The Effectiveness of Hot machining process for the Machinability of Hard to cut materials: A REVIEW

Kamal AbdulkareemMohammed*1, Jaafar Jaber Abdulhameed1, and Ehsan Sabh Al-Ameen1

1Mechanical Eng. Dept, College of Engineering, AL-Mustansiriya University, Baghdad-Iraq

Abstract:In the manufacturing field of industrial firms, some materials are hard to cut and do not meet the mechanical operation requirements in conventional and unconventional machining methods due to their high mechanical properties which poorer their machinability. The need is ongoing and growing to these materials in important industries, therefore hot machining is considered one of the most advanced methods of machining which help to solve the problem of these materials. This process involves heating the work piece at elevated temperature during or before machining on conventional cutting machine by using various external heating techniques, which soften it and becomes more ductile and this leads to improve the machinability. This paper displays a review on hot machining process and presents its effectiveness for the industrial firm in machining hard-to cut- materials which reflect on cost and productivity in relation to other aspects of machining. The review paper presents a survey on various researches which indicates the effect of variation process parameters in hot machining.

Keywords: Hot machining, Hard to cut materials, Machinability, Heatingtechniques, and Machining parameters

1. Introduction

The industrial firms are always seeking to increase their productivities by activation one or more of the factors (less cost, less time, improved quality) which represents the development triangle heads, one of obstacles is the machining of hard-to cut-materials like; Super alloys, Hardened steel. Metal--Matrix-Composites, Ceramics which do not meet the mechanical operation requirements in using conventional and unconventional machining methods to achieve the design and production requirements of the product in economic and practical ways due to their very high hardness, shear strength, wear resistance and toughness which this is reflected negatively on theperformance characteristics (tool life, material removal rate and surface quality), in other words, these materials are characterized by poor machinability when dealing with conventional and unconventional machining methods. The great demand for these materials and growing need to obtain their machining requirements in more economical and practical ways is a major challenge in important industries like; Aerospace, Marine, Nuclear,Automobile, Petrochemical,Biomedical so the tendency was to adopt alternative ways to overcoming the problems of these materials instead of going to very costly means like; increasing the capacity of machinery and equipment and improve the cutting tool capacity. Because these materials withstand elevated temperatures, therefore hot machining is considered

1 Content from this work may be used under the terms of the CreativeCommons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
one of the most advanced and important methods of machining which help to solve the problem of these materials, this results reducing the cutting resistance of the material and improved machinability with optimization performance characteristics.

2. Hard to cut materials

Hard to cut materials have high mechanical properties represented by high hardness and strength, wear resistance, corrosion resistance, toughness, weld ability, low distortion and low thermal conductivity, like; super alloys, hardened steels, stainless steels, tool steels, titanium, nickel, high manganese steel, Inconel, quenched steels, composites, Ceramic, heat resistant materials, etc. these materials are in great demand for many industries in the field of nuclear, aerospace, automotive, missile, biomedical, marine, petrochemical, electrical and chemical industries, etc, where high dimensional accuracy, tool life and acceptable surface quality are required but this type of materials are difficult to cut and machining them required for high hardness and strength cutting tools which making it uneconomical and sometimes impractical due to the problems (rapid tool wear and shortage in cutting tool life, low feed, poor surface quality, high power consumption, damage of work piece material, low material removal rate) which arise when machining them in conventional and unconventional methods, and this refers to poor machinability, increased costs and reduction in productivity, so the need for these materials with overcoming their machining problems and enhancing their machinability is one of the main tasks and objectives of the industrial firms and workers in the field [1,2,3,4,5,6].

3. Machinability

The machining of materials is a major manufacturing process to produce variety of parts and components with higher dimensional accuracy and surface quality [7]. Shear deformation is the base of material removal in machining process and this depends on the material behavior with machining conditions which effect performance characteristics and indicate the material machinability with consideration that Strain hardening which results in machining of material has main effect on the machinability (inversely proportional relationship). The term Machinability expresses the ease of machining of material with acceptable material removal rate and surface quality to achieve the design and manufacturing requirements for parts and components in a more economical way without affecting performance.

