certain cutting parameters	The J–C parameters of the material are suitable and can be used in future studies
[50]	Ti–6Al–4V titanium	J–C model/Taguchi L16 vertical array	The usability of the model parameters was emphasized

material models include Zerilli-Armstrong, Bodner-Partom, and J–C, with the J–C material model being better appropriate for machining procedures. As a result of the evaluations, it is seen that most of the simulation studies in the literature are done with the material models available in the material library of the simulation program.

Today, with the increase in the processing capacity of computers and the use of the finite element method in system simulation, the results of the studies can be determined approximately without the need for any experiment related to cutting mechanics. However, metal cutting simulations still remain a research topic due to geometric complexity, insufficient experimental data in the material models used, the inability to model the chip contact with the tool realistically, and long calculation times. Cutting forces and temperatures are very important in machining operations because they are used to design the machine tool structure [16]. Based on the phenomena, Ezilarasan et al. [54] conducted an experimental investigation and analyses in the turning of Nimonic C-263 super alloy using a cemented carbide cutting tool using the finite element method (FEM). The Lagrangian finite element-based machining model is utilized in FEM machining simulations to determine cutting force, temperature distribution at the cutting point, and effective stress. The workpiece is made of flawless plastic material and is shaped into a curved design. The tool's friction coefficient with the workpiece material was found to be 0.6. When the cutting force and temperature at the tool tip acquired from the trials were compared to the simulated findings, a 6% error rate was discovered. It was highlighted that the model's validity was determined by the findings of the FE assessment under the cutting conditions used was proven. Parida and Maity [55] investigated the variation of cutting tool tip radius on the force of cutting, cutting temperature, along with stress

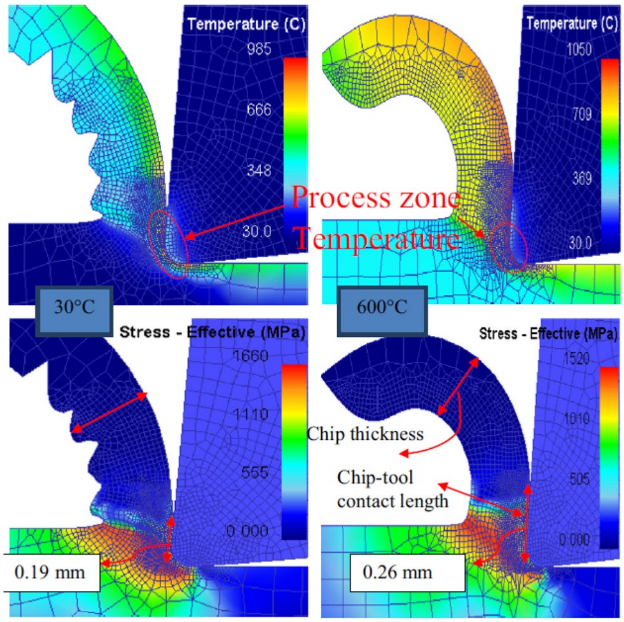

Fig. 6 Effective stress distribution process zone temperature at room and heating condition at nose radius 0.4 mm [55]

during the Inconel 718 hot turning by applying finite element modeling as shown in Fig. 6. Three different tool nose radii were used in the simulations (0.4, 0.8, and 1.2 mm). Actual cutting force, stress, feed force and cutting temperature were estimated using DEFORM software at both room temperature and elevated temperature. In both conditions, it was found that the tool nose radius increased and the cutting force plus force of thrust increased under high machining conditions. Cutting temperature, tool-chip contact length, as well as uncut chip thickness were also investigated. An tentative research was performed to confirm the finite element analysis findings, and a high degree of similarity was found when the results were evaluated.

Vijayaraghavan et al. [56] established a FE-based hybrid model. FE modeling was utilized to estimate the shear force, though genetic coding was applied to derive the statistical relationship among procedure parameters as well as shear force. According to the genetic programming evaluation, the cutting depth besides the cutting angle had a substantial impact on the force of cutting. According to the finite element evaluation results, it is emphasized that this developed model can be used for materials that are difficult to process without the need for preliminary experiments, and thus power savings can be achieved [56]. Jafarian et al. [57] aimed to apply the FE model during orthogonal process machining concerning Inconel 718 alloy and to predict changes in its microstructure through processing. To begin, cutting forces, chip shape, and maximum temperature were considered in order to select the most appropriate material model from a list of seven available in the literature. Following that, using an iterative approach based on the comparison of experimental data, the finite element numerical model is simulated and suitably calibrated. In addition, during orthogonal machining of Inconel 718 alloy, a user function was utilized in the FE code to model dynamic recrystallization and, as a result, to anticipate grain refinement and hardness fluctuation. Grain size and microhardness were calculated using the Zener-Hollomon and Hall-Petch equations, respectively. The critical stress equation was also used to adjust the depth of the impacted layer. In terms of grain size, microhardness, and depth of the impacted layer, there was a lot of consistency between the experimental and simulated results [57]. Reddy et al. [58] investigate the temperature generated during the turning of Inconel 718 utilizing TiAlN coated carbide inserts, a viable finite element analysis model was built and utilized. This study made use of the ABAQUS software. The thermo-elastic-plastic characteristics of the material to be treated were coupled using finite element analysis. The simulation model's results were compared to the data from the experiments. It was also discovered that when the cutting speed rise, the cutting temperature increased as well. The developed finite element model has proven the usability of complicated-to-machine resources without the need for experiments, and it has been emphasized that time and economy can be gained [58].

To accurately explain the thermal softening of matrix-induced damage in CFRP orthogonal cutting, Zhang et al. [59] integrated the influence of temperature on material characteristics into the FE model (Fig. 7). In another study, the models for cutting forces were developed by Huang and Liang [60] that incorporate temperature-dependent thermal characteristics into the constitutive connection including strain, strain rate, and temperature. In the thermal model, the assumption of a uniform moving band heat source to represent the primary shear zone heat production and a semi-infinite semi-infinite medium to represent the secondary shear zone heat source were used to generate analytical solutions for the temperatures. Comparable cutting force models were used by Chou and Song [61] to determine how much the tool temperature rose. The thermal model was built on the use of superimposition methods and the discretization of main and secondary heat sources into tiny segments of rectangular heat sources. The total heat source's temperature rise was measured by superimposing the temperature rises of the separate heat source components. Yen et al. [62] have shown that changing the edge radius of the hone tools significantly influences plastic deformation and contact temperature. Using FEM analysis to examine some thermodynamical effects in the cutting zone is particularly relevant because these effects cannot yet be evaluated directly. The chip breaking performance of uncoated and coated tools has been studied by Marusich et al. [63] using a finite element-based simulation. This research found that

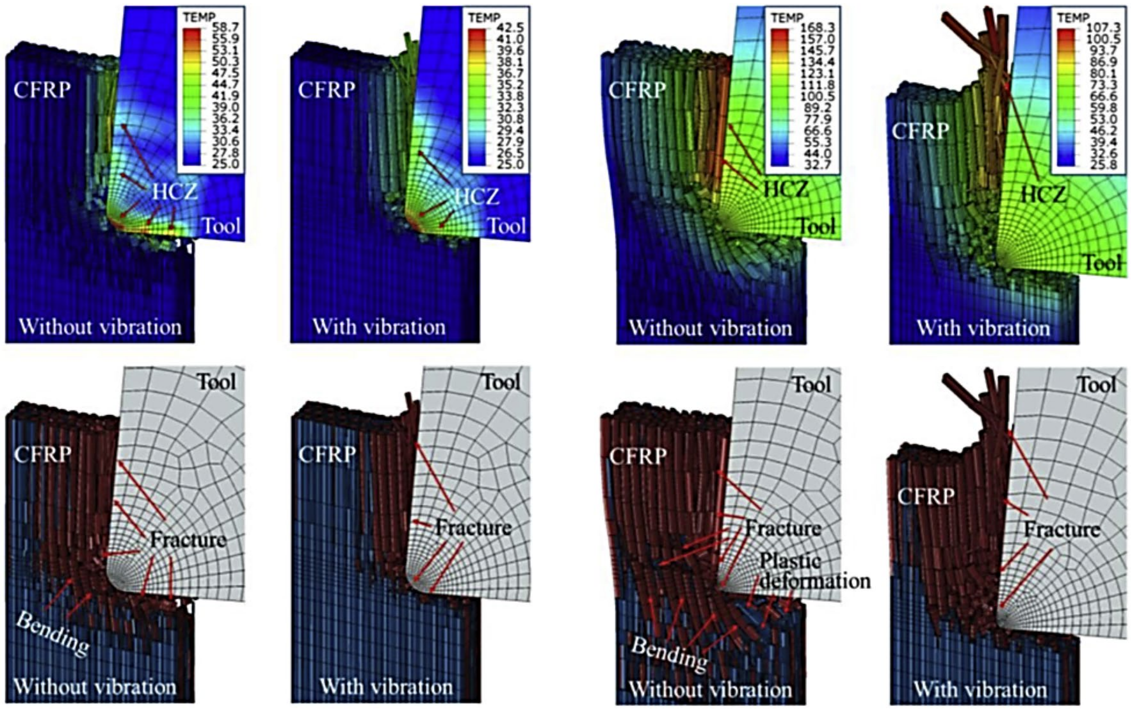

Fig. 7 Thermal softening of matrix-induced damage in CFRP orthogonal cutting [59]

the temperature of the coated tool dropped significantly, and the coated substrate was found to be 100 °C cooler than the uncoated. A coating was applied, however it had no effect on the coefficient of friction numerically. In addition, Table 2 summarizes the reviews of cutting force models to improve machining processes.

2.2 Chip Formation Models

The evaluation and simulation of finite element machining are novel topics. Using the FE analysis, critical production conditions such as temperature distribution, cutting forces, deformation rates, and chip formation may be calculated without the requirement for experimental investigations and observations. This situation reduces both the cost and the time allocated for scientific studies. Of course, it is not possible to give exactly the same results as experimental studies and computer studies, but scientists are bringing the results of their studies using finite element models closer to the results of experimental studies with each passing day. Thus, chip removal marshmallow studies with finite element models increase its reliability day by day (Fig. 8) [66].

When the machining is performed, it has been observed that the numerical analyses made by commonly DEFORM 2D-3D, ThirdWave AdtanEdge give very successful results. Especially on chip formation, studies comparing experimental studies and finite element simulation results have demonstrated this success. As seen in Fig. 9, the simulation is very similar geometrically to the sawdust obtained in the experimental study. Chip form, chip segments, pitch, and thickness are very close. In this case, finite element analysis and simulation with DEFORM 2D can give real results without the need for experimental work.

In machining, it is not possible to correctly examine the chip formation and chip shaping alone. This is because chip formation depends on many factors. However, when it is considered chip formation as a factor, this factor affects both the manufacturing process and the expectations from the product obtained. In this case, what is seen is that the machining process is like an equation with many unknowns, the purpose of this and similar studies is to contribute to the reduction of these unknowns and to reach a solution to the problem, in other words, to fully control the process inputs and outputs. Considering all these, not only chip formation, shaping, and breaking were examined in the literature research, but also interpretations were made considering the literature about the whole process. Today approaches to complete the production process in a minimum time have brought automation with it, in order to aim for the most ideal use of time and to be considered successful in the competitive environment in the production industry. As of the manufacturing perspective, the continuity concerning production is the highly critical condition for time-saving and more production. Some of the most effective circumstances impacting the continuity in machining is ensuring that the chip is broken regularly. Otherwise, there will be disruptions in the

Table 2 Reviews of cutting force models to improve the machining processes

[54]	Nimonic C-263 alloy as well as cemented carbide	Experimental study and analysis utilizing the finite element approach (FEM)	The validity of the model obtained corresponding to the outcomes of the FE analysis under the cutting conditions used was proven
[64]	Inconel 100 alloy	3D customized finite element simulations	Simulation estimates of typical grain sizes, form transformations, and microhardness obtained were associated with investigational quantities and it was stated that high accuracy was obtained
[55]	Inconel 718	Finite element modeling	An investigational survey was organized to confirm the finite element analysis effects, and a high degree of similarity was found when the results were evaluated
[56]	Inconel 718 alloys	Finite element-based hybrid model	Developed model can be used for materials that are difficult to process without the need for preliminary experiments
[57]	Inconel 718 alloy	Finite element modeling	Incredibly excellent settlement was discovered among the investigational and simulated outcomes in conditions of grain sizing, microhardness, as well as depth of the impacted layer
[58]	Inconel 718 and TiAlN coated carbide	Practical finite element analysis model	The established finite element prototype has proven the usability of difficult-to-machine materials without the need for experiments
[59]	CFRP	Finite element modeling	The thermal softening of matrix-induced damage in CFRP orthogonal cutting
[60]	CBN hard turning	Finite element modeling	Incorporate temperature-dependent thermal characteristics into the constitutive connection including strain, strain rate, and temperature
[61]	AISI 52100 steel	Finite element modeling	The thermal model was built on the use of superimposition methods and the discretization of main and secondary heat sources into tiny segments of rectangular heat sources
[62]	Steel D6	Finite element modeling	Changing the edge radius of the hone tools significantly influences plastic deformation and contact temperature
[65]	Inconel 100 nickel-based alloy	3D customized finite element simulations	Simulation estimates using the JMAK model parameter set determined on typical grain dimensions, form changes, and obtained microhardness were evaluated with trial quantities and a high degree of similarity was obtained

manufacturing process from time to time, and the cost will be reflected in the whole production. In this respect, ensuring the regular breaking of sawdust is an event that should be emphasized. Both industrialists and researchers have tried to find optimal solutions to this problem by making many experimental, analytical, and numerical studies about chip formation, effective factors in its formation, breaking, and active factors. Determining the cutting implement as well as cutting conditions are the highly essential operations in the planning of the manufacturing process. However, due to the importance of this process, the process is traditionally determined by planners using manufacturing manuals or tool catalogs. The process planner faces some difficulties during the manufacturing process. The reason for this is that there is not enough information about the features such as chip breaker channel structure and effective chip breaker for different materials, coatings, and high wear resistance of many advanced cutting tools that are widely used. In addition, the data on the performance of the manufacturing also take into account the results of measurements such as surface roughness, chip form, and cutting force, which is difficult to reach due to the very few predictive models for this information. In machining processes, chip control is considered as a few of the really crucial factors concerning good surface value and result quality, process safety, machine productivity, cost, and sustainable tool life. On the other hand, because the

