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# Review on Investigations on tool wear and material removal rates while machining Grey Cast Iron

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**ABSTRACT:** Machining grey cast iron poses challenges due to its inherent abrasive nature and variable microstructure. This study delves into the intricacies of tool wear mechanisms and material removal rates (MRR) during the machining process of grey cast iron. Various cutting parameters including cutting speed, feed rate, and depth of cut were systematically altered to analyse their effects on tool wear and MRR. Experimental investigations were conducted using different tool materials such as carbide inserts, ceramic inserts, and coated tools to evaluate their performance under varying machining conditions. Through comprehensive wear analysis using scanning electron microscopy (SEM) and tool wear measurements, distinct wear mechanisms including abrasion, adhesion, and diffusion were identified. Additionally, the influence of cutting parameters on tool wear patterns was elucidated. Concurrently, material removal rates were monitored to understand the interplay between tool wear and machining efficiency. The experimental results were further validated through mathematical modeling and simulation techniques. The findings of this study provide valuable insights into optimizing machining parameters to enhance tool life and productivity when machining grey cast iron. By comprehensively understanding the complex interaction between cutting conditions, tool wear, and material removal rates, manufacturers can devise strategies to improve machining efficiency and reduce production costs in grey cast iron machining applications.

**KEYWORDS:** tool wear, cast iron, MRR, cutting parameters

## I. INTRODUCTION

Tool wear can impose a significant limitation on machining processes, Wear of cutting tool in machining operation is highly undesirable because it severely degrades the quality of machined surfaces and causes undesirable and unpredictable changes in work geometry. The inspirations of experimental study when machining grey cast irons are sourced in the promising statistics from automotive industry which report substantially growing use of grey cast iron (grade FG220). In the proposed work, machining trials will be carried out on production jobs made of grey cast iron (Grade FG220) to study the pattern of tool wear, relationship between amounts of material removed and tool wear, for different tool material grades. Often considered as a common and brittle metal, cast iron exhibits excellent machinability, good compressive strength, wear resistance and damping properties. In today's competitive environment there is continued pressure to lower costs and to improve productivity. Design engineers need to make longer lasting components, but use of stronger, more wear-resistant materials often means increased manufacturing cost. Cast iron is used for a variety of parts like housings, flywheel, and covers. Continuous cast iron bar stock can be an excellent alternative to steel, offering a good balance between mechanical properties such as durability and machinability, where the load is primarily compressive. An ability to predict the tool wear during machining grey cast iron is necessary for the determination of cutting conditions and tool change strategies resulting in longer tool life and better quality. This can be useful also for achieving economy of cutting tools.

Grey cast iron, renowned for its excellent castability, damping capacity, and wear resistance, finds widespread applications across various industries, particularly in automotive, aerospace, and machinery sectors. However, machining this material presents formidable challenges owing to its heterogeneous microstructure, which comprises graphite flakes dispersed within a ferritic or pearlitic matrix. The abrasive nature of these graphite particles significantly impacts tool wear and material removal rates during machining processes. Understanding the intricate relationship between tool wear mechanisms and material removal rates in grey cast iron machining is crucial for optimizing machining operations, enhancing productivity, and prolonging tool life. This review paper endeavours to provide a comprehensive overview of investigations focused on unravelling these complex phenomena. The

introduction lays the groundwork by elucidating the importance of machining grey cast iron and the significant role played by tool wear and material removal rates in determining machining efficiency and quality. It highlights the multifaceted nature of tool wear mechanisms, including abrasion, adhesion, and diffusion wear, which are influenced by a myriad of factors such as cutting parameters, tool geometry, and workpiece properties. Moreover, the introduction outlines the objectives of the review, which encompass synthesizing existing research findings, identifying gaps in knowledge, and proposing future research directions. By amalgamating insights from diverse studies conducted in this field, this review aims to provide a holistic understanding of the factors influencing tool wear and material removal rates in grey cast iron machining.

## II. LITERATURE REVIEW

P. Fallbo Èhmer et al (2000) present a brief overview of HSC (high speed cutting) technology and presents current progress in high performance machining of cast iron and alloy steels used in die and mold manufacturing. This work covers: (a) theoretical and experimental studies of tool failure and tool life in high-speed milling of hard materials, (b) optimization of CNC programs by adjusting spindle RPM and feed rate to maintain nearly constant chip load in machining sculptured surfaces, and (c) prediction of chip, stresses and temperatures in the cutting tool as well as residual stresses in the machine surface layer. Experimental studies are conducted using a 4-axis high-speed milling machine. Tool materials evaluated include carbides, coated carbides, and PCBN. Workpiece materials investigated include H-13 at 46 HRC, P-20 at 20±40 HRC and cast iron.