George Schneider, Jr [8]; Defined the machinability and explained that; the factors affecting it (individually and in combinations) are the condition and physical properties of the work material which help for the optimum machining and superior productivity. Hardness, yield strength and tensile strength are considering to be from the important factors of the condition of the work material and the productivity can be enhanced with lower hardness which that causes lower cutting speed and positively effect on tool life, also the same effect for yield strength and tensile strength. The material machinability can be determined or evaluated by using methods or criteria:

a. Tool life which effect on the time and costs of the machining and production.

b. Tool forces which effect on power consumption.

c. Cutting temperature which effect tool wear.

d. Surface finish of the machined part.

e. Chip form.

Therefore; good machinability refers to a long tool life (less tool wear), low tool forces and power consumption and better surface finish [8, 9].
Continuous development in manufacturing field and materials and the emergence of new and advanced materials and enduring pursuit to optimize the productivity, Hot machining process is considered to be one of a variety of ways and means that help to bypass and solve machining problems of difficult and hard to cut materials, the researchers agree that it is a popular process used to facilitate machining by softening these materials to be machined instead of focusing on strengthening or increasing the hardness of the cutting tool and to overcome the problems of low cutting speed, feed, depth of cut and also in reducing tool forces, heavy loads on machine bearings and high temperature and pressure on cutting edge which cause rapid tool wear [1,2,4,10,11,12,13], therefore hot machining can be considered as one of the preferred methods for improvement the machinability of hard to cut materials.

4. Hot machining process

The basis of the hot machining process is softening the work piece of the hard to cut material to be machined by preheating the whole or a part of it using one of variety external heating sources before or during machining process above room temperature below or at re-crystallization temperature, but in some cases the material work piece has been also heated above re-crystallization temperature, heating requires being localize and control in machining zone in front of the cutting tool, the process does not require specialized cutting machines, but can be implemented on conventional machines for turning and milling operations where the preheating of work piece is done by external means, so that different conventional and non-conventional manufacturing processes can be used within hot machining which requires lower time and cost [2,5,10,11,14,15].

The importance of this process is through its advantages which can be summarized in decreasing tool wear (figure 1.a), cutting forces and power consumption, increasing cutting speed, feed rate, depth of cut and material removal rate, these advantages result increased tool life, good surface finish (figure 1.b), easy formation of the chip, and consequently increasing the machinability of hard to cut materials, a decrease in production time and costs is achieved and increasing productivity [2,4,7,10,14,16], other benefits are the possibility of using hot machining as finishing process, bulk deformation operation and also prevents cold working hardening in addition to use it in machining [10,11,17].

![Graphs showing decreasing tool wear and surface roughness in hot machining in comparison with conventional machining](image)

(a): decreasing tool wear  
(b): decreasing surface roughness

Figure 1 :(a, b): shows the decreasing tool wear and surface roughness in hot machining in comparison with conventional machining [18]

The rule of hot machining is to increase the difference in hardness between the work piece and cutting tool and make the work piece less hardness (by decreasing the bonding energy and yield strength) and become more ductile as a result of softening its surface (on machining area is to be done) at the shear zone (where the deformation occurs), this leading to reduce shear strength and deformation hardening (strain...
hardening) which causes a reduction in the component forces with increasing in tool life and surface integrity and enhancing the machining performance parameters [5, 11, 15, 19]. The optimum heating temperature varies for different materials and be close to the temperature at which the materials strength begin to drop abruptly [15], the main influencing factor is temperature and its increase leads to a decrease in the mechanical properties of all materials due to decreasing the plastic flow stress of them [19], figure (2.a, b) show the change of hardness and strength of different materials with effect of temperature.