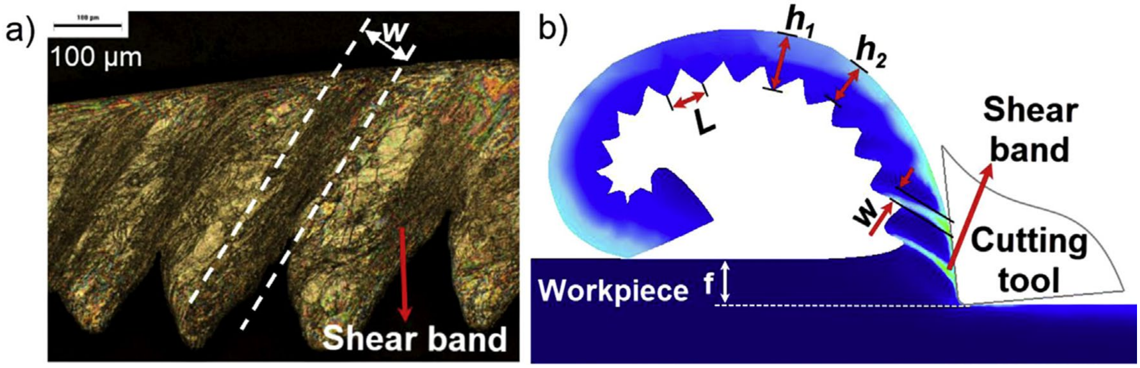

Fig. 8 Prediction of temperature and chip geometry during orthogonal cutting [66]

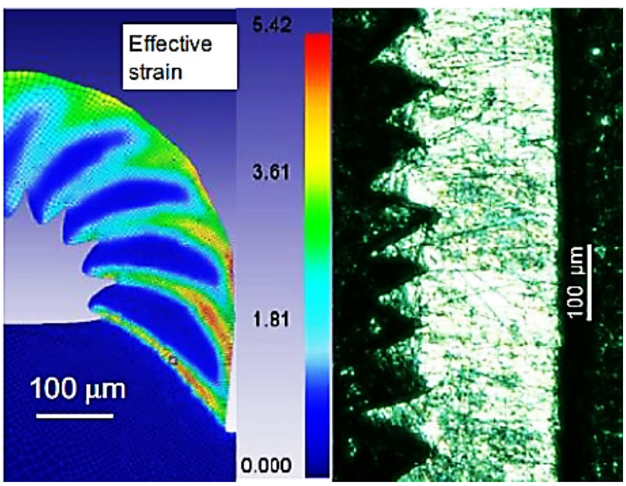

Fig. 9 Comparison of numerical work with DEFORM 2D with experimental work [67]

process is complex and requires complex cutting tools and extensive material changes; In many practical manufacturing operations, chip control has tended to be overlooked. The continuous impact of sawdust on the machined surface poses a problem in conditions of the value of the machined surface. This problem occurs especially in the finishing process. Considering that even small scratches on the manufactured part are a problem and the part is not accepted, for this reason, the importance of this situation can be understood in terms of professional production. If the part has a complex structure, the negative effect of chip collisions will be greater because of the height differences in each region and the drastic change in chip flow along with the workpiece profile [46]. Hagiwara et al. stated that the chip flow can be changed as convex and concave. In addition, they stated that this change was due to the change in cutting conditions and cutting tool geometry [46].

The various studies on chips morphology, software used, materials models etc are discussed here. Wu et al. [68], simulated the FE model concerning the cutting mechanism of diamond single-ended turning. The standard is centered on a meshing adaptive methodology along with a simple deformation system. In the chip forming model, they applied the traditional finite element model based on the chip disconnection principle. In the research in which the ABAQUS program was chosen as the software, the shape properties of chip formation were found to be compatible with previous studies. Albert Shih's [69], employed a material model in which the temperature is dependent on elastic/viscoplastic, high strain, and high strain rate in a work where he devised a finite element approach for the simulation of orthogonal cutting based on continuous chip creation. The authors presented the simulation results such as normal and shear stresses, temperature, and strain rate under the first and second deformation zones, as well as the machined surface, using the finite difference method to estimate the rate of change of time-dependent parameters and the Eulerian deformation definition to show the change of seven selected elements that will pass through the deformation zone. The chip generation was modeled using the finite element approach based on the separation between the elements in front of the cutting tool, with the element separation criteria being the distance between the cutting tool tip and the nearest node to the tip in the cutting direction.

Deshayes [70] modeled cutting tools with four different chip breaker geometries and three different cutting tool materials in his study. In this study, Third Wave AdvanEdge software was used for chip removal simulation, experimental study results and FE model study results were compared considering chip formation, forces, and temperature. This study showed that, it is possible to obtain findings close to the cutting force and chip formation obtained in the experimental study. Carroll and Strenkowski [71] compared two different orthogonal finite element models based on developed Lagrangian and Eulerian formulations, in which stress and stress zones in the chip and sample, chip shape, and forces of cutting acting on the cutting implement can be

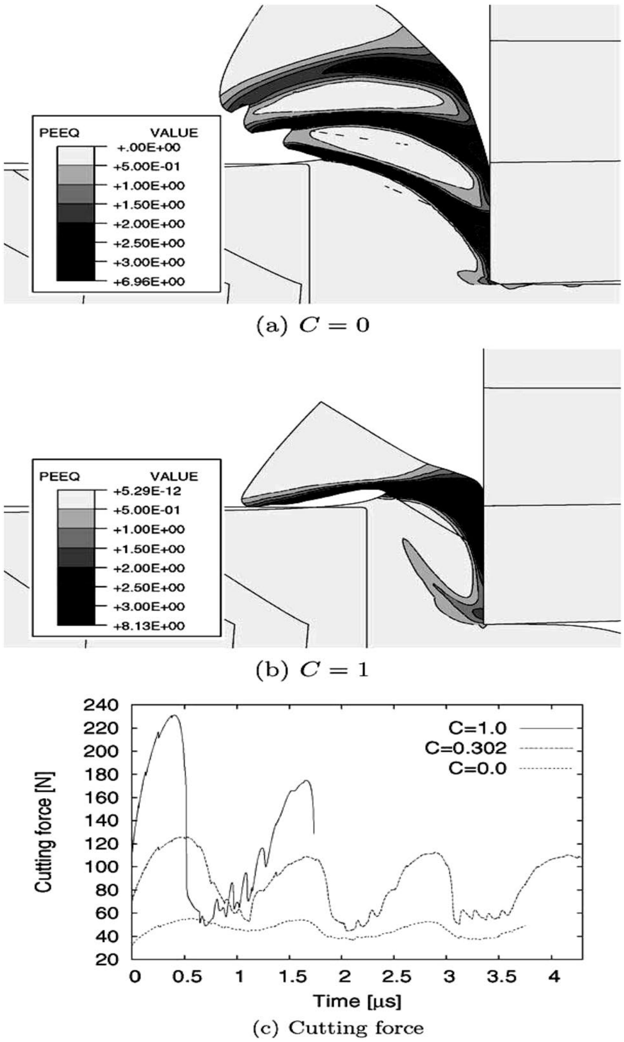

Fig. 10 Equivalent plastic strain and time-resolved cutting force for a variation of the strain rate hardening factor [72]

determined. In the model based on the developed Lagrangian formulation where large deformation takes place, they used the NIKE2D program with a finite element code containing an elastic-plastic material model, and in the Eulerian model, they used a viscoplastic material model of the specimen material in which the area around the cutting tool behaves like an Eulerian flow region. Baker [72, 73] created a two-dimensional finite element analysis model as shown in Fig. 10 to determine the impact of cutting constraints on cutting forces and chip development in the vertical cutting process. Friction is neglected when using the generative flow stress law for this model. The ABAQUS software program was used in this study, in which the two-dimensional full thermomechanical double implicit FE model was utilized as the finite element model. In this study, segmented chips were produced at high cutting speeds. Gu et al. [74] established a computer simulation of the machining of steels based on stable chip forming. In this study, the developed Lagrangian finite element approach is used with an aim of longest tool life and optimal cutting conditions by providing minimum cutting forces, minimum deformation, and lowest temperature. In the work of Aurich et al. [75], flow stress modification was performed using Rhim's material model. In this study, Aurich et al. presented the workpiece as a rigid plastic data and deformable structure. A continuous adaptive mesh refresh algorithm is used to remove chips from the workpiece. In this algorithm, shear localization and crack initiation and propagation methods are used and compared by adapting to continuous adaptive mesh regeneration. According to the results of the study, it was stated that the above-mentioned models could be used for uninterrupted and segmented chip development.

Umbrello et al. [76] utilized the J–C constitutive calculation, in which five different material constants were established, in the Lagrangian implicit network structure of DEFORM 2D software to express the behavior of AISI 316L material. In this study, cutting force, temperature distribution, chip geometry, as well as residual stress estimations were made and associated with investigational measurement outcomes. The model simulation findings obtained with the material constants used coincided with the results of the experimental studies. Baker [77] sought a solution to the question by using the FE model in his research in which he investigated whether chip formation slows down the machining process in machining. In this study, the two-dimensional FE model is built on the isotropic elastic plasticity theory, and the theoretical values are taken from Merchant's approach. Although the working deceleration criterion does not immediately affect the slip plane angle, it is presented as a result of this study, where it plays an important role in chip forming. MacGinley et al. [78, 79] applied a FE model to see the influence of coating on the machinability of Inconel material. In this study, the stress distribution with the FE technique was analyzed. The FORCE2 software was used in this study, in which the chip cutting tool contact point was predicted as the main slip zone, and the results are parallel to the experimental results. Lo [80] studied the influence of cutting tool rake angle on-chip and machined surface quality during precision machining. The effects of various rake angles on cutting forces, chip shape, equivalent stress distribution, residual stresses, and surface quality were explored in the cutting simulation. According to the findings, increasing the cutting tool rake angle reduced the amount of cutting force required for machining, resulted in a smoother chip formation, and resulted in a very tiny difference between the undeformed and deformed chip thickness. Yen et al. [62] conducted a study on the impact of cutting tool geometric parameters on chip formation and cutting forces in vertical cutting.. Using finite element

Table 3 Analyses of chip morphology models to develop machining processes

[68]	Diamond	Finite element model	The shape properties of chip development were found to be compatible with previous studies
[81]	AISI 1020 carbon steel	FE technique concerning the orthogonal cutting simulation	The chip structure was developed by means of the FE approach
[70]	Three different cutting tool materials	Finite element assessment	It is possible to obtain findings close to the cutting force and chip formation obtained in the experimental study
[71]	Aluminium 2024-T361	Two different orthogonal finite element models	Large deformation takes place
[72]	Titanium alloy Ti6Al4V	Two-dimensional finite element analysis models	Segmented chips were produced at high cutting speeds
[74]	Mild carbon steels	Computer simulation	The verification of the simulation study is done with the experimental study and verifiable results are obtained from the simulation
[75]	Copper, titanium and tantalum	Flow stress modification was performed using Rhim's material model	The mentioned models could be utilized for both constant and segmented chip growth
[76]	AISI 316L steel	J–C constitutive equation	The model simulation results obtained with the material constants used coincided with the results of the experimental studies
[78]	Inconel material	Finite element model	Results parallel to the experimental results were obtained
[80]	Copper (OFHC) and aluminum	Elastic-plastic finite element method	The growth in the cutting device rake angle caused a drop in the cutting force requirement for machining, a softer chip formation
[62]	Thermo visco plastic and 0.2% carbon-containing steel	Finite element simulation	The results of this study, in which the DEFORM 2D software program was used, coincide with the experimental study results in the literature

simulation, the influence of the cutting tool's corner (round and chamfered) qualities on chip formation, cutting forces, and process variables (temperature, stress, and deformation) was attempted to be determined. Cutting simulations using Lagrangian Thermo visco plastic and 0.2% carbon-containing steel were conducted out in DEFORM 2D until steady chip flow and cutting force were achieved. On the basis of the estimated cutting force and chip shape, finite element models for cutting tools with various corner angles were compared to experimental data in the literature. The results of this investigation, which employed the DEFORM 2D software tool, are consistent with the findings of previous experimental studies.

All the studies examined in the chip morphology section have shown that it is possible to achieve results that are compatible with experimental studies in the finite element model simulation. The precise determination of the appropriate inputs in the finite element model is the issue that should be taken into consideration here. The analysis of the chip breaker's performance is especially targeted in chip formation, shaping, and breaking. Thus, it is ensured that the sawdust is broken continuously and contributes positively to the machinability. In demand to achieve this, the geometric characteristics of the cutting tool must be best represented in the FE model. The only precision in reaching the goal is the analysis of the effect of the chip breaker geometric structure of the cutting implement on chip formation and breakage, that is, on the machining process. In this study, the necessary data were used in the finite element model, taking into account the experimental studies. Table 3 analyses of chip morphology models to develop machining processes.

