E-NSGA-II FOR MACHINING PROCESS PARAMETERS OPTIMIZATION

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requirements for the award of the degree of
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Especially dedicated to:

To my beloved husband, Mohd Asri bin Ahad

My lovely parents, Yusoff Bin Ahmad @Mohd Rejab and Baidah Binti Yahaya

My cuties, Hazmi Aniq Bin Mohd Asri and Hazmi Afiq Bin Mohd Asri

For their understanding, support, encourages, pray and time.

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ABSTRACT

Optimization of machining process parameters is important to improve the machining performances. There are two consecutive ways to improve the machining performances namely modeling followed by optimization. In this study, modeling technique, namely regression is used to develop the machining model and optimization technique, multi objective genetic algorithm (MoGA) to optimize the machining process. Known as a popular MoGA, non dominated sorting genetic algorithm II (NSGA-II) is able to produce many sets of solutions with good spread of solutions from the Pareto optimal front in one time run. However, the confusion of selecting the best solution has led to the idea of using genetic algorithm (GA) and weight sum average (WSA) based as the preference points for NSGA-II. In this study, GA, WSA and combination of GA-WSA are selected as point to direct the best solutions among Pareto optimal front of NSGA-II. The machining processes for this study are cobalt bonded tungsten carbide electrical discharge machining and powder mixed electrical discharge machining. Surface roughness and material removal rate are the machining performances considered. GA-NSGA-II, WSA-NSGA-II and GA-WSA-NSGA-II known as enhanced NSGA-II (E-NSGA-II) are proposed. Two datasets from previous studies are used in this study. The results are compared with the previous studies and statistical analyses are performed to describe the significant of techniques proposed. In conclusion, E-NSGA-II is an improved technique that can increase the ability to provide best sets of optimal solutions and better stable process parameters values based on selected performance measurements compared to the previous techniques proposed.

ABSTRAK

Pengoptimuman parameter proses penting dalam membaiki pencapaian pemesinan. Terdapat dua kaedah berturutan bagi meningkatkan pencapaian pemesinan; dinamakan pemodelan dan pengoptimuman. Dalam kajian ini, teknik pemodelan, regresi digunakan untuk membangunkan model pemesinan dan teknik pengoptimuman, algoritma genetik pelbagai objektif (AGPO) untuk mengoptimum proses pemesinan. Dikenali sebagai salah satu AGPO yang terkenal, algoritma genetik tidak terdominasi II (AGTT-II) boleh menghasilkan banyak set penyelesaian pada satu masa yang sama dengan penyerakan Pareto yang baik. Namun begitu, kekeliruan dalam memilih set-set penyelesaian terbaik telah mencetuskan ide untuk menggunakan algoritma genetik (AG) dan purata jumlah berpemberat (PJB). Dalam kajian ini, AG, PJB dan gabungan AG-PJB digunakan sebagai titik rujuk dalam pencarian set-set penyelesaian terbaik. Proses pemesinan ialah nyahcaj elektrik tungsten karbida bersalut kobalt dan nyahcaj elektrik bercampur serbuk. Kekasaran permukaan (KP) dan kadar pengurangan bahan (KPB) dipertimbangkan sebagai pencapaian pemesinan. AG-AGTT-II, PJB-AGTT-II dan AG-PJB-AGTT-II dikenali sebagai AGTT-II dipertingkat (AGTT-II-D) dicadangkan. Dua set data daripada kajian sebelum ini digunakan untuk kajian ini. Keputusan yang diperolehi dibandingkan dengan hasil kajian sebelum ini dan analisa statistik dilaksanakan bagi menggambarkan kepentingan teknik yang dicadangkan. Sebagai kesimpulan, didapati bahawa AGTT-II-D ialah teknik diperbaiki yang boleh meningkatkan kebolehan menyediakan set-set penyelesaian terbaik dan nilai parameter proses yang lebih stabil berdasarkan kepada kadar prestasi yang dipilih berbanding dengan teknik-teknik yang pernah dicadangkan sebelum ini.

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LIST OF ABBREVIATIONS

AFM - ABRASIVE FLOW MACHINING
ECH - ELECTROCHEMICAL HONING
ECM - ELECTROCHEMICAL MACHINING
EDM - ELECTRICAL DISCHARGE MACHINING
E-NSGA-II - ENHANCED NSGA-II
FL - FUZZY LOGIC
FR - FACTORIAL REGRESSION
GA - GENETIC ALGORITHM
MoGA - MULTI OBJECTIVE GENETIC ALGORITHM
MR - MULTIPLE REGRESSION
MRR - MATERIAL REMOVAL RATE
MSR - MIXTURE SURFACE REGRESSION
NSGA - NON DOMINATED SORTING GENETIC ALGORITHM
NSGA-II - NON DOMINATED SORTING GENETIC ALGORITHM-II
PMEDM - POWDER MIXED ELECTRICAL DISCHARGE MACHINING
PR - POLYNOMIAL REGRESSION
Ra - SURFACE ROUGHNESS
R-NSGA-II - REFERENCE POINT BASED NSGA-II
RSM - RESPONSE SURFACE METHODOLOGY
SR - SIMPLE REGRESSION
WC/Co - COBALT-BONDED TUNGSTEN CARBIDE
WEDM - WIRE ELECTRICAL DISCHARGE MACHINING
WSA - WEIGHT SUM AVERAGE