Figure (2.a, b): show the change of hardness and strength with effect of temperature

5. Heating techniques

Hot machining process is heat assistance machining so it must be requires the selection of a proper and optimum method for heating the hard to cut materials to be machined to avoid the undesirable structural changes which causes increasing in the machining cost [7, 18, 21, 22]. The heat is applied as a whole or local heating of the work piece but the local application of heat in the front of cutting tool is more suitable and acceptable than whole heating of the work piece. In order to avoid any problems in machining work piece material [7], the heat should effect on a small area of the machining zone as possible without penetrating deeply of the work piece surface and without overheating to avoid getting undesirable metallurgical changes may be occur and limiting work piece expansion to guarantee accuracy requirement [9].

The selection of the optimum heating method depends on following factors [4, 7, 11];

a - Shear zone (cutting zone) where the plastic deformation will be occurred is the maximum

b - The size and shape of the material work piece, and minimal machining parameters (cutting conditions)

c - Heating capacity to provide specific heat in the front of the tool

d - Adaptation to Machine tool

e - Preheating temperature and its control and regulation, using device with high degree of accuracy
The various heati

The various heating techniques which can be used in hot machining process are [4, 5, 7, 11];

- Furnace heating
- Friction heating
- Resistance heating
- Electron beam
- Flame heating (oxy-acetylene, oxy-LPG)
- Electric contact
- Arc heating
- Induction heating
- Plasma arc heating
- Radio frequency heating apparatus
- Laser assisted heating

Heating techniques have advantages and disadvantages and are suitable for some machining process and unsuitable for other [15], the figure (3.a, b) gives idea about the experimental set up hot machining process using different heating technique.

(a) Flame heating technique [the authors] (b) Induction Heating technique [20]

Figure (3.a, b): show experimental set up hot machining process using different heating technique

6. Literature review

Many researchers and workers in the field of manufacturing and production search and investigate to optimize the hot machining process for overcoming the machining problems and enhancing the
machinability of hard to cut materials and achieve optimal results of different performance characteristics by optimizing and evaluating the effects of different machining parameters (cutting speed, feed rate, depth of cut) with the effect of preheating temperature on (tool life, surface roughness and integrity, material removal rate and cutting forces), this is evident in the set of results achieved for some of the following researchers in this regard;

Maher Baili et. al. [20] Study the influence of temperature in hot machining process with induction heating system on the machinability of titanium alloy Ti-5553. The results analysis at elevated temperature shows a reduction of specific cutting force by 13% at 500°C reaches 34% at 750°C compared to room temperature, also it has the effect on surface quality and tool wear.

OrhanÇakır and ErhanAltan[17] applied hot machining method on high manganese steels and examined the effects of machining parameters (cutting speed, feed rate, depth of cut) on tool wear, surface roughness and cutting forces with comparison the results with conventional machining, they introduced literature review for various experimental studies in the same field of work for high manganese steels which reported higher tool life, lower cutting forces and better surface finish quality, their conclusion included that material removal rate and machining costs has positively affected according to this.

VenkateshGanta and D Chakradhar [1] worked to optimize the cutting conditions and evaluate the effect of them on surface roughness and metal removal rate applying the statistical method of signal-to-noise ratio (S/N) and (ANOVA) in hot machining of 15-5PH martensitic stainless steel with 40 HRC which done using K313 carbide tool insert on lathe machine, the results obtained were smallest average surface roughness of 0.49 μm at cutting speed of 120 m/min, feed rate of 0.2 mm/rev, 0.4 depth of cut and temperature of 250°C, in addition to highest metal removal rate values as obtained at cutting speed of 120 m/min, feed rate of 0.4 mm/rev, 0.6 depth of cut and temperature of 250°C).

Nikunj R Modhet. al.[12] studied the effect of machining parameters on cutting force, feed force, and surface roughness at (200 °C, 400 °C and 600 °C), and used the ANOVA analysis to obtain optimum cutting parameters which are cutting speed – 965 rev/min, Depth of Cut - 0.8 mm, Feed - 0.265 mm/rev at 600 °C the results analysis refers to the benefits of hot machining method in giving good surface finish at high cutting speed, high temperature and low feed rate also low cutting force and feed force. They used multi regression equation to determine the relation between the machining parameters and the performance measure.