2.3 Residual Stresses

Residual stresses are a system of stresses that occur in a body independent of external forces. In other words, residual stresses can be thought of as stresses that are not dependent on external forces. Since residual stresses occur due to non-regular plastic deformation, it is necessary to consider permanent stresses in all processes that produce irregular plastic deformation which may be thought as machining [82]. Recent trends have resulted in the development of a further approach that makes use of numerical models to estimate residual stresses. As a component of the hybrid process, calculating the mechanical and thermal stresses that are caused by chip formation and imposing an equivalent thermomechanical load on the surface of the item that has been machined are both included. Figure 11 illustrates this strategy used to measure the residual stresses. It was initially developed to anticipate increasing stresses during steel turning [83] and is now being used to forecast increased stresses

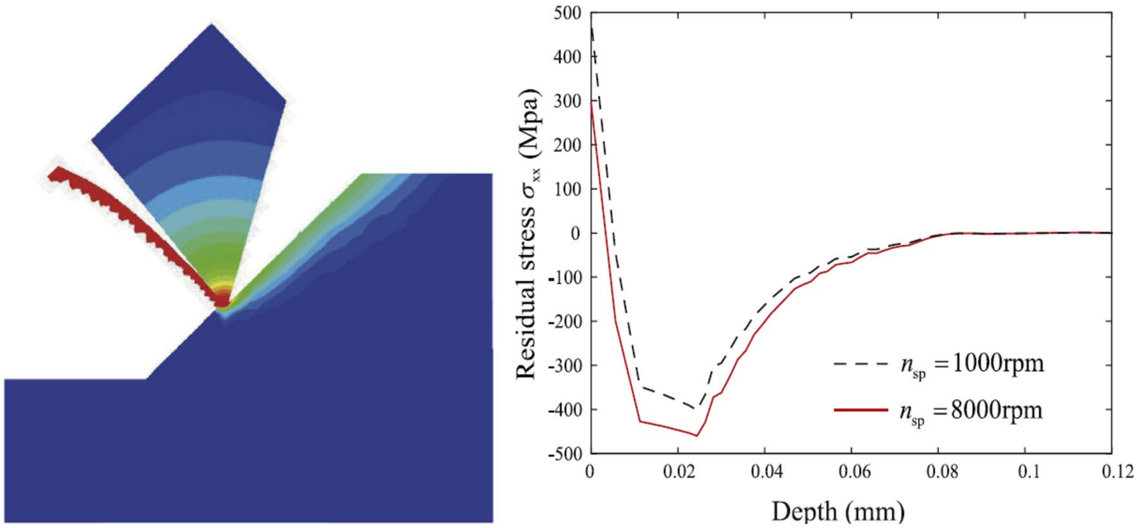

Fig. 11 Residual stress approach [83]

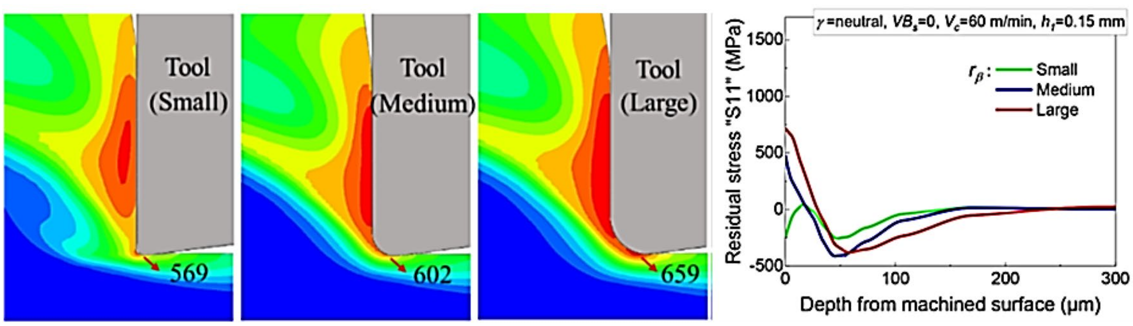

Fig. 12 Corner radius effect on the residual stress [86]

during steel ball-end milling. The anticipated and observed residual stress patterns were found to be in good agreement. The main advantage of this method is that it avoids the time-consuming simulation of chip production.

Further, in the case of residual tensions in aluminum alloys caused by machining, Denkena et al. [84, 85] done some research. The grinding-induced residual stresses in aluminum alloy workpieces were investigated using a combination of X-ray diffraction measurements and finite element simulations in these studies. The impact of cutting settings and tool shape was investigated. As demonstrated in Fig. 12, cutting speed, feed rate, and cutting edge shape all have an impact on residual stresses created during milling. Cutting speed and feed rate, which have a significant impact on residual stresses created during machining, were determined to be less essential than tool corner radius and tool wear. In any event, the effect depth is minor, remaining below 250 μm.

Mittal and Liu [87] worked on modeling residual stress in hard turning. The residual stress profiles were expected to suit a polynomial profile that was a function of the workpiece depth in the model. The polynomial coefficients are dependent on the processing settings. The calibration of a large number of coefficients is required for this model. Furthermore, it provided little insight into the development of residual stress. El-Axir [88] developed residual stress comparable to Sridhar [89]. Mishra and Prasad [90], using the principle of the moving heat source, created an analytical model based on FEM to calculate residual stresses. In a grinding process, the model tried to forecast thermal and mechanical residual stresses. The author examined how residual stresses are affected by the amount of the mechanical force, the rate of heat input, and the speed at which the workpiece moves. Lin et al. [91] determined the stress field in the workpiece by using the finite element technique. The idea of particle flow is utilized to calculate the stress history of the material's strain history using the strain field.

Table 4 The FE modelling studies on residual stresses in machining processes

[85]	Aluminum alloy	A combination of X-ray diffraction measurements and finite element simulations	Device corner radius along with tool wear were found to be even more important parameters than cutting speed and feed rate, which had a major influence on the residual stresses generated
[87]	Hardened bearing steel	Residual stress model	The model requires the correction of a huge amount of coefficients. In addition, it achieved no awareness into residual stress generation
[90]	100 Cr 6	Analytical model based on FEM	The model attempted to predict thermal in addition to mechanical residual stresses in a grinding operation
[91]	AISI 304	Finite element means to establish the stress field	Using the strain field, the idea of element flow is used to establish the stress record of the material's strain record
[95]	AISI 304	Finite element technique to ascertain residual stresses	Low shear angles and working angles have been identified as factors that increase positive residual stresses
[69]	AISI 1020 carbon steel	Plane-expansion finite element simulation	The model and experimental results matched each other, the model, like others, did not clarify causing thick stresses

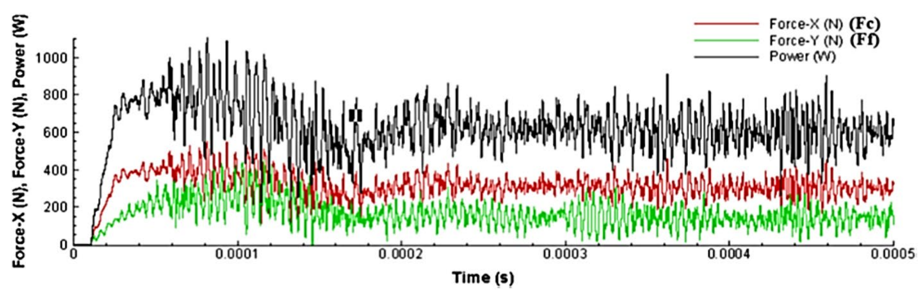

Fig. 13 The relationship between cutting forces and power consumption in FE simulation of machining processes [23]

The residual stresses induced by machining were estimated using Merwin and Johnson [92] was used to estimate the residual stresses produced by machining. Lin et al. [93] used a model that includes both thermal and mechanical stressors. The model's results were compared to the data from the experiments. Shear angle and other model boundary constraints are considered to take precedence. Lin and Lee [94] employed the same modeling technique as before, but added the impression of cheek wear. Wiesner [95] utilized a finite element approach to evaluate residual stresses arising from orthogonal machining of AISI 304 in a similar work aimed at determining the interplay between thermal and mechanical loads. A finite difference approach was used to compute constant workpiece temperatures. The model's results revealed that the thermal and mechanical consequences of orthogonal shearing resulted in tensile, or positive residual stresses. X-ray diffraction measurements of the treated samples were used to validate the model. According to research, the positive residual stresses are increased by low shear angles and working angles. Shih [69] created a finite element simulation of orthogonal metal cutting based on plane expansion. The study included thorough material modeling that took into account elasticity, viscoplasticity, temperature, huge strain, and high strain rate. By comparing the model to earlier research and comparing the experimental data, the model was shown to be valid. Despite the fact that the model and experimental data were identical, the model, like others, failed to explain what was creating the thick stresses.

Analytical modeling of the shear tool condition on residual stresses is still inadequate for use in industrial settings. Jacobus et al. [96] created models that need considerable model calibration based on shear experiments. Other approaches for estimating residual stress need a large amount of experimental data. FEM is frequently sufficient for estimating residual stresses, but it is time-consuming and difficult to adjust to changing process conditions. Analytical models address a wide range of residual stress sources and mechanisms that influence profile profiles. However, there is presently no complete model for predicting residual stresses that takes into consideration the tool edge state. Table 4 shows the FE modelling studies on residual stresses in machining processes.

2.4 Power Consumption

Power consumption during machining processes accounts for a significant amount of industrial expenses and has a significant environmental impact [97]. Machining limitations influence the amount of energy consumed throughout the evolution of machining. Adjusting these machining limits during the development planning phase would be facilitated

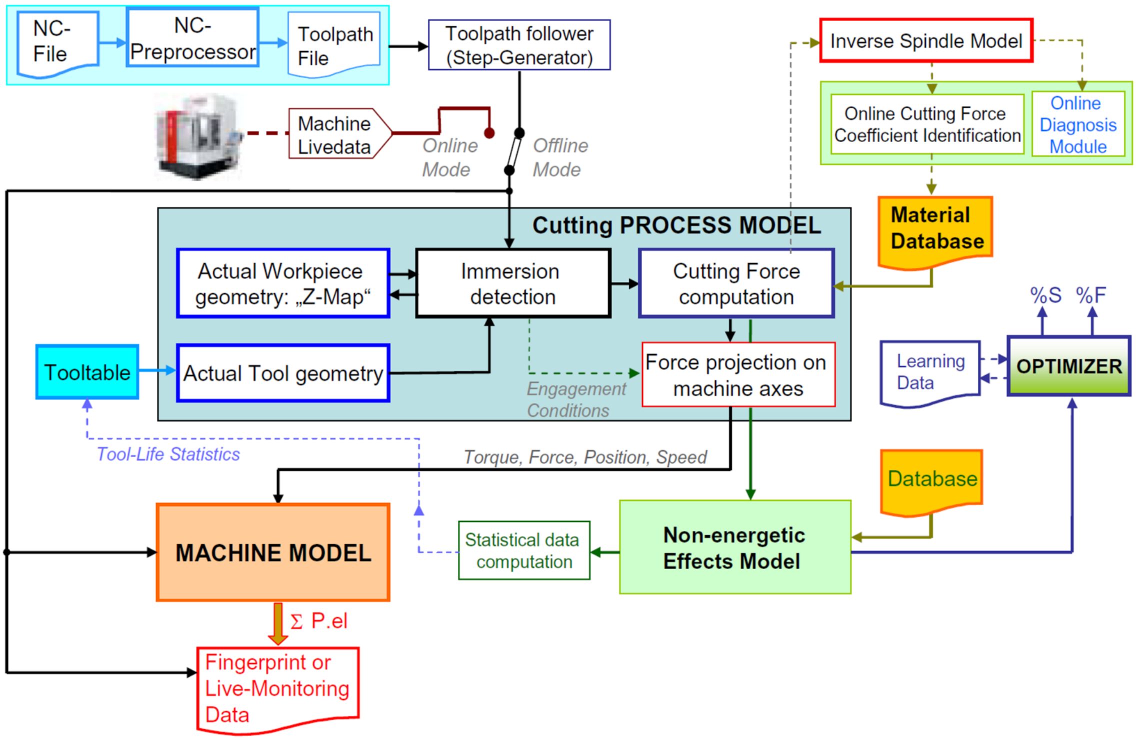

Fig. 14 The simulation prototype [106]

by a trustworthy expectation model for energy consumption, which would aid the manufacturing sector in achieving energy efficiency [98]. During the past years, and with the progressively serious power expenditure combined with ecological difficulties within the manufacturing sector, the machining procedures power utilization became a serious concern within the discipline of environmentally friendly manufacturing [99]. This machining procedure implies the procedure of replacing the empty size, structure, shared place, coupled with surface excellence through machining, to get a competent element [100–102]. Nevertheless, during the earlier period, it remained constantly believed that the power utilization concerning machining apparatus within distinct manufacturing remained comparatively modest associated with the development of industrial sectors. Consequently, researchers, as well as the industries, give inadequate consideration to the power utilization as well as effectiveness regarding the machining procedures, leading to the absence of important investigation [30, 103]. The relationship between cutting forces and power consumption in machining processes are commonly indicated as in Eq. 5. Moreover, the relationship between them are llustrated in Fig. 13.

$$P = Fc * V/60 \tag{5}$$

Kant et al. [104] investigated power consumption limiting by enhancing and predicting machining parameters. Their research aimed to supply a multi-predictive objective simulation concerning the limitation of energy depletion as well as surface roughness during machining procedures. They used a principal element analysis besides a relational grey analysis in the manner of acquiring the ideal machining constraints. They stated that the feed is the main factor affecting the machining power expenditure reduction followed by cutting depth then cutting velocity. Moreover, the peak load lessening via optimization will lead to power utilization of the machining tools dropping [104]. Larek et al. [105] developed a discrete simulation model to forecast power utilization during machining activities. The approach was designed to demonstrate machining processes as well as to produce sample-certain energy expenditure profiles along with energy traces. Their the objective was to offer a foundation regarding additional products like the simulation as well as energy intake optimization within production procedures and operation chains in arrangement with logistical simulations. The simulation standard expressed in their study was meant to be applied concerning the approximation of the machining process's power expenditure in addition to examining the impact of machine device elements coupled with procedure constraints to produce a particular specimen energy track. The authors emphasized that the attained power