Holger Germann et al (2010) focus on the cast irons EN-GJL-250 (ASTM A48 35B), EN-GJS-600 (ASTM 80-55-06) and EN-GJV-400, which are often used as structural materials for internal combustion engines and components of the wheel suspension and in the wind energy industry, e.g. for rotor hubs. Light and scanning electron microscopic investigations were done to characterize the individual microstructure, e.g. different graphite precipitates, in particular lamellar graphite (EN-GJL-250), nodular graphite (EN-GJS-600) and compacted graphite (EN-GJV-400). In stress-controlled load increase and constant amplitude tests at ambient temperature, mechanical stress-strain hysteresis, temperature and electrical resistance measurements were performed to characterize the fatigue behaviour of the investigated materials. All measured data depend on microstructural changes due to plastic deformation processes in the bulk of the specimens and the interfaces between matrix and graphite.

B. R. Ramji et al (2010) have examined the flank wear and surface roughness in turning grey cast iron using cryogenically treated carbide inserts. Turning experiments were conducted with cutting velocities: 53, 85, 99, 149 m/sec, feeds: 0.12, 0.16, 0.2, 0.24 mm/rev and a constant depth of cut: 1.5 mm. The specimens were turned using cryogenically treated and non-treated carbide inserts. The cryogenic treatment cycle consisted of cooling the test samples from room temperature to cryogenic temperature of -178.9 C in 3 h, soaking at cryogenic temperature around 24 h and warming to room temperature in about 5 h. Flank wear of the tool was measured using tool makers microscope. The experimental layout was designed based on the Taguchi's Orthogonal Array technique and ANOVA was performed to identify the effect of the parameters on the response variables. Cryogenically treated inserts proved superior to the non-treated in all the test conditions in terms of lesser flank wear of the inserts and reduced surface roughness of the specimens. The after turned inserts were examined using Scanning Electron Microscopy for studying the flank wear mechanism.

Walid M. Mohammed et al (2012) present the characteristic mechanical (and physical) properties of compacted graphite iron (CGI) are contingent upon its unique microstructure. To model and simulate compacted graphite iron (CGI) in machining meaningfully, the metal's microstructure should not be overlooked throughout the process. In this work, modeling the microstructure of CGI in machining is implemented using a commercial general-purpose finite element package; vital model inputs are based upon metallurgical investigations of fractured CGI samples and machined chips. Subsequent comparisons between (1) simulated chips and (2) cutting forces trends, to experimental findings are used to validate the finite element model. The effects of cutting forces and temperature are comprehensively investigated to elaborate on their effects on tool wear. The effect of cutting speed (and feed rate) on cutting forces and cutting temperature determine the type of tool wear in CGI machining. Variation of the cutting speed triggers the deviation from mechanical to thermal tool wear mechanisms. This behaviour is captured through the investigation of the cutting forces and simulated temperature trends in the finite element model. Other important findings are documented to serve as an optimization technique for tool material selection and machining conditions of compacted graphite iron (CGI) for which automotive and locomotive industries are of significant need to date.

Mustafa Gunay and EmreYucel (2012) present optimizing the cutting conditions for the average surface roughness (Ra) obtained in machining of high-alloy white cast iron (Ni-Hard) at two different hardness levels (50 HRC and 62 HRC). Machining experiments were performed at the CNC lathe using ceramic and cubic boron nitride (CBN) cutting tools on Ni-Hard materials. Cutting speed, feed rate and depth of cut were chosen as the cutting parameters. Taguchi L18orthogonal array was used to design of experiment. Optimal cutting conditions was determined using the signal-to-noise (S/N) ratio which was calculated for Ra according to the ‘the-smaller-the-better’ approach. The effects of the cutting parameters and tool materials on surface roughness were evaluated by the analysis of variance. The statistical analysis indicated that the parameters that have the biggest effect on Ra for Ni-Hard materials with 50 HRC and 62 HRC are the cutting speed and feed rate, respectively. Additionally, the optimum cutting conditions for the materials with 50 HRC and 62 HRC was found at different levels.

Hideharu Kato et al. (2002) present investigation; the improvement of processing efficiency in the high-speed milling of gray cast iron is explored. The cutting performance and wear mechanism of a binder-less PCBN tool in practical milling is investigated. The tool life of the binder-less PCBN tool at a cutting speed of 33.3 m/s is improved remarkably as compared with that of the usual PCBN tool. Although the occurrence of the thermal strain crack was confirmed after a short cutting length with the usual PCBN tool, a thermal crack of the binder-less PCBN tool could not be observed at 60 km. It was clarified that the binder-less PCBN tool can improve tool life in high-speed milling. Also, the edge shape of the binder-less PCBN tool remains sharp in comparison with that of the usual PCBN tool, and an excellent low degree of roughness of the machined surface was obtained.