Nirav M. Kamdar, and Vipul K. Patel [23] Studied the influence of different machining parameter at 200 °C, 300 °C, 400 °C, 500 °C and 600 °C at constant depth of cut 0.8 mm on cutting force, feed force and surface roughness during hot machining (with gas flame) the EN 36 Steel specimens, the optimum machining parameters were obtained by using the ANOVA analysis and the results achieved in the experimental study by employing Design of experiments with Taguchi. The achieved results were decreasing in Cutting force, Feed force, surface roughness and Power consumption with the increase in temperature.

Ketul M. Trivediet. al. [24] Studied the effect of the cutting parameters on surface roughness of AISI 4340 steel which was machined by hot machining through burning a mixture of oxygen and acetylene gas and using a tungsten carbide cutting tool at operating temperatures 200°C, 400°C and 600°C. The relationship between the parameters and the performance measure is determined using multiple linear regression equation. Surface roughness decreased from maximum value 1.52 μm at 200 °C to minimum value 0.678 μm at 600 °C. It is beneficial to increase feed rate and which results in higher production rate.

Rahul D. Rajopadhye and Achyut S. Raut[16] Applied Taguchi methods and ANOVA in Optimization the machining Parameters that effect on tool life of carbide tools which used to machine High Manganese Steel by hot Machining process, the results showed increasing in tool life with increasing temperature, the optimized parameters which obtained were (140 rpm )Spindle Speed, ( 0.5 mm) Depth of Cut and (0.05 mm/rev) Feed Rate at 600 °C. According to the results of ANOVA for Tool life; depth of cut followed by temperature are the most parameters affecting the tool life than other machining parameters.
K.A. Patelet. al. [6] carried out hot machining of EN-8 steel material in lathe machine to optimize the input machining parameters which influence surface quality with using taguchi orthogonal array. The optimum results show good surface finish at high cutting speed of 300 rev/min, low feed rate of 0.111 mm/rev and depth of cut of 0.8 mm at preheating temperature of 500 °C.

N. Tosun and L. Ozler[22] Worked on hot turning high manganese steel (through heating with liquid petroleum gas flame) and using M20 sintered carbide tool under various cutting parameters and investigated their effect on multiple performance characteristics ((tool life and surface roughness) which improved where the results showed an increased in tool life by 2.45 times and an decreased in surface roughness by 2.34 times at the optimum cutting parameters cutting speed( 22 m/min), feed rate (0.1 mm/rev) and depth of cut(0.5 mm) at 600 °C.

A. Kiran Kumar and P. Venkataramaiah[25] Studied the effect of combination parameters of cutting speed, feed rate and preheating temperature on vonmises stress in hot machining Inconel 718 alloy using finite element method, the simulation tests and results showed a reduction in stress with increase of speed, temperature and decrease in feed rate, and the optimum parameters were V=150m/min., f=0.5mm/rev at preheating temperature of 600 °C which has more influence on stress.

Asit Kumar Parida[26] studied and calculated by a FEM analysis the effect of preheating temperature on tool wear on hot machining Inconel 718, the results were evaluated with same cutting conditions and compared with machining condition at the room temperature, the results show that the preheating temperature cause the tool life increased by reducing tool wear, good correlation between predicted tool wear, tool temperature and chip morphology and the experimental results.

S.K. Thandra and S. K. Choudhury[27] Investigated the effect of machining parameters: cutting speed, Feed rate, depth of cut and temperature of work piece surface on cutting forces, surface roughness and tool wear when the work piece was machined both in an oxy-acetylene hot machining and conventional machining on a lathe machine. A factorial regression method was used to express the effect of cutting conditions and the results compared with conventional machining, it referred that hot machining was decreasing cutting forces, surface roughness and flank wear by about 34%.

Asit Kumar Parida and Kalipada Maity[13] applied finite element method to hot machining of Ti–6Al–4V alloy to investigate heating temperature effect for different machining conditions, The simulation results are compared to achieved results in room temperature and also for hot machining which there is good correlation between them, results showed that in hot conditions, the increase in process zone temperature cause a reduction in cutting force and shear strength and also in chip thickness and chip pitch, cutting force decreased again with the increase of cutting speed and when increasing cause increasing in feed rate for both in hot conditions and room temperature.