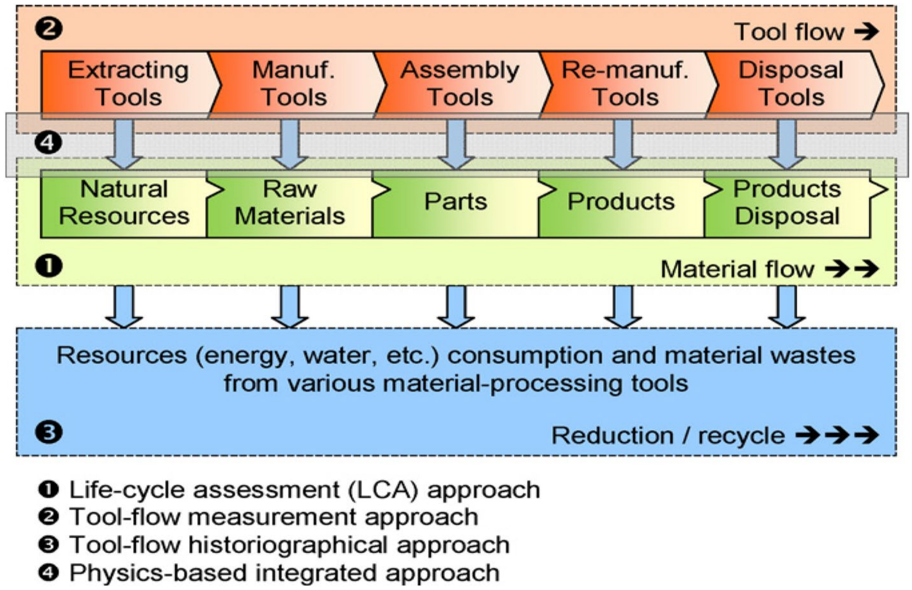

Fig. 15 Categorization of power modeling [109]

utilization reports precision was sufficient to be employed by concerning the cost optimization as well as an environmental influence [105]. Abele et al. [106] instituted a simulation prototype concerning the prediction of machine devices' power consumption. The paper describes a standard-established simulation plus estimation of the expected energy utilization regarding machine instruments by utilizing a complete simulation setting, which in turn provides a foundation concerning energetic enhancement. Built on the stated simulation methodology, in additional investigation effort, a structure concerning power optimizer was established, adjusting the spindle velocity, feed rates, coolant lubricant amounts in addition to changing conditions of peripheral appliances to the expected situations. The simulation model is displayed in Fig. 14 [106].

Meng et al. [107] established a power utilization prediction model concerning machining procedures. The model is offered for a purpose of cutting velocity, spindle velocity, the cutting depth as well as feed rate. Turning tests were performed to corroborate the suggested model efficiency. The authors stated that the model presents further precise power expenditure estimation when compared to the models that take into account only MRR plus spindle velocity. Consequently, they added that the energy requirement concerning cutting procedures could be effectively attained via employing such a model, which in turn could assist technologists to estimate the power utilization regarding their products at the early design phase [107]. Bhinge et al. [108] considered the development of a power calculation model concerning machine instruments. Initially, they introduced a procedure that could professionally as well as successfully gather and manage information obtained from a machine instrument in addition to its sensors. They stated that some considerations could probably influence the power consumption form during machining tasks. For instance, the sample substance or cutting device geometry, as well as substance, could alter this consumption. The power prognostication model could be more advanced plus simplified by incorporating these factors as key elements [108]. Bi and Wang [109], investigated the consumption of power during machining operations. An analytical power model concerning the precise associations of machining constraints as well as power utilization was examined, the modeling technique was established for both the dynamic plus kinematic machine tools actions. The main aim of this advance model was to enhance the energy saving of the machining process. The simulation findings imply that the enhancement model could cause a 67% power reduction regarding the particular drilling procedure. The authors implied that this methodology could be expanded in addition to utilized to additional machines in the matter of establishing their power models intended for viable manufacturing [109]. The categorization of power modeling is represented in Fig. 15.

Guo et al. [110] created a simulation model to evaluate the power utilization of certain machining instruments. To improve the power preservation of machine implements, a control-method-established approach, which combines substance elimination simulation to foresee the power utilization concerning machining procedures, was intended then confirmed during their investigation. The authentication findings suggest that via employing the established methodology, the machining power of a certain product could be forecasted precisely in a 10% divergence. Furthermore, the assessment reveals that further power-conserving possibility remains in constraint assortment. Consequently, utilizing the established simulation methodology could accelerate the

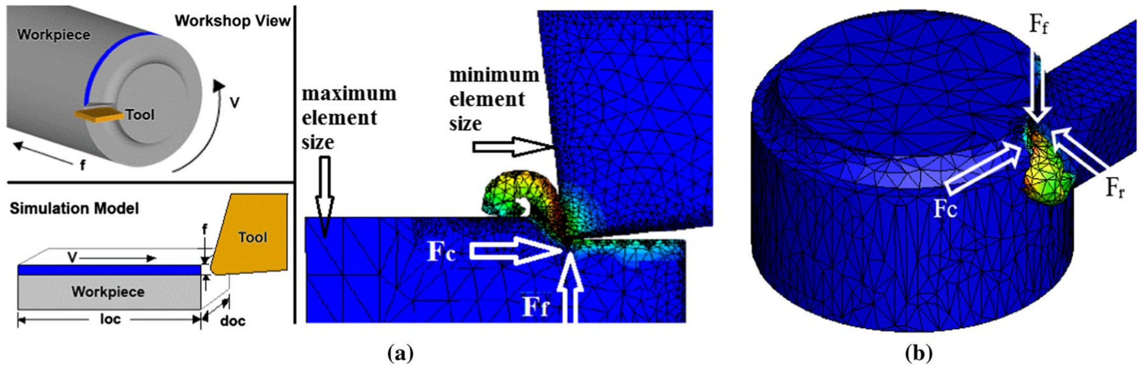

Fig. 16 Cutting system concerning the 2D and 3D simulations [23]

method development as well as improve the power preservation concerning various machine instruments in a way that the ecological influence of manufacturing procedures could be efficiently decreased [110]. Borgia et al. [111] developed an investigation research to foresee the power consumption upon milling processes by using a simulation model. Power models were characterized via an investigational classification process that could be implemented in manufacturing situations. The model was proven by evaluating the assessed power with the calculations presented on various cutting experiments, assessing as well its computational attempt [111]. Korkmaz and Günay [23], developed a finite element model regarding energy utilization within the turning procedure concerning. The FE model was chosen to approximate optimal cutting factors concerning less energy utilization. Incidentally, FE simulations were accomplished centered on three distinct stages like the cutting speed, cutting depth, coupled with feed rate. The authors stated that the cutting depth is the highly significant component having a 49.55% contribution ratio regarding energy expenditure. They emphasized that the FE model concerning the cutting forces combined with energy expenditure was fairly consistent with the investigational findings. Likewise, it could be completed with superior correctness, not including unnecessary machining tests of tough-to-cut substances. The cutting system concerning the 2D and 3D simulations is shown in Fig. 16 [23].

Liu et al. [112] also studied the power utilization of machining operations via FE models. In their research, the curved microgroove constructs were enhanced plus constructed to help enhance the cutting functioning concerning reducing particular cutting power. The outcomes showed that constraints of the micro-groove, involving the spacing, width, edge gap, and depth demonstrated apparent impact on certain cutting power within their particular aspects. Furthermore, the particular metal cutting processes cutting power could be successfully decreased via the ideal curved micro-grooved cutting implements. Besides, the smallest certain cutting power expenditure was achieved at a width of 50 μm of the microgroove. But during the turning ending situation, the greater the width of the micro-groove, the greater particular cutting power was achieved [112].

The optimization of power consumption is considered an important field of study to several researchers due to its influence on the machining operation of different types and materials. Investigations were carried out on the machining parameters that lead to a critical impact on the energy consumption during machining processes. Different models including FE simulation models were developed to predict the influence of such parameters to enhance them before machining processes. Some studies have shown that decreasing the peak load optimizes power consumption, others indicated that the bigger the micro-groove, the better the consumption, while certain findings suggested that the improvement of cutting parameters is critical. Table 5 illustrates the FE modelling studies on power consumption during machining processes.

2.5 Surface Integrity

The surface integrity of a manufactured metal component is essential for its work-related usability, durability, and overall application. The surface flaws caused by machining techniques progress from the nano to the macro scale, resulting in mechanical, microstructural, and chemical effects. Therefore, they necessitate complex assessment and post-management techniques [113]. Surface integrity indicates surface finish off along with the diverse manufactured surface circumstances. It could be separated into the quality of the surface combined with the subsurface situations concerning the machined element [114]. Moreover, machined surface integrity is turning out to be further critical to fulfilling the ever-increasing requirements of superior element execution, durability, efficiency, along dependability [115]. Jawahir et al. [116] carried out a review study concerning the surface integrity during substance removal procedures.

Table 5 The FE modelling studies power consumption during machining processes

[104]	AISI 1045 steel	Principal element analysis besides a relational grey analysis	The peak load lessening via optimization will lead to power utilization of the machining tools dropping
[105]	TiAN	A discrete simulation model to forecast power utilization	The attained power utilization reports precision was sufficient to be employed concerning the cost optimization as well as an environmental influence
[106]	Different machine tools	Simulation model	The model provides a foundation concerning energetic enhancement
[107]	Cutting tools	Power utilization prediction model	The model presents further precise power expenditure estimation when compared to the models that take into account only MRR plus spindle velocity
[108]	Machine tools	Power calculation model	The power prognostication model could be more advanced plus simplified by incorporating these factors as key elements
[109]	Machine tools	An analytical power model	The authors implied that this methodology could be expanded in addition to utilized to additional machines in the matter of establishing their power models
[110]	Machine tools	A simulation model to analyze the power consumption	Utilizing the established simulation methodology would accelerate the method development as well as improve the power preservation concerning various machine instruments
[111]	Machine tools	Power simulation model	The model was proven by evaluating the assessed power with the calculations presented on various cutting experiments
[23]	Martensitic stainless steel AISI 420	Finite element model for power consumption	The FE model concerning the cutting forces combined with energy expenditure was fairly consistent with the investigational findings
[112]	Curvilinear micro-grooved cutting tools	Power utilization of machining operations via FE models	During the turning ending situation, the greater the width of the micro-groove, the greater particular cutting power was achieved

The study includes several investigations on surface integrity using different models including those based on finite element aspects. The subsequent assumptions could be illustrated from their research and they found a reduction in the usage of analytical-established models concerning the metal cutting estimation behavior when associated with the usage of FEM-established models. In addition, nearly 90% of utilized FE software during the current cutting simulations were profitable. Additionally, they detailed that it was so hard to assess the finest FEM software subsequently they include numerous strictures besides expectations that influence the validity [116].

Wardany et al. [117] Researched the surface integrity of die substance during elevated velocity machining. A 3D FE standard was established to foresee the specimen's surface residual stresses. Within the model, the cutting area was given centered on the device state (for instance, sharp or damaged). The FE assessment reveals the substantial impact of the heat produced through the cutting process. The findings also demonstrate the probability of decreasing the elevated tensile produced residual stresses within the sample

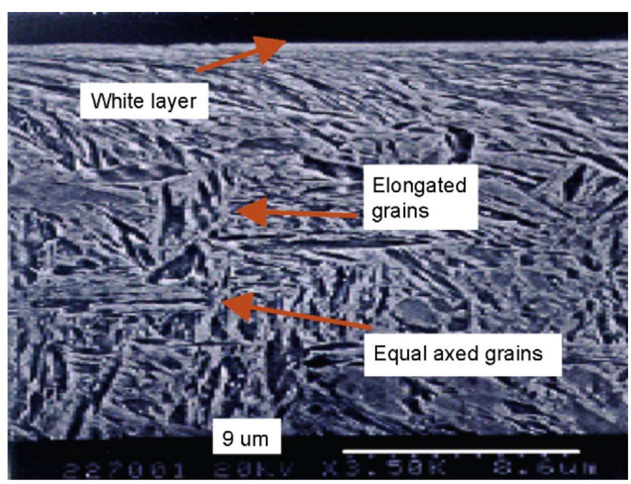

Fig. 17 White cover as well as distorted layer [120]

surface, via choosing the proper cutting depth of cut [117]. Arrazola et al. [118] conducted tests to predict the surface integrity behavior of IN718 nickel-established alloy via FE