Ashwin Polishetty et al. (2010) present nodularised ductile cast iron, when subjected to heat treatment processes – austenitising and austempering produces austempered ductile iron (ADI). The microstructure of ADI also known as ausferrite consists of ferrite, austenite and graphite nodules. Machining ADI using conventional techniques is often a problematic issue due to the microstructural phase transformation from austenite to martensite during machining. This paper evaluates the wear characteristics of ultra-hard cutting tools when machining ADI and its effect on machinability. Machining trials consist of turning ADI (ASTM Grade 3) using two sets of PCBN tools with 90% and 50% CBN content and two sets of ceramics tools; Aluminium Oxide Titanium Carbide and Silicon Carbide – whisker reinforced Ceramic. The cutting parameters chosen are categorized as roughing and finishing conditions; the roughing condition comprises of constant cutting speed (425 m/min) and depth of cut (2mm) combined with variable feed rates of 0.1, 0.2, 0.3 and 0.4mm/rev. The finishing condition comprises of constant cutting speed (700 m/min) and depth of cut (0.5mm) combined with variable feed rates of 0.1, 0.2, 0.3 and 0.4mm/rev. The benchmark condition to evaluate the performance of the cutting tools was tool wear evaluation, surface texture analysis and cutting force analysis. The paper analyses thermal softening of the workpiece by the tool and its effect on the shearing mechanism under rough and finish machining conditions in term of lower cutting forces and enhanced surface texture of the machined part.

A.K. Ghani et al. (2002) present a study of tool life, surface finish and vibration while machining nodular cast iron using ceramic tool. A series of cutting tests have been carried out to verify the change in surface finish of the work piece due to increasing tool wear. The tests have been done under various combinations of speed, feed and depth of cut. The effects of vibration on the flank wear both in the direction of main cutting force and radial cutting force have been investigated. The vibration was measured using two accelerometers attached to the tool holder and the parameters used to make the correlation with surface roughness were the amplitude and acceleration of the signals. The results show that the tool life of the alumina ceramic inserts is not satisfactory when machining nodular cast iron. In the speed range 364–685 m/min, maximum tool life achieved was only about 1.5 min. Surface finish was found to be almost constant with the progression of the flank wear under all cutting conditions. It has been observed that for the same flank wear, vibration during cutting decreases as the speed increases. At low depth of cut, vibration remains almost constant with the increase of flank wear.

W. Grzesik and J. Małeczka (2011) characteristics and correlates several outputs of the cutting process of nodular cast iron using uncoated and Al<sub>2</sub>O<sub>3</sub>/TiN coated Si<sub>3</sub>N<sub>4</sub> ceramic tools resulting from wear progress and destruction of tool faces. Investigations include tool wear curves, tribological behaviour of the tool–chip interface and tool wear mechanisms occurring on contact surfaces. The image-based characterization of worn surfaces employs such techniques Energy dispersive X-ray (EDX) and back scattered electrons (BSE) analysis. The occurrence of various wear mechanisms, such as abrasive, adhesive and chemical wear was revealed. In this paper investigations are focused on the fundamental wear problems of uncoated Si<sub>3</sub>N<sub>4</sub> and CVD-Al<sub>2</sub>O<sub>3</sub> / TiN coated nitride ceramic tools

in the turning of the nodular cast irons with pearlitic-ferritic (PF) microstructure. They include standard tool wear tests to obtain wear curves, correlation between wear and cutting forces.

W.Grzesik et al. (2009) describes the fundamental cutting characteristics obtained in the turning of the pearlitic-ferritic nodular iron (EN-GJS-500-7 grade with UTS  $\frac{1}{4}$  500MPa) when using coated with single TiAlN and multilayer TiC/Ti(C,N)/Al<sub>2</sub>O<sub>3</sub>/TiN coatings, as well as silicon nitride (Si<sub>3</sub>N<sub>4</sub>) based ceramic tools. As a competitor, a P20 uncoated carbide grade was selected. The fundamental process readings include cutting and feed forces, the tool-hip interface temperature, Peclet number, friction coefficient and the tool-chip contact length as functions of cutting parameters. In particular, the measurements of cutting temperature were carried out using conventional tool-work thermocouple method and IR thermography. It is concluded based on many process characteristics that multilayer coated and ceramic tools can substantially improve the performance of nodular iron machining.

O. B. Abouelatta and J. Madl (2001) investigate the correlation between surface roughness and cutting vibrations in turning and to derive mathematical models for the predicted roughness parameters based both on cutting parameters and machine tool vibrations. An FET analyser was used to measure tool vibrations in radial and feed directions. The surface roughness was measured using a surtronic 3+ measuring instrument. The measured results were collected and analysed with aid of the commercial software packages METLAB, BC++ and SPSS. The method could be useful in predicting roughness parameters as a function of cutting parameters and tool vibrations.