7. Conclusion

The importance of hot machining process in the manufacturing and production sector is evident and confirmed in enhancing and improving the machinability of hard to cut materials which have high mechanical properties make machining them very difficult to achieve the design and production requirements of the product in economic and practical ways, many experimental studies on this process have reported its positively influence on the machinability and the performance characteristics which that boosts productivity as a certain result to the reduction in total machining costs and time. As a future scope, it requires to provide advanced researches on the optimization of hot machining process through the working to optimize machining parameters which have high effect on performance characteristics and the heating techniques to get optimum preheating temperature. The abilities and benefits of hot machining can be summarized in the following;

1. Hot machining is one of the important alternatives and acceptable process for part production to ease the machining of high hardness and strength materials by the impact effect of heating in the deformation zone which causes a modification in the mechanical properties of these types of materials.
2. By the effect of heating in optimum preheating temperature, the process improves the performance characteristics as follow;

a. decreased cutting forces
b. increased tool life (decreased tool wear rate)
c. good surface finish
d. large materials rate
e. improved chip formation

3. Temperature with machining parameters (cutting speed, feed rate and depth of cut) has a significant effect on performance characteristics.

4. The process minimizes the costs and time of machining, power consumption and reduces strain hardening in material work piece.

5. In addition to use the process in machining, it can be used as finishing process and bulk deformation process.

Acknowledgments

The authors are grateful to the University of Mustansiriyah (www.uomustansiriyah.edu.iq) and the college of engineering for supporting to achieve this work.

References

[1] VenkateshGanta and D Chakradhar, (AIMTDR 2014), An Experimental Investigation of Hot Machining Performance Parameters using Oxy-Acetylene gas setup, 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR),IITGuwahati, Assam, India

[2] ShatarupaG.Gurav, Prof. (Dr.) Rajiv B. and SuvrnaPatil, (2016 IJEDR), A Review on Effect of Cutting Parameters in Hot Turning Operation on Surface Finish, Volume 4, Issue 2 , ISSN: 2321-9939

[3] M.Davami, M.Zadshakoyan ,(2008) Investigation of Tool Temperature and Surface Quality in Hot Machining of Hard-to-Cut Materials, World Academy of Science, Engineering and Technology, International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering Vol:2, No:10

[4] SwayattBehera ,(May, 2013)Finite Element Modelling and Analysis of Hot Turning Operation,Department of Mechanical Engineering, National Institute of Technology,Rourkela , India

[5] Shalini Singh, (July, 2014), Experimental investigation and modeling of hot machining operation using high-strength material, Department of Mechanical Engineering, National Institute of Technology, Rourkela, India

[6] K.A.Patel, S.B.Patel and K.A.Patel,(June, 2014), Performance Evaluation and Parametric Optimization of Hot Machining Process on En-8 Material, International Journal For Technological Research In Engineering Volume 1, Issue 10
[7] OrhanÇakır and İbrahim Şahin,(31 August - 2 September 2016), Heating Techniques in Hot Machining, International Conference on Advances in Science ICAS, Istanbul, Turkey

[8] George Schneider, Jr. CMfgE,Cutting Tool Applications, www.toolingandproduction.com

[9] D. Kramar, M. Sekulić, Z. Jurković and J. Kopač,(2013), The Machinability of Nickel-Based Alloys in High-Pressure Jet Assisted (HPJA) Turning, Metalurgija 52 (2013) 4, 512-514

[10] Sandip B. Patel and Mitesh M. Patel,( March 2016 ) , A Review on Optimization of Hot Machining Process, GRD Journals- Global Research and Development Journal for Engineering , Vol:1 Issue 4

[11] Md. Orooj, Dr. P SudhakarRao,(May-2019), Machining Optimization at Elevated Temperature (Hot Machining): A Literature Review, International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES), e-ISSN: 2455-2585 Volume 5, Issue 05