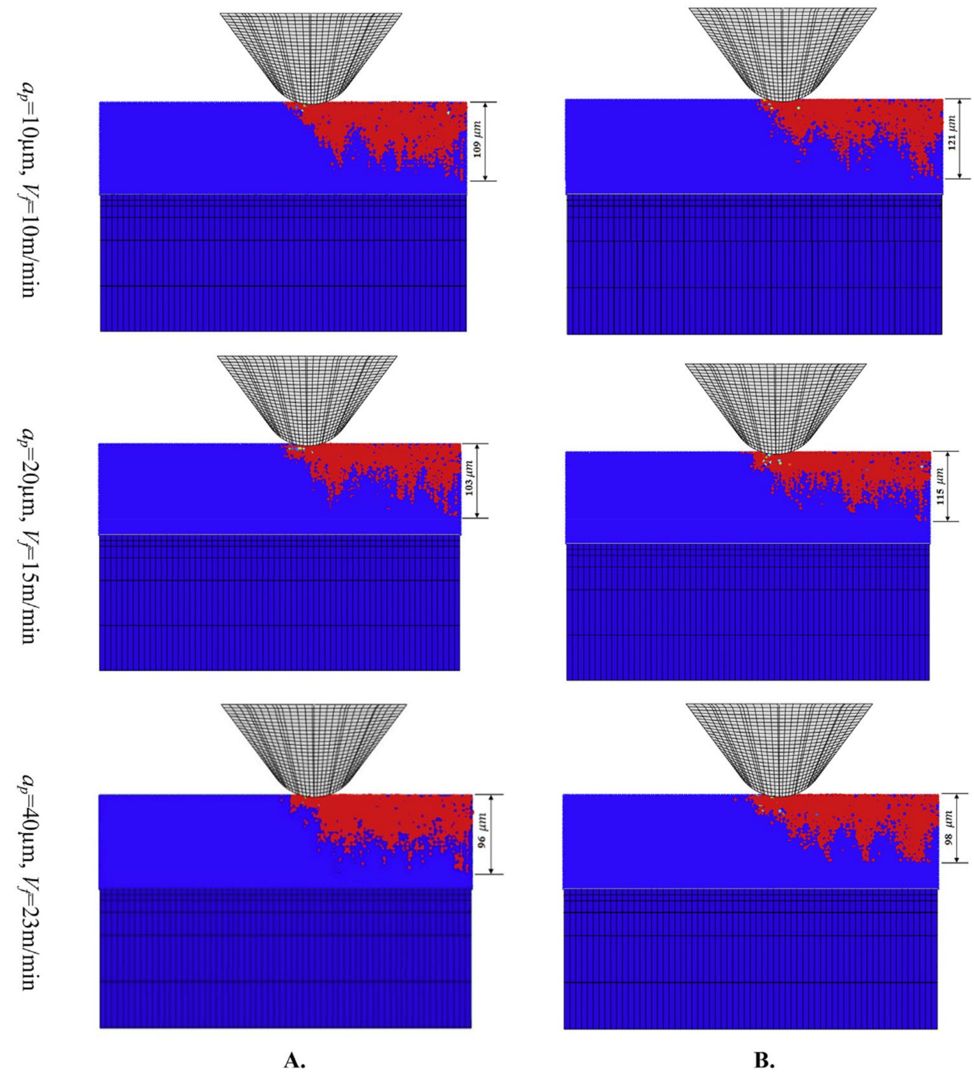

Fig. 18 Horizontal cross-segment concerning the outcomes of the mathematical simulation in conditions of surface destruction intensity: **a** metal, D125, 50, plus **b** resin, D125, 100 [121]

simulation model. The major techniques concerning the residual stresses quantifying incorporating diffraction methods were examined. The authors indicated that the stress estimates have considerable alterations concerning the FE simulation standard could be obtained, also the consequent surface integrity could be well characterized. Thus, expected residual stresses at every position of the depth were presented within an interval having a standard deviation besides an average [118]. Lotfi et al. [119] Studied the surface integrity behavior of Ti6Al4V by conducting FEM modeling and investigational tests. Consequently, results showed that the 3D vibration technique produces a lesser grain range to be produced associated with the standard procedure. Additionally, such a technique can enhance surface isotropy via semi-spherical micro-surface production. Furthermore, the simulation standard can appropriately expect the grain range plus the cutting forces wherever its conclusions were in a great deal with the tests [119]. Ranganath et al. [120] established a FE simulation methodology to calculate the growth of a white sheet within nickel superalloys. A section-wise J–C prototype was assembled meant for illustrating the performance of the substance flow. Chips forecasted and accumulated throughout impertinent turning experiments reveal an obvious shear band still at low velocity. The deformation layer in addition to the white layer appearance is shown in Fig. 17.

Khodaii et al. [121] examined the impact of grinding on the PSZ surface integrity by numerical, analytical, as well as investigational experiments. A numerical model was accomplished within the ABAQUS Software through the attached FE—flattened element hydrodynamics (FE-SPH) technique. The outcomes demonstrated that, during all instances, the investigational information dropped in the scales assessed by the analytic method. Additionally, the mathematical simulation unveiled that, on standard, the mathematical findings varied as of the corresponding investigational statistics by fewer than 15%. Analysis of SEM pictures concerning the base surface revealed further than 17% progress within the surface integrity [121]. The horizontal cross-segment concerning the outcomes of the simulation model is shown in Fig. 18.

Maximov et al. [122] used various approaches of FE simulation models concerning mechanical static surface management methods. The FE model is a simple simulation technique applied during the mathematical examinations of MST procedures. It was revealed that a completely attached 3D FE thermal-stress assessment of an SDB procedure in conjunction with kinematic nonlinear strengthening must be brought out. Moreover, as the burnishing speed was fairly little, the thermal impact could be ignored [122]. Maranhão and Davim [123], studied the machining surface integrity behavior of AISI 316 steel by performing a FE simulation model. As of all the mathematical models that have been done, it was feasible to retract that the coefficient of friction affects the cutting energy, highest cutting temperature, cutting, as well as feed forces, along with plastic strain considerably. Regrettably, the coefficient of friction could not be determined with accuracy besides it requires to be repeated. The authors added that by utilizing the testing experiments, a Coulomb coefficient of friction was observed regarding every instance of the research. They concluded that applying the numerical simulation was effective to control the mentioned constraints above. In addition, FEM calculations were significantly affected through the coefficient of friction as well as the substance movement stress, nevertheless, the coefficient of friction was the highly critical characteristic while developing machining processes [123].

The enhancement of surface integrity-related constraints is deemed an essential requirement throughout numerous machining developments. Various machining circumstances affect such as the cutting depth, velocity, feed rate, etc. enhancing these parameters will lead to better surface

Table 6 The FE modelling studies on surface integrity after machining processes

[116]	Crystalline materials	Different models include those based on finite element aspects	It was so hard to assess the finest FEM software subsequently they include numerous strictures besides expectations that influence the validity
[117]	Steel (60–62 Hrc), Polycrystalline Cubic Boron Nitride (PCBN)	3D FE model was established to foresee the specimen's surface residual stresses	The probability of decreasing the elevated tensile produced residual stresses within the sample surface, via choosing the proper cutting depth of cut
[118]	IN718 nickel-established alloy	FE simulation model	Expected residual stresses at every position of the depth were presented within an interval having a standard deviation besides an average
[119]	Ti6Al4V	FEM modeling and investigational	The simulation standard can appropriately expect the grain range plus the cutting forces wherever its conclusions were in a great deal with the tests
[120]	Nickel superalloys	FE model methodology	Chips forecasted and accumulated throughout impertinent turning experiments reveal an obvious shear band still at low velocity
[121]	Bioceramic partially stabilized zirconia	numerical, analytical, as well as investigational experiments by FE models	Analysis of SEM pictures concerning the base surface revealed further than 17% progress within the surface integrity
[122]	37Cr4 steel	FE simulation models concerning mechanical static surface management methods	The burnishing speed was fairly little, the thermal impact could be ignored
[123]	AISI 316 steel	FE simulation model	FEM calculations were significantly affected through the coefficient of friction as well as the substance movement stress

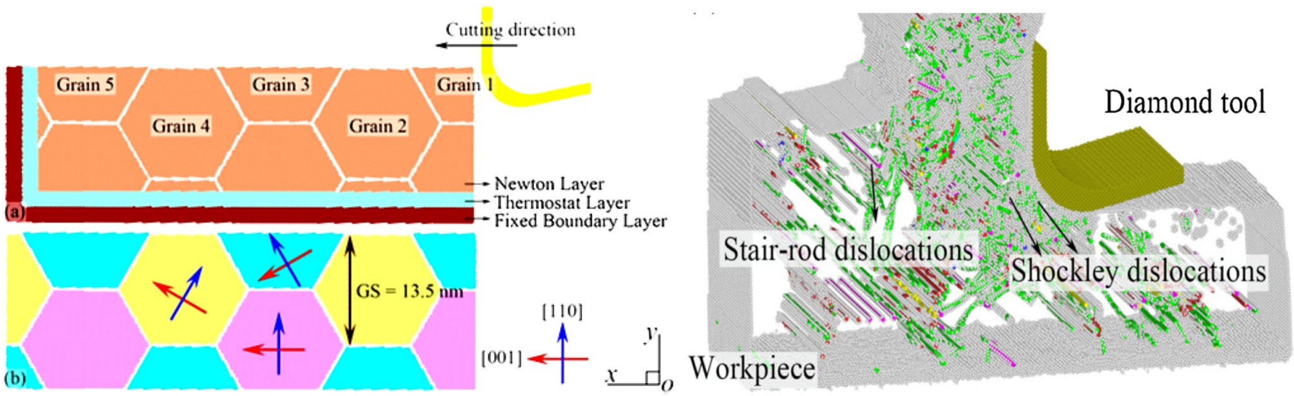

Fig. 19 Molecular dynamics simulation (MD) for nanocutting [124]

integrity throughout the machining operation. For this purpose, many studies were carried out to investigate these parameters via various prediction models including FE simulation models in the manner of finding concerns that may affect the machining process and enhance them before the operation. Such a simulation model will help find the product effectiveness, stability, as well as trustworthiness. Table 6 demonstrates the FE modelling studies on surface integrity after machining processes.

3 Molecular Dynamic (MD) and Smoothed Particle Hydrodynamics (SPH) Simulation

Molecular dynamic is one of the main tool in the theoretical studies of the dynamic behavior of biological and chemical macromolecules. With this computerized computation method, the time dependent behavior of a biomolecular system is calculated. Atoms can interact with each other using potential energy functions based on experiments and observations or various force fields selected depending on the field of study, and each force acting on atoms is calculated for a particular configuration based on these functions or force fields. By integrating Newton's equation of motion, a sequential configuration of the system over a given time interval is obtained [124].

Molecular dynamics simulation (MD) is a powerful technique for modeling shearing at the nanoscale (Fig. 19). However, here is the concern with this process (i) the availability of correct potential energy surfaces, (ii) the need to use high shear rates (100–500 m/s), and (iii) the consideration of fewer workpiece atoms (several thousand). The last two are used to keep accounting time at an acceptable value. Concerns brought by these limitations have led many researchers working in this field to think of simulating chip removal at nanoscale for larger workpieces (a few million atoms and more) and conventional cutting speeds (2–5 m/s).

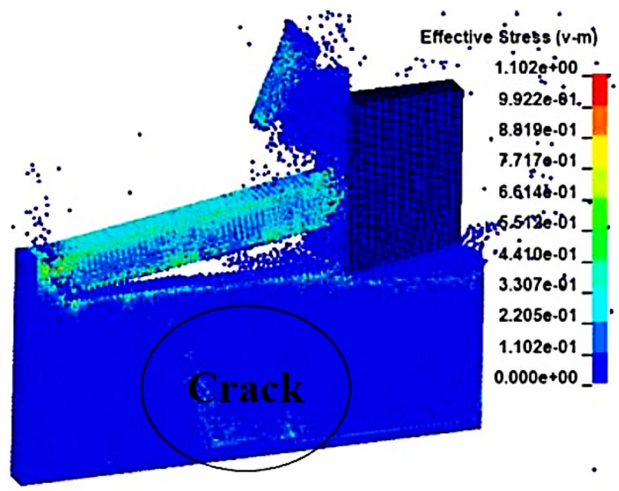

Fig. 20 The cutting process simulated using smoothed particle hydrodynamics (SPH) [125]

Currently, it is not possible to perform MD simulation using even the fastest computers equipped with powerful parallel processors. As a solution to overcome the last two of the above limitations, Monte Carlo (MC) method is used since time or cutting speed is not directly involved in the process. At the same time, some of the detailed time-consuming calculations in MD simulations are useful, albeit a small part. For example, no detailed information about the precise motions of atoms at the time before they reach their equilibrium positions may be of any importance. This way, valuable computation time and memory can be used sparingly if we use a method that does not include trivial matters.

Consequently,

1. Monte Carlo simulation of the nanometric cut is optimally run at a cutting rate of 1–5 m/s. The Monte Carlo method combines Markov random measurement with the Accept-Reject Metropolis-Hastings adapted for use

with temperature gradients to determine new shapes of atoms.

2. In Monte Carlo and molecular dynamics simulations of nanometric cutting, the temperature in the cutting zone will be estimated at the macroscopic scale using the thermal model of the cutting process developed by Komanduri and Hou. There is a very good similarity between the results of the thermal model and the results of the molecular dynamics simulation obtained using harmonic oscillator energy distribution. This local temperature was used in the Boltzmann Accept-Reject criterion. Therefore, the cutting speed is indirectly included in the Monte Carlo simulation through the temperature in the cutting zone, as the cutting speed is related.
3. The forces obtained from the Monte Carlo calculations, as expected when comparing the Monte Carlo and molecular dynamics simulations of the nanometric cut, resulting in fairly good fit under similar cut conditions, it exceeds the results obtained from molecular dynamics simulation due to the presence of inertial forces in molecular dynamics simulation and the long depth of cut for Monte Carlo studies.

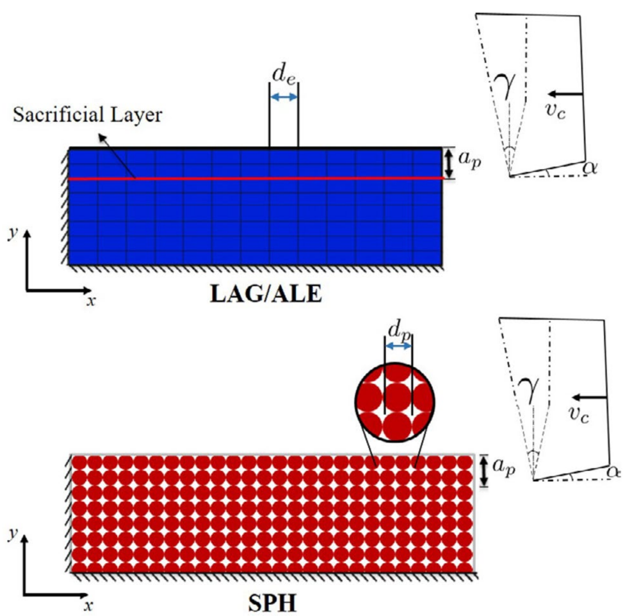

Fig. 21 The difference between Lagrangian (LAG), ALE, and SPH method [32]

On the other hand, a direct view into the machining process is provided by numerical simulation, which is capable of obtaining transient stresses and strains as well as revealing the chip creation mechanism. However, mesh deformation is common when using finite element methods to simulate hard-brittle materials. The cutting process is simulated using smoothed particle hydrodynamics (SPH) (Fig. 20), a mesh-free approach. When compared to the finite element method, the SPH method has an advantage in that it does not require a rupture criterion to separate the chip from the workpiece [125]. Figure 21 shows the difference between Lagrangian (LAG), ALE, and SPH method [32].