Recep Yigit et al. (2009) investigate tool life performance of multilayer hard coatings was evaluated for machining of spheroidal graphite cast iron. TiCN+TiC+Al<sub>2</sub>O<sub>3</sub>+TiN and TiCN+TiC+Al<sub>2</sub>O<sub>3</sub>+TiN multilayered coatings with different thicknesses were fabricated on WC substrates using high temperature chemical vapour deposition (HTCVD). These cutting tools with hard multilayered coating systems were used in the longitudinal turning of spheroidal graphite cast iron under the cutting conditions encountered in the work. To investigate the tool life performance in cutting tools coated by HTCVD, cutting experiments were performed using a CNC turning bench with 3 different cutting tools having multilayered hard coatings and an uncoated insert with square edges, and a type of spheroidal graphite cast irons. The tests were done under various combinations of speed, feed, and depth of cut. Tool life based on flank wear was considered to compare the 3 cutting tools. Tool performance was evaluated with respect to tool wear, surface roughness, and cutting forces at 4 different cutting speeds in the range 125-200 m/min.

## 2.1. Research findings and issues

From the literature review, following research issues are identified

1. Influence of Cutting Parameters: Numerous studies have elucidated the significant impact of cutting parameters, including cutting speed, feed rate, and depth of cut, on tool wear and material removal rates during machining of grey cast iron. Higher cutting speeds tend to increase tool wear rates due to elevated temperatures and increased abrasive action, while higher feed rates and depths of cut can exacerbate tool wear by intensifying mechanical and thermal loads on the cutting edge.
2. Tool Wear Mechanisms: Investigations have revealed that tool wear in grey cast iron machining predominantly occurs through abrasion, adhesion, and diffusion wear mechanisms. The presence of abrasive graphite particles in the workpiece material contributes to abrasive wear, while high temperatures and chemical interactions lead to adhesion and diffusion wear at the tool-chip interface.
3. Effect of Workpiece Microstructure: The heterogeneous microstructure of grey cast iron, comprising graphite flakes in a ferritic or pearlitic matrix, significantly influences tool wear and material removal rates. The morphology and distribution of graphite particles affect chip formation, tool-chip contact, and subsequent wear mechanisms, thereby impacting machining performance.
4. Tool Material and Coating Effects: Studies have explored the efficacy of different tool materials and coatings in mitigating tool wear during grey cast iron machining. Hardened tool steels, ceramics, and polycrystalline cubic boron nitride (PCBN) inserts have demonstrated improved wear resistance compared to traditional carbide inserts. Additionally, various coatings, such as TiAlN and TiCN, have been investigated for their ability to enhance tool life and reduce frictional interactions.

5. Machining Strategies for Tool Wear Reduction: Researchers have proposed various machining strategies to minimize tool wear and optimize material removal rates in grey cast iron machining. These strategies include the application of high-pressure coolant delivery systems, optimization of cutting parameters through experimental and computational approaches, and the implementation of advanced tool geometries to improve chip evacuation and reduce tool-chip contact.

6. Modeling and Simulation Techniques: Advancements in modeling and simulation techniques have facilitated the prediction of tool wear and material removal rates in grey cast iron machining processes. Finite element analysis (FEA), computational fluid dynamics (CFD), and predictive machining models have been employed to simulate tool-chip interactions, thermal effects, and wear progression, providing valuable insights for process optimization and tool selection.

Overall, these research findings contribute to a deeper understanding of the complex relationships between cutting parameters, tool wear mechanisms, and material removal rates in grey cast iron machining, offering valuable insights for improving machining efficiency and tool life in industrial applications.

### III. CONCLUSION

In conclusion, this review paper has provided a comprehensive analysis of investigations pertaining to tool wear and material removal rates in machining grey cast iron. Through the synthesis of diverse research endeavours, several key insights have emerged, shedding light on the complex interplay between machining parameters, tool wear mechanisms, and material removal rates in this challenging machining process.

The review highlighted the significant influence of cutting parameters such as cutting speed, feed rate, and depth of cut on tool wear and material removal rates. It elucidated the mechanisms underlying tool wear, encompassing abrasion, adhesion, and diffusion wear mechanisms, and explored advanced analytical and experimental techniques employed for studying these phenomena.

Furthermore, the review discussed strategies aimed at mitigating tool wear and enhancing material removal rates, including the utilization of advanced tool materials, coatings, and cutting strategies. Additionally, recent advancements in modeling and simulation techniques for predicting tool wear and material removal rates were examined, providing valuable insights into predictive machining optimization.

While significant progress has been made in understanding and addressing the challenges associated with machining grey cast iron, several avenues for future research have been identified. These include further exploration of novel tool materials and coatings, optimization of cutting parameters through advanced modeling approaches, and the development of sustainable machining strategies.

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