[12] Nikunj R Modh, G. D. Mistry and K. B. Rathod,(2011), An experimental investigation to optimize the process parameters of AISI 52100 steel in hot machining, International Journal of Engineering Research and Applications (IJERA), Vol. 1, Issue 3, pp.483-489

[13] Asit Kumar Parida and Kalipada Maity, (2019), Hot machining of Ti–6Al–4V: FE analysis and experimental validation, Indian Academy of Sciences, Sādhana 44:142 https://doi.org/10.1007/s12046-019-1127-8

[14] R. D. Rajopadhye, M. T. Telsang and N. S. Dhole, Experimental Setup for Hot Machining Process to Increase Tool Life with Torch Flame, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), ISSN: 2278-1684, PP: 58-62, www.iosrjournals.org

[15] AKM Nurul Amin,(2014) , Heat-Assisted Machining, International Islamic University Malaysia, Kuala Lumpur, Malaysia, TL Ginta, University Technology, PETRONAS, Malaysia Elsevier Ltd

[16] Rahul D. Rajopadhye and Achyut S. Raut,( March 2015), Application of Taguchi methods and ANOVA in Optimization of Process Parameters for Tool Life in Hot Machining of High Manganese Steel, International Journal of Research in Advent Technology, Vol.3, No.3, E-ISSN: 2321-9637

[17] OrhanÇakır and Erhan Altan, (26-30 August, 2008), Hot Machining Of High Manganese Steel: A Review, 12th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology” TMT 2008, Istanbul, Turkey

[18] Mehmet AlperSofuoğlu, Fatih HayatiÇakır, Selim Gu’r gen, Sezan Orak and Melih Cemal KUS, han,(2018), Numerical investigation of hot ultrasonic assisted turning of aviation alloys, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 40:122 https://doi.org/10.1007/s40430-018-1037-4

[19] Maher Baili, Vincent Wagner, Gilles Dessein, Julien Sallaberry and Daniel Lallement,( Dec 2012), An experimental investigation of hot machining with induction to improve Ti-5553 machinability, Open Archive TOULOUSE Archive Ouverte (OATAO),( Dec 2012) http://oatao.univ-toulouse.fr/

[20] S. Ranganathan & T. Senthivelan, (2011), Multi-response optimization of machining parameters in hot turning using grey analysis, Int J AdvManufTechnol (2011) 56:455–462, Springer-Verlag London Limited
[21] N. Tosunand EL. Ozler,(2004), Optimisation for hot turning operations with multiple performance characteristics, Int J AdvManufTechnol, 23: 777–782, Springer-Verlag London Limited

[22] Mrs. Swetha Patil, Nitin K. Kamble and S. S. Sarnobat,(Oct 2013), Multi-response Optimization of Hot Machining Process Using Grey Relational Analysis (GRA) Method, Indian Journal Of Applied Research, Volume : 3 , Issue : 10, ISSN - 2249-555X

[23] Nirav M. Kamdar and Prof. Vipul K. Patel,(May-Jun 2012), Experimental Investigation of Machining Parameters of EN 36 Steel using Tungsten Carbide Cutting Tool during Hot Machining, International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622 Vol. 2, Issue 3, pp.1833-1838, www.ijera.com

[24] Ketul M. Trivedi, Jayesh V. Desai and Kiran Patel,(May 2014), Optimization of Surface Roughness for hot machining of AISI 4340 steel using DOE method, International Journal of Advance Engineering and Research Development (IJAERD) Volume 1, Issue 5, e-ISSN: 2348 - 4470

[25] A. Kiran Kumar and Dr. P. Venkataramaiah,(2018), Optimization of Process parameters in hot machining of Inconel 718 alloy using FEM, International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 13, Number 5, pp. 2158-2162, Research India Publications. http://www.ripublication.com

[26] Asit Kumar Parida,(2019), Finite Element Analysis of Tool Wear in Hot Machining Process: Hot Machining, Indian Institute of Technology, India

[27] S. K. Thandra and S. K. Choudhury, (May 2010), Effect of cutting parameters on cutting force, surface finish and tool wear in hot machining, International Journal of Machining and Machinability of Materials 7(3)