4 Challenges and Trends

When it is taken into consideration the trends and challenges that may face machining processes, Mourtzis et al. [126] suggested several opinions, initially, they stated that creators of simulation devices are progressively establishing cloud-established knowledge to simplify the application's flexibility as well as the interoperability among various collaborators. Moreover, they indicated that simulation software devices typically present just devoted product purpose records concerning fast development combined with capable simulations regarding conventional situations. Likewise, there is similarly a shortage of appropriate information discussion between distinct fields as well as little or even no general principles or incorporated structures, which produce problems within the cooperation among organizations in addition to collaborators. Ultimately, they assumed that all the concerns can be forwarded through the growth in addition to the consumption of multi-corrective combined with multi-field incorporated simulation models [126]. Mourtzis [127], also investigated the future machining simulation trends. Specific emphasis was provided to tools within the future digitalized sectors that are achieving a position in the field of industrial products simulation, presenting several benefits. The author represented the advantages, constraints, along with potential challenges presented by the latest simulation methodologies as shown in Fig. 22 [127].

Machine implements require correct work as well as good dynamics in the manner of keeping up with the innovative machining procedures conditions. Above and beyond the technological concerns, period to the marketplace is overly brief to create a true model in the potential future. A new method for predicting the machining behavior is therefore needed by cooperation between different models including FE simulation models. Zaeh and Siedl [128], suggested a new approach meant for machining behavior simulation by employing FE modeling concerning machine implements. The sequence of both a finite element technique in addition to a multi-body simulation within a single procedure offers the foundation when it comes to the simulation of huge activities as well as the functioning concerning machine implements [128].

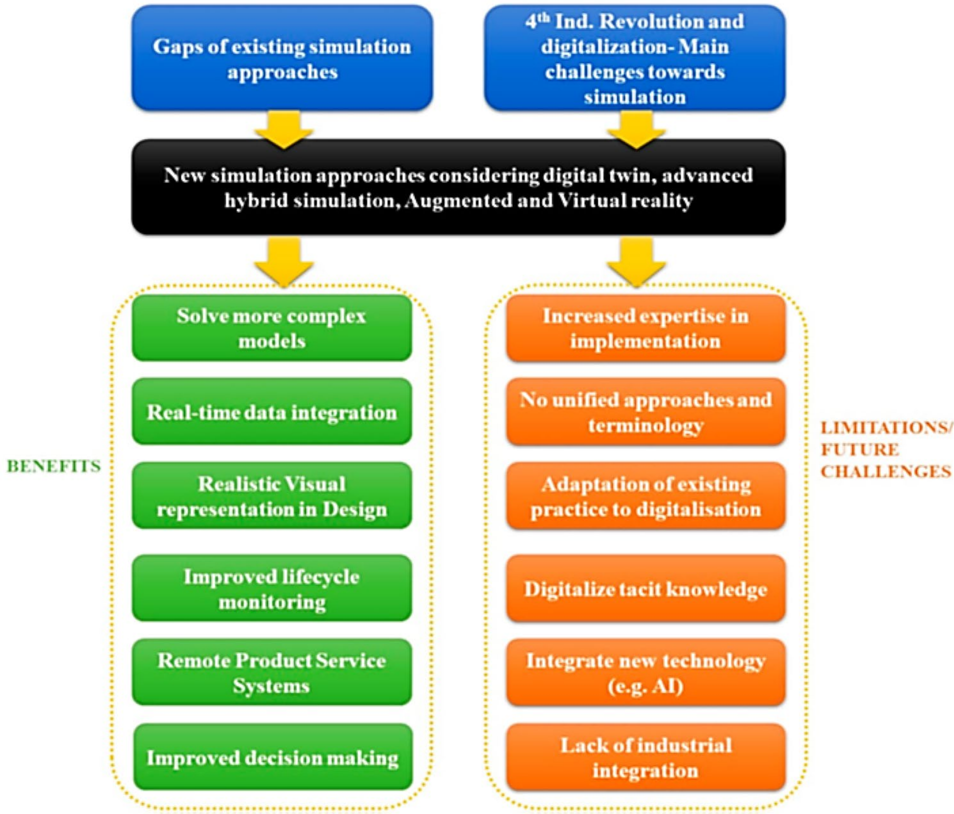

Fig. 22 Advantages, constraints, along upcoming questions as presented through the latest simulation models [127]

Currently, most FE simulations develop modern knowledge concerning the machining procedure into construction. Nevertheless, prospects occur to be examined, taking into consideration a structural approach, exactly how the substance performs throughout machining. A few of these concerns were discovered in the following portion. Athavale and Strenkowski [129], stated that FE simulations offer an approach to improve the basic knowledge necessary to explain complicated machining as well as tooling difficulties. Though, this knowledge had a restricted workable benefit except it could be prepared concerning answering sensible manufacturing difficulties. Consequently, it is important to incorporate these FE simulations in addition to additional machining development simulations including CAD/CAM technology [129]. Dixit et al. [130] recommended that the subsequent arguments should be under a specific understanding by the investigators: The impact of hardening performance on the anisotropy improvement was not examined significantly. In the field of machining, developing constitutive simulations concerning the machining of composite substances are needed. The collapse principle regarding composite structures is distinct from other conventional metals. They also stated that certain attempts were done during the modeling of composite substances [131, 132]. As well, there is an opportunity to identify the materials fracture performance in support of forecasting the metal forming faults in addition to the machining operation. A wide-ranging analysis of the growth of faults is missing. Likewise, they included that the subsequent investigation fields would be leading shortly:

Metallurgical characteristics are integrated within the notion of plasticity. Numerous ideas were developed to produce fundamental models [133, 134]. Nevertheless, there are several difficult problems taking part in the application of crystal plasticity FE simulations. Micro in addition to nanomanufacturing operation modeling is another field of interest. Numerous crystal plasticity models are appropriate concerning significant distortion only [166]. Size impacts could be presented into FE simulations of crystal plasticity via applying phenomenological strain grade assumptions [130, 135, 136]. Jayal et al. [137] analyzed ecological manufacturing trends via modeling along with optimization tasks. They stated that mathematical approaches, for example, FE simulation, suggest substantial ability concerning the machining processes modeling owing to their capability to grip multifaceted geometries [138]. The contemporary effort includes the improvement of further convincing FE simulations to examine 2D machining residual stresses [137].

5 Conclusions

The following outcomes were obtained from this critical review:

- Good number of quality characteristics have been widely investigated with several modeling approaches to this date. They can be sorted as the workpiece based properties such as surface integrity, dimensional accuracy and cutting tool based specifications such as tool life and wear texture. Since machining operations stand as the final station of a long journey of the product, minimum error and high-quality work are the primary necessities. From this point of view, becoming popular of these approaches can be clearly understood.
- Developing mechanistic models require time and experience which makes it also costly method. Owing to their complexity and deep-knowledge requirements especially for specific applications cause limitations in industry. Therefore, basic issues need to be understood for wider usage of these methods.
- Since the modelling approaches aim to reflect the actual conditions, there are numerous details in developing such models which requires to understand the physical phenomena of the shop-floor conditions. There is a need for collaborations between industry and academia including operator, researcher and engineering experiences.
- One of the significant problem of developing of models in machining processes is the lack of knowledge of constitutive properties of the materials. There is a need for a comprehensive big-data of the industrially important materials for such applications.
- Mesh distortion is prevalent when simulating hard and brittle materials using finite element methods in Molecular Dynamic simulation. On the other hand, the SPH approach has an advantage over the finite element method in that it does not require a rupture criterion to remove the chip from the workpiece.
- When looking to the previous works, hybrid models such as analytical/numerical are critically effective compared to single types especially for their ability to reduce the total computational times. This will provide fast results and improve their reliability in achieving the results for the materials applied these techniques for the first time.
- For more industrial applications, more facilities are required to merge the laboratory experience and the demands in the market. Unless, there are two separate knowledge will develop unaware from each other.
- In a word, simulation based analysis is impressively effective when studied by the experts in the field. But new initiatives, more knowledge and collaborative works are required.

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References

1. Danish M, Ginta TL, Habib K et al (2017) Thermal analysis during turning of AZ31 magnesium alloy under dry and cryogenic conditions. Int J Adv Manuf Technol 91:2855–2868. https://doi.org/10.1007/s00170-016-9893-5
2. Danish M, Ginta TL, Habib K et al (2019) Effect of cryogenic cooling on the heat transfer during turning of AZ31C magnesium alloy. Heat Transf Eng 40:1023–1032
3. Markopoulos AP, Karkalos NE, Papazoglou E-L (2020) Meshless methods for the simulation of machining and micro-machining: a review. Arch Comput Methods Eng 27:831–853. https://doi.org/10.1007/s11831-019-09333-z
4. Lorong P, Yvonnet J, Coffignal G, Cohen S (2006) Contribution of computational mechanics in numerical simulation of machining and blanking: state-of-the-art. Arch Comput Methods Eng 13:45–90. https://doi.org/10.1007/BF02905931
5. Danish M, Ginta TL, Habib K et al (2017) Thermal analysis during turning of AZ31 magnesium alloy under dry and cryogenic conditions. Int J Adv Manuf Technol 91:2855–2868. https://doi.org/10.1007/s00170-016-9893-5
6. Danish M, Ginta TL, Abdul Rani AM et al (2019) Investigation of surface integrity induced on AZ31C magnesium alloy turned under cryogenic and dry conditions. Proc Manuf 41:476–483. https://doi.org/10.1016/j.promfg.2019.09.035
7. Maruda RW, Krolczyk GM, Wojciechowski S et al (2018) Effects of extreme pressure and anti-wear additives on surface topography and tool wear during MQCL turning of AISI 1045 steel. J Mech Sci Technol 32:1585–1591. https://doi.org/10.1007/s12206-018-0313-7
8. Maruda RW, Krolczyk GM, Michalski M et al (2017) Structural and microhardness changes after turning of the AISI 1045 steel for minimum quantity cooling lubrication. J Mater Eng Perform 26:431–438. https://doi.org/10.1007/s11665-016-2450-4
9. Rodríguez JM, Carbonell JM, Jonsén P (2020) Numerical methods for the modelling of chip formation. Arch Comput Methods Eng 27:387–412. https://doi.org/10.1007/s11831-018-09313-9
10. Krolczyk GM, Maruda RW, Krolczyk JB et al (2019) Ecological trends in machining as a key factor in sustainable production: a review. J Clean Prod 218:601–615

11. Maruda RW, Krolczyk GM, Nieslony P et al (2016) The influence of the cooling conditions on the cutting tool wear and the chip formation mechanism. J Manuf Process 24:107–115. https://doi.org/10.1016/j.jmapro.2016.08.006
12. Maruda RW, Feldshtein E, Legutko S, Krolczyk GM (2016) Analysis of contact phenomena and heat exchange in the cutting zone under minimum quantity cooling lubrication conditions. Arab J Sci Eng 41:661–668. https://doi.org/10.1007/s13369-015-1726-6
13. Nieslony P, Krolczyk GM, Wojciechowski S et al (2018) Surface quality and topographic inspection of variable compliance part after precise turning. Appl Surf Sci 434:91–101
14. Maruda RW, Krolczyk GM, Feldshtein E et al (2017) Tool wear characterizations in finish turning of AISI 1045 carbon steel for MQCL conditions. Wear 372–373:54–67. https://doi.org/10.1016/j.wear.2016.12.006
15. Krolczyk GM, Maruda RW, Krolczyk JB et al (2018) Parametric and nonparametric description of the surface topography in the dry and MQCL cutting conditions. Measurement 121:225–239. https://doi.org/10.1016/j.measurement.2018.02.052
16. Wojciechowski S, Matuszak M, Powałka B et al (2019) Prediction of cutting forces during micro end milling considering chip thickness accumulation. Int J Mach Tools Manuf 147:103466. https://doi.org/10.1016/j.ijmachtools.2019.103466
17. Maruda RW, Krolczyk GM, Wojciechowski S et al (2020) Evaluation of turning with different cooling-lubricating techniques in terms of surface integrity and tribologic properties. Tribol Int 148:106334. https://doi.org/10.1016/j.triboint.2020.106334
18. Maruda RW, Krolczyk GM, Feldshtein E et al (2016) A study on droplets sizes, their distribution and heat exchange for minimum quantity cooling lubrication (MQCL). Int J Mach Tools Manuf 100:81–92. https://doi.org/10.1016/j.ijmachtools.2015.10.008
19. Wojciechowski S, Maruda RW, Nieslony P, Krolczyk GM (2016) Investigation on the edge forces in ball end milling of inclined surfaces. Int J Mech Sci 119:360–369
20. Wojciechowski S, Maruda W, Krolczyk RM, Niesłony G P (2018) Application of signal to noise ratio and grey relational analysis to minimize forces and vibrations during precise ball end milling. Precis Eng 51:582–596. https://doi.org/10.1016/j.precisioneng.2017.10.014
21. Laghari RA, Li J, Laghari AA, Wang S (2020) A review on application of soft computing techniques in machining of particle reinforcement metal matrix composites. Arch Comput Methods Eng 27:1363–1377. https://doi.org/10.1007/s11831-019-09340-0
22. Korkmaz ME, Yaşar N, Günay M (2020) Numerical and experimental investigation of cutting forces in turning of Nimonic 80A superalloy. Eng Sci Technol an Int J 23:664–673. https://doi.org/10.1016/j.jestch.2020.02.001
23. Korkmaz ME, Günay M (2018) Finite element modelling of cutting forces and power consumption in turning of AISI 420 martensitic stainless steel. Arab J Sci Eng 43:4863–4870. https://doi.org/10.1007/s13369-018-3204-4
24. Korkmaz ME, Nafiz Y (2021) FEM modelling of turning of AA6061-T6: Investigation of chip morphology, chip thickness and shear angle. J Prod Syst Manuf Sci 2:50–58
25. Zou SF, Li JZ, Xie XY (2018) A semi-analytical solution for one-dimensional elasto-viscoplastic consolidation of layered soft clay. Appl Clay Sci 153:9–15. https://doi.org/10.1016/j.clay.2017.11.042
26. Banerjee B (2007) The Mechanical Threshold Stress model for various tempers of AISI 4340 steel. Int J Solids Struct 44:834–859. https://doi.org/10.1016/j.ijsolstr.2006.05.022
27. Majzoobi GH, Rahimi Dehgolan F (2011) Determination of the constants of damage models. Proc Eng 10:764–773. https://doi.org/10.1016/j.proeng.2011.04.127
28. Tan JQ, Zhan M, Liu S et al (2015) A modified Johnson-Cook model for tensile flow behaviors of 7050-T7451 aluminum alloy at high strain rates. Mater Sci Eng A 631:214–219. https://doi.org/10.1016/j.msea.2015.02.010
29. Zhang DN, Shangguan QQ, Xie CJ, Liu F (2015) A modified Johnson-Cook model of dynamic tensile behaviors for 7075-T6 aluminum alloy. J Alloys Compd 619:186–194. https://doi.org/10.1016/j.jallcom.2014.09.002
30. Li L, Yan J, Xing Z (2013) Energy requirements evaluation of milling machines based on thermal equilibrium and empirical modelling. J Clean Prod 52:113–121. https://doi.org/10.1016/j.jclepro.2013.02.039
31. da Silva FAV, Outeiro JC (2021) Machining simulation of Inconel 718 using Lagrangian and coupled Eulerian-Lagrangian approaches. Proc CIRP 102:453–458. https://doi.org/10.1016/j.procir.2021.09.077
32. Sridhar P, Rodríguez Prieto JM, de Payrebrune KM (2020) Discretization approaches to model orthogonal cutting with Lagrangian, Arbitrary Lagrangian Eulerian, particle finite element method and smooth particle hydrodynamics formulations. Proc CIRP 93:1496–1501. https://doi.org/10.1016/j.procir.2020.03.139
33. Gupta MK, Korkmaz ME, Sarıkaya M et al (2022) Cutting forces and temperature measurements in cryogenic assisted turning of AA2024-T351 alloy: An experimentally validated simulation approach. Meas J Int Meas Confed 188:110594. https://doi.org/10.1016/j.measurement.2021.110594
34. Ambroziak A (2005) Numerical modelling of elasto-viscoplastic Chaboche constitutive equations using MSC. Marc Task Q 9:157–166
35. Cai Z, Ji H, Pei W et al (2019) Constitutive equation and model validation for 33Cr23Ni8Mn3N heat-resistant steel during hot compression. Results Phys 15:102633. https://doi.org/10.1016/j.rinp.2019.102633
36. Rusinek A, Zaera R, Klepaczko JR (2007) Constitutive relations in 3-D for a wide range of strain rates and temperatures: application to mild steels. Int J Solids Struct 44:5611–5634. https://doi.org/10.1016/j.ijsolstr.2007.01.015
37. Haghgoo M, Babaei H, Mostofi TM (2022) 3D numerical investigation of the detonation wave propagation influence on the triangular plate deformation using finite rate chemistry model of LS-DYNA CESE method. Int J Impact Eng 161:104108. https://doi.org/10.1016/j.ijimpeng.2021.104108
38. Vandana AS, Sundaram NK (2020) Simulation of machining of ductile polycrystalline aggregates using a remeshing framework. J Manuf Process 54:1–13. https://doi.org/10.1016/j.jmapro.2020.02.041
39. Mirzaie T, Mirzadeh H, Cabrera J-M (2016) A simple Zerilli–Armstrong constitutive equation for modeling and prediction of hot deformation flow stress of steels. Mech Mater 94:38–45. https://doi.org/10.1016/j.mechmat.2015.11.013
40. Korkmaz ME, Verleysen P, Günay M (2018) Identification of constitutive model parameters for nimonic 80A superalloy. Trans Indian Inst Met 71:2945–2952. https://doi.org/10.1007/s12666-018-1394-9
41. Huh H, Kang WJ, Han SS (2002) A tension split Hopkinson bar for investigating the dynamic behavior of sheet metals. Exp Mech 2002 421 42:8–17. https://doi.org/10.1007/BF02411046
42. Gambirasio L, Rizzi E (2016) An enhanced Johnson-Cook strength model for splitting strain rate and temperature effects on lower yield stress and plastic flow. Comput Mater Sci 113:231–265. https://doi.org/10.1016/j.commatsci.2015.11.034

43. Buzyurkin AE, Gladky IL, Kraus EI (2015) Determination and verification of Johnson-Cook model parameters at high-speed deformation of titanium alloys. Aerosp Sci Technol 45:121–127. https://doi.org/10.1016/j.ast.2015.05.001
44. Banerjee A, Dhar S, Acharyya S et al (2015) Determination of Johnson cook material and failure model constants and numerical modelling of Charpy impact test of armour steel. Mater Sci Eng A 640:200–209. https://doi.org/10.1016/j.msea.2015.05.073
45. Šlais M, Dohnal I, Forejt M (2012) Determination of Johnson-Cook equation parameters. Acta Metall Slovaca 18:125–132. https://doi.org/10.12776/ams.v19i3.162
46. Guzmán R, Meléndez J, Zahr J, Pérez-Castellanos JL (2010) Determination of the constitutive relation parameters of a metallic material by measurement of temperature increment in compressive dynamic tests. Exp Mech 50:389–397. https://doi.org/10.1007/s11340-009-9223-z
47. Dorogoy A, Rittel D (2009) Determination of the Johnson-Cook material parameters using the SCS specimen. Exp Mech 49:881–885. https://doi.org/10.1007/s11340-008-9201-x
48. Hokka M, Gomon D, Shrot A et al (2014) Dynamic behavior and high speed machining of Ti-6246 and alloy 625 superalloys: experimental and modeling approaches. Exp Mech 54:199–210. https://doi.org/10.1007/S11340-013-9793-7
49. Ma Y, Yu D, Feng P et al (2015) Finite element method study on the influence of initial stress on machining process. Adv Mech Eng 7:1–10. https://doi.org/10.1177/1687814015572457
50. Vijay Sekar KS, Pradeep Kumar M (2012) Optimising flow stress input for machining simulations using taguchi methodology. Int J Simul Model 11:17–28. https://doi.org/10.2507/IJSIMM11(1)2.195
51. Zhang Y, Lackner R, Zeiml M, Mang HA (2015) Strong discontinuity embedded approach with standard SOS formulation: Element formulation, energy-based crack-tracking strategy, and validations. Comput Methods Appl Mech Eng 287:335–366. https://doi.org/10.1016/j.cma.2015.02.001
52. Khatir FA, Sadeghi MH, Akar S (2022) Investigation of surface integrity in laser-assisted turning of AISI 4340 hardened steel: Finite element simulation with experimental verification. Opt Laser Technol 147:107623. https://doi.org/10.1016/j.optlastec.2021.107623
53. Wojciechowski S, Twardowski P, Pelic M (2014) Cutting forces and vibrations during ball end milling of inclined surfaces. Proc CIRP 14:113–118. https://doi.org/10.1016/j.procir.2014.03.102
54. Ezilarasan C, Senthil Kumar VS, Velayudham A (2014) Theoretical predictions and experimental validations on machining the Nimonic C-263 super alloy. Simul Model Pract Theory 40:192–207. https://doi.org/10.1016/j.simpat.2013.09.008
55. Parida AK, Maity K (2017) Effect of nose radius on forces, and process parameters in hot machining of Inconel 718 using finite element analysis. Eng Sci Technol an Int J 20:687–693. https://doi.org/10.1016/j.jestch.2016.10.006
56. Vijayaraghavan V, Garg A, Gao L et al (2016) A finite element based data analytics approach for modeling turning process of Inconel 718 alloys. J Clean Prod 137:1619–1627. https://doi.org/10.1016/j.jclepro.2016.04.010
57. Jafarian F, Imaz Ciaran M, Umbrello D et al (2014) Finite element simulation of machining Inconel 718 alloy including microstructure changes. Int J Mech Sci 88:110–121. https://doi.org/10.1016/j.ijmecsci.2014.08.007
58. Rajashekhar Reddy S, Kumar MS, Vasu V (2017) Temperature study in Turning Inconel-718: 3D simulation and experimentation. Mater Today Proc 4:9946–9950. https://doi.org/10.1016/j.matpr.2017.06.299
59. Xu W, Zhang L (2019) Heat effect on the material removal in the machining of fibre-reinforced polymer composites. Int J Mach Tools Manuf 140:1–11. https://doi.org/10.1016/j.ijmachtools.2019.01.005
60. Huang Y, Liang SY (2003) Cutting forces modeling considering the effect of tool thermal property—application to CBN hard turning. Int J Mach Tools Manuf 43:307–315. https://doi.org/10.1016/S0890-6955(02)00185-2
61. Chou YK, Song H (2003) Thermal modeling for finish hard turning using a new tool. In: Manufacturing, ASMEDC, pp 183–192
62. Yen YC, Jain A, Altan T (2004) A finite element analysis of orthogonal machining using different tool edge geometries. J Mater Process Technol 146:72–81. https://doi.org/10.1016/S0924-0136(03)00846-X
63. Marusich TD, Brand CJ, Thiele JD (2002) A methodology for simulation of chip breakage in turning processes using an orthogonal finite element model. In: Proceedings of the Fifth CIRP International Workshop on Modeling of Machining Operation, West Lafayette, USA. pp 139–148
64. Arisoy YM, Guo C, Kaftanoɪlu B, Özel T (2016) Investigations on microstructural changes in machining of Inconel 100 alloy using face turning experiments and 3D finite element simulations. Int J Mech Sci 107:80–92. https://doi.org/10.1016/j.ijmecsci.2016.01.009
65. Özel T, Arisoy YM, Guo C (2016) Identification of microstructural model parameters for 3D finite element simulation of machining Inconel 100 alloy. Proc CIRP 46:549–554. https://doi.org/10.1016/j.procir.2016.04.021
66. Uçak N, Aslantas K, Çiçek A (2020) The effects of Al2O3 coating on serrated chip geometry and adiabatic shear banding in orthogonal cutting of AISI 316L stainless steel. J Mater Res Technol 9:10758–10767. https://doi.org/10.1016/j.jmrt.2020.07.087
67. Sima M, Özel T (2010) Modified material constitutive models for serrated chip formation simulations and experimental validation in machining of titanium alloy Ti–6Al–4V. Int J Mach Tools Manuf 50:943–960. https://doi.org/10.1016/j.ijmachtools.2010.08.004
68. Wu HY, Lee WB, Cheung CF et al (2005) Computer simulation of single-point diamond turning using finite element method. J Mater Process Technol 167:549–554. https://doi.org/10.1016/J.JMATPROTEC.2005.06.015
69. Shih AJ (1995) Finite element simulation of orthogonal metal cutting. J Eng Ind 117:84–93. https://doi.org/10.1115/1.2803283
70. Deshayes L (2007) Analysis of an equivalent tool face for the cutting speed range prediction of complex grooved tools. J Mater Process Technol 190:251–262. https://doi.org/10.1016/J.JMATPROTEC.2007.02.037
71. Carroll JT, Strenkowski JS (1988) Finite element models of orthogonal cutting with application to single point diamond turning. Int J Mech Sci 30:899–920. https://doi.org/10.1016/0020-7403(88)90073-2
72. Bäker M (2005) Finite element investigation of the flow stress dependence of chip formation. J Mater Process Technol 167:1–13. https://doi.org/10.1016/J.JMATPROTEC.2004.09.076
73. Bäker M (2005) Does chip formation minimize the energy? Comput Mater Sci 33:407–418. https://doi.org/10.1016/J.COMMATSCI.2004.08.007
74. Gu LZ, Wang D, Xing L et al (2002) Computer simulation and optimization of metal cutting process for mild carbon steels. J Mater Process Technol 129:60–65. https://doi.org/10.1016/S0924-0136(02)00576-9
75. Aurich JC, Bil H (2006) 3D finite element modelling of segmented chip formation. CIRP Ann 55:47–50. https://doi.org/10.1016/S0007-8506(07)60363-1

76. Umbrello D, M'Saoubi R, Outeiro JC (2007) The influence of Johnson–Cook material constants on finite element simulation of machining of AISI 316L steel. Int J Mach Tools Manuf 47:462–470. https://doi.org/10.1016/J.IJMACHTOOLS.2006.06.006
77. Bäker M (2006) Finite element simulation of high-speed cutting forces. J Mater Process Technol 176:117–126. https://doi.org/10.1016/J.JMATPROTEC.2006.02.019
78. MacGinley T, Monaghan J (2001) Modelling the orthogonal machining process using coated cemented carbide cutting tools. J Mater Process Technol 118:293–300. https://doi.org/10.1016/S0924-0136(01)00969-4
79. Monaghan J, MacGinley T (1999) Modelling the orthogonal machining process using coated carbide cutting tools. Comput Mater Sci 16:275–284. https://doi.org/10.1016/S0927-0256(99)00070-1
80. Lo SP (2000) An analysis of cutting under different rake angles using the finite element method. J Mater Process Technol 105:143–151. https://doi.org/10.1016/S0924-0136(00)00650-6
81. Shih AJ (1996) Finite element analysis of orthogonal metal cutting mechanics. Int J Mach Tools Manuf 36:255–273. https://doi.org/10.1016/0890-6955(95)98765-Y
82. Zhuang K, Zhou S, Zou L et al (2022) Numerical investigation of sequential cuts residual stress considering tool edge radius in machining of AISI 304 stainless steel. Simul Model Pract Theory 118:102525. https://doi.org/10.1016/j.simpat.2022.102525
83. Wan M, Ye X-Y, Yang Y, Zhang W-H (2017) Theoretical prediction of machining-induced residual stresses in three-dimensional oblique milling processes. Int J Mech Sci 133:426–437. https://doi.org/10.1016/j.ijmecsci.2017.09.005
84. Denkena B, de León-García L, Köhler J (2006) Influence of high performance cutting operations on the residual stresses of aluminum structural workpieces. ICAS-Secretariat – 25th Congr Int Counc Aeronaut Sci 2006 4:2558–2564
85. Denkena B, de Leon L (2008) Milling induced residual stresses in structural parts out of forged aluminium alloys. Int J Mach Mach Mater 4:335–344. https://doi.org/10.1504/IJMMM.2008.023717
86. Liu Y, Xu D, Agmell M et al (2021) Numerical and experimental investigation of tool geometry effect on residual stresses in orthogonal machining of Inconel 718. Simul Model Pract Theory 106:102187. https://doi.org/10.1016/j.simpat.2020.102187
87. Mittal S, Liu CR (1998) A method of modeling residual stresses in superfinish hard turning. Wear 218:21–33. https://doi.org/10.1016/S0043-1648(98)00201-4
88. El-Axir MH (2002) A method of modeling residual stress distribution in turning for different materials. Int J Mach Tools Manuf 42:1055–1063. https://doi.org/10.1016/S0890-6955(02)00031-7
89. Sridhar BR, Devananda G, Ramachandra K, Bhat R (2003) Effect of machining parameters and heat treatment on the residual stress distribution in titanium alloy IMI-834. J Mater Process Technol 139:628–634. https://doi.org/10.1016/S0924-0136(03)00612-5
90. Mishra A, Prasad T (1985) Residual stresses due to a moving heat source. Int J Mech Sci 27:571–581. https://doi.org/10.1016/0020-7403(85)90073-6
91. Lin Z-C, Lin Y-Y, Liu CR (1991) Effect of thermal load and mechanical load on the residual stress of a machined workpiece. Int J Mech Sci 33:263–278. https://doi.org/10.1016/0020-7403(91)90040-A
92. Merwin JE, Johnson KL (1963) An analysis of plastic deformation in rolling contact. Proc Inst Mech Eng 177:676–690. https://doi.org/10.1243/PIME_PROC_1963_177_052_02
93. Lin CT, Kao PW, Yang FS (1991) Fatigue behaviour of carbon fibre-reinforced aluminium laminates. Composites 22:135–141. https://doi.org/10.1016/0010-4361(91)90672-4
94. Lin Z, Lee B (1995) An investigation of the residual stress of a machined workpiece considering tool flank wear. J Mater Process Technol 51:1–24. https://doi.org/10.1016/0924-0136(94)01322-R
95. Wiesner C (1992) Residual stresses after orthogonal machining of AlSl 304: numerical calculation of the thermal component and comparison with experimental results. Metall Trans A 23:989–996. https://doi.org/10.1007/BF02675573
96. Jacobus K, DeVor RE, Kapoor SG (2000) Machining-induced residual stress: Experimentation and modeling. J Manuf Sci Eng Trans ASME 122:20–31. https://doi.org/10.1115/1.538906
97. Zhao GY, Liu ZY, He Y et al (2017) Energy consumption in machining: Classification, prediction, and reduction strategy. Energy 133:142–157. https://doi.org/10.1016/j.energy.2017.05.110
98. Li X, Lu J (2017) Machining process energy consumption modelling using response surface methodology and neural network. Proc 2017 IEEE 21st Int Conf Comput Support Coop Work Des CSCWD. 2017:378–383. https://doi.org/10.1109/CSCWD.2017.8066724
99. Li T, Kong L, Zhang H, Asif I (2014) Recent research and development of typical cutting machine tool's energy consumption model. Jixie Gongcheng Xuebao/Journal Mech Eng 50:102–111. https://doi.org/10.3901/JME.2014.07.102
100. Jia S, Tang R, Lv J et al (2016) Energy modeling for variable material removal rate machining process: an end face turning case. Int J Adv Manuf Technol 85:2805–2818. https://doi.org/10.1007/S00170-015-8133-8
101. Tristo G, Bissacco G, Lebar A, Valentinčič J (2015) Real time power consumption monitoring for energy efficiency analysis in micro EDM milling. Int J Adv Manuf Technol 78:1511–1521. https://doi.org/10.1007/S00170-014-6725-3
102. Zhong Q, Tang R, Lv J et al (2016) Evaluation on models of calculating energy consumption in metal cutting processes: a case of external turning process. Int J Adv Manuf Technol 82:2087–2099. https://doi.org/10.1007/S00170-015-7477-4
103. Liu F, Wang Q (2013) Energy efficiency assessment of mechanical manufacturing system: characteristics, state-of-the-art and future trends. Zhongguo Jixie Gongcheng/China Mech Eng 24. https://doi.org/10.3969/J.ISSN.1004-132X.2013.11.025
104. Kant G, Sangwan KS (2014) Prediction and optimization of machining parameters for minimizing power consumption and surface roughness in machining. J Clean Prod 83:151–164. https://doi.org/10.1016/j.jclepro.2014.07.073
105. Larek R, Brinksmeier E, Meyer D et al (2011) A discrete-event simulation approach to predict power consumption in machining processes. Prod Eng 5:575–579. https://doi.org/10.1007/s11740-011-0333-y
106. Abele E, Braun S, Schraml P (2015) Holistic simulation environment for energy consumption prediction of machine tools. Proc CIRP 29:251–256. https://doi.org/10.1016/j.procir.2015.02.059
107. Meng L, Zhou M, Zhang C, Tian G (2016) A new model for predicting power consumption of machining processes: a turning case. IEEE Int Conf Autom Sci Eng 2016–Novem:1289–1294. https://doi.org/10.1109/COASE.2016.7743556
108. Bhinge R, Park J, Law KH et al (2017) Toward a generalized energy prediction model for machine tools. J Manuf Sci Eng Trans ASME. https://doi.org/10.1115/1.4034933
109. Bi ZM, Wang L (2012) Optimization of machining processes from the perspective of energy consumption: a case study. J Manuf Syst 31:420–428. https://doi.org/10.1016/j.jmsy.2012.07.002
110. Guo Y, Duflou JR, Qian J et al (2015) An operation-mode based simulation approach to enhance the energy conservation of machine tools. J Clean Prod 101:348–359. https://doi.org/10.1016/j.jclepro.2015.03.097

111. Borgia S, Albertelli P, Bianchi G (2017) A simulation approach for predicting energy use during general milling operations. Int J Adv Manuf Technol 90:3187–3201. https://doi.org/10.1007/s00170-016-9654-5
112. Liu G, Özel T, Li J et al (2020) Optimization and fabrication of curvilinear micro-grooved cutting tools for sustainable machining based on finite element modelling of the cutting process. Int J Adv Manuf Technol 110:1327–1338. https://doi.org/10.1007/s00170-020-05906-6
113. Liao Z, la Monaca A, Murray J et al (2021) Surface integrity in metal machining - Part I: Fundamentals of surface characteristics and formation mechanisms. Int J Mach Tools Manuf 162:103687. https://doi.org/10.1016/J.IJMACHTOOLS.2020.103687
114. Bhattacharyya B, Doloi B (2020) Machining processes utilizing chemical and electrochemical energy. Mod Mach Technol. https://doi.org/10.1016/B978-0-12-812894-7.00005-0
115. Shabgard MR, Ivanov A, Rees A (2006) Influence of EDM machining on surface integrity of WC-Co. 4M 2006 - Second Int Conf Multi-Material Micro Manuf 331–334. https://doi.org/10.1016/B978-008045263-0/50075-1
116. Jawahir IS, Brinksmeier E, M'Saoubi R et al (2011) Surface integrity in material removal processes: recent advances. CIRP Ann 60:603–626. https://doi.org/10.1016/j.cirp.2011.05.002
117. El-Wardany TI, Kishawy HA, Elbestawi MA (2000) Surface integrity of die material in high speed hard machining, part 1: micrographical analysis. J Manuf Sci Eng Trans ASME 122:620–631. https://doi.org/10.1115/1.1286367
118. Arrazola PJ, Kortabarria A, Madariaga A et al (2014) On the machining induced residual stresses in IN718 nickel-based alloy: experiments and predictions with finite element simulation. Simul Model Pract Theory 41:87–103. https://doi.org/10.1016/j.simpat.2013.11.009
119. Lotfi M, Amini S, Akbari J (2020) Surface integrity and microstructure changes in 3D elliptical ultrasonic assisted turning of Ti–6Al–4V: FEM and experimental examination. Tribol Int 151:106492. https://doi.org/10.1016/j.triboint.2020.106492
120. Ranganath S, Guo C, Hegde P (2009) A finite element modeling approach to predicting white layer formation in nickel superalloys. CIRP Ann - Manuf Technol 58:77–80. https://doi.org/10.1016/j.cirp.2009.03.109
121. Khodaii J, Adibi H, Barazandeh F et al (2020) Improvement of surface integrity in the grinding of bioceramic partially stabilized zirconia using analytical, numerical, and experimental methods. Ceram Int 46:13784–13797. https://doi.org/10.1016/j.ceramint.2020.02.168
122. Maximov JT, Duncheva GV, Dunchev VP, Anchev AP (2021) Different strategies for finite element simulations of static mechanical surface treatment processes—a comparative analysis. J Braz Soc Mech Sci Eng 43:1–18. https://doi.org/10.1007/s40430-021-03085-3
123. Maranhão C, Paulo Davim J (2010) Finite element modelling of machining of AISI 316 steel: numerical simulation and experimental validation. Simul Model Pract Theory 18:139–156. https://doi.org/10.1016/J.SIMPAT.2009.10.001
124. Zhao P, Wu J, Chen H et al (2021) Molecular dynamics simulation study of interaction mechanism between grain boundaries and subgrain boundaries in nano-cutting. J Manuf Process 67:418–426. https://doi.org/10.1016/j.jmapro.2021.04.075
125. Deng B, Yang M, Zhou L et al (2019) Smoothed particle hydrodynamics (SPH) simulation and experimental investigation on the diamond fly-cutting milling of zirconia ceramics. Proc CIRP 82:202–207. https://doi.org/10.1016/j.procir.2019.04.001
126. Mourtzis D, Doukas M, Bernidaki D (2014) Simulation in manufacturing: review and challenges. Proc CIRP 25:213–229. https://doi.org/10.1016/j.procir.2014.10.032
127. Mourtzis D (2020) Simulation in the design and operation of manufacturing systems: state of the art and new trends. Int J Prod Res 58:1927–1949. https://doi.org/10.1080/00207543.2019.1636321
128. Zaeh M, Siedl D (2007) A new method for simulation of machining performance by integrating finite element and multi-body simulation for machine tools. CIRP Ann - Manuf Technol 56:383–386. https://doi.org/10.1016/j.cirp.2007.05.089
129. Athavale SM, Strenkowski JS (1998) Finite element modeling of machining: from proof-of-concept to engineering applications. Mach Sci Technol 2:317–342. https://doi.org/10.1080/10940349808945674
130. Dixit US, Joshi SN, Davim JP (2011) Incorporation of material behavior in modeling of metal forming and machining processes: a review. Mater Des 32:3655–3670. https://doi.org/10.1016/j.matdes.2011.03.049
131. Mkaddem A, Demirci I, Mansori M El (2008) A micro–macro combined approach using FEM for modelling of machining of FRP composites: Cutting forces analysis. Compos Sci Technol 68:3123–3127. https://doi.org/10.1016/j.compscitech.2008.07.009
132. Santiuste C, Soldani X, Miguélez MH (2010) Machining FEM model of long fiber composites for aeronautical components. Compos Struct 92:691–698. https://doi.org/10.1016/J.COMPSTRUCT.2009.09.021
133. Robi PS, Dixit US (2003) Application of neural networks in generating processing map for hot working. J Mater Process Tech 1:289–294. https://doi.org/10.1016/S0924-0136(03)00579-X
134. Roters F, Eisenlohr P, Hantcherli L et al (2010) Overview of constitutive laws, kinematics, homogenization and multiscale methods in crystal plasticity finite-element modeling: theory, experiments, applications. Acta Mater 58:1152–1211. https://doi.org/10.1016/J.ACTAMAT.2009.10.058
135. Fleck NA, Muller GM, Ashby MF, Hutchinson JW (1994) Strain gradient plasticity: Theory and experiment. Acta Metall Mater 42:475–487. https://doi.org/10.1016/0956-7151(94)90502-9
136. Huang Y, Qu S, Hwang KC et al (2004) A conventional theory of mechanism-based strain gradient plasticity. Int J Plast 20:753–782. https://doi.org/10.1016/J.IJPLAS.2003.08.002
137. Jayal AD, Badurdeen F, Dillon OW, Jawahir IS (2010) Sustainable manufacturing: modeling and optimization challenges at the product, process and system levels. CIRP J Manuf Sci Technol 2:144–152. https://doi.org/10.1016/j.cirpj.2010.03.006
138. Outeiro JC, Dias AM, Jawahir IS (2006) On the effects of residual stresses induced by coated and uncoated cutting tools with finite edge radii in turning operations. CIRP Ann - Manuf Technol 55:111–116. https://doi.org/10.1016/S0007-8506(07)60378-3