LIST OF SYMBOLS

$\prec_n$ - CROWDED COMPARISON OPERATOR
A - ROTATIONAL CURRENT
B - DUTY CYCLE
C - CONSTANT
C - POWDER CONCENTRATION
d - DEPTH OF CUT
D - TOOL DIAMETER
f - FEED
I - CURRENT
k - CONSTANT
M - COEFFICIENT
η - MECHANICAL EFFICIENCY
P - FLUSHING PRESSURE
R - ELECTRODE ROTATION
T - PULSE ON TIME
v - CUTTING SPEED
V - VOLUME OF MATERIAL REMOVED
x - PREDICTED VARIABLE
Y - DEPENDENT VARIABLE
α - CONSTANT
β - CONSTANT
γ - CONSTANT
ε - EPSILON

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter presents the problem background, problem statement, research aim, objective, scope, research significant and contributions of this study.

1.2 Problem Background

Generally, there are several major concerns of this research which are, machining processes, modeling, and optimization. The main idea of this study is to model and optimize process parameters.

Machining is a very important process in the manufacturing world. In the manufacturing world, machining can be divided into two categories, traditional machining and modern machining (El-Hofy, 2006; Kalpakjian, 1995). Traditional machining (Gutowski, 2009; Venkatesh and Narayanan, 1986) includes machining processes that use single or multi point tools to remove material in the form of chips (turning, milling, drilling, grinding etc.). Traditional machining unable to meet the challenges in today’s world and being enhanced to a new trend of modern machining due to global economics demands (Chatterjee, 1990; Jain, 2010; Pandey and Shan, 2008). Modern machining is the use of chemical, thermal, or electrical processes to machine a workpiece and remove material. Modern machining such as laser beam machining (Dubey and Yadava, 2008), abrasive jet machining (Ramachandran and Ramakrishnan, 1993; Venkatesh *et al.*, 1989), electrical discharge machining (EDM) (Ho and Newman, 2003; Mohd Abbas *et al.*, 2007), electrochemical machining (ECM) (Bannard, 1977; Meleka and Glew, 1977; Rajurkar *et al.*, 1999), wire electrical discharge machining (WEDM) (Ho *et al.*, 2004) etc.

Two major issues in the machining studies are modeling and optimization. Modeling in machining can be described as estimation of the potential value of machining performances. Machining models are developed to represent relationship between input and output variables. There are three manufacturing conflicting objectives based on Venkataraman (2012) which are maximizing production rate, maximizing product quality and minimizing the production cost. Tool wear rate, material removal rate (MRR) and surface roughness (Ra) are some of the machining performances or output variables that are widely discussed among the researches (Chandrasekaran *et al.*, 2010). Meanwhile the process parameters or input variables are depending on the composites and materials of machining processes. Optimization of process parameters such as depth of cut, peak current, electrode type and many more have been studied by many researches (Deb and Sundar, 2006; Dhavamani and Alwarsamy, 2011; Thiyagarajan *et al.*, 2012). There are many modeling techniques in machining optimization such as regression modeling, fuzzy logic, artificial neural network etc. (Palanikumar *et al.*, 2009; Vundavilli *et al*., 2012; Zain *et al*., 2011a; Zain *et al*., 2011b).

The target of process parameters optimization is to determine the optimal values of the machining process conditions that lead to a reliable minimum or maximum value of machining performances. There are many optimization techniques used in optimizing machining processes such as particle swarm optimization, simulated annealing (SA), Taguchi method, genetic algorithm (GA) etc. (Aouici *et al*., 2012; Asiltürk and Neşeli, 2011; Datta and Deb, 2009; Palanikumar, 2011; Krishnamoorthy *et al.*, 2012; Mandal *et al.*, 2011; Neşeli *et al.*, 2011; Ramesh *et al.*, 2012; Solimanpur and Ranjdoostfard, 2009). GA has taken a wide range of monopoly in solving the process parameters optimization problems due to its advantages in reducing operational cost and production time besides maximizing the production rate and quality (Ahmad *et al.*, 2006; Cus and Balic, 2003; Cus *et al.*, 2002; Manolas *et al.*, 1996; Wong *et al.*, 2003; Zain *et al.*, 2008, 2010a, 2010b). Different from single objective optimization, multi objective genetic algorithm (MoGA) is able to search many Pareto optimal solutions in optimizing multiple objectives of process parameters simultaneously.

As the first step of generating the idea of this study, machining processes, machining performances and process parameters that involved are intensely studied. The next step is by understanding the techniques related to modeling and optimizing the process parameters. Furthermore, investigate the most reliable MoGA in optimizing process parameters. Final step is by identifying an applicable modification approaches in the algorithm so that it is acceptable in the EDM optimization process. Figure 1.1 briefly describes the flow of optimizing process parameters using MoGA. Machining model is generated based on previous experimental data to correlate between machining performances and process parameters. The process parameters of MoGA are considered as decision variables for minimizing or maximizing the machining performances, known as the fitness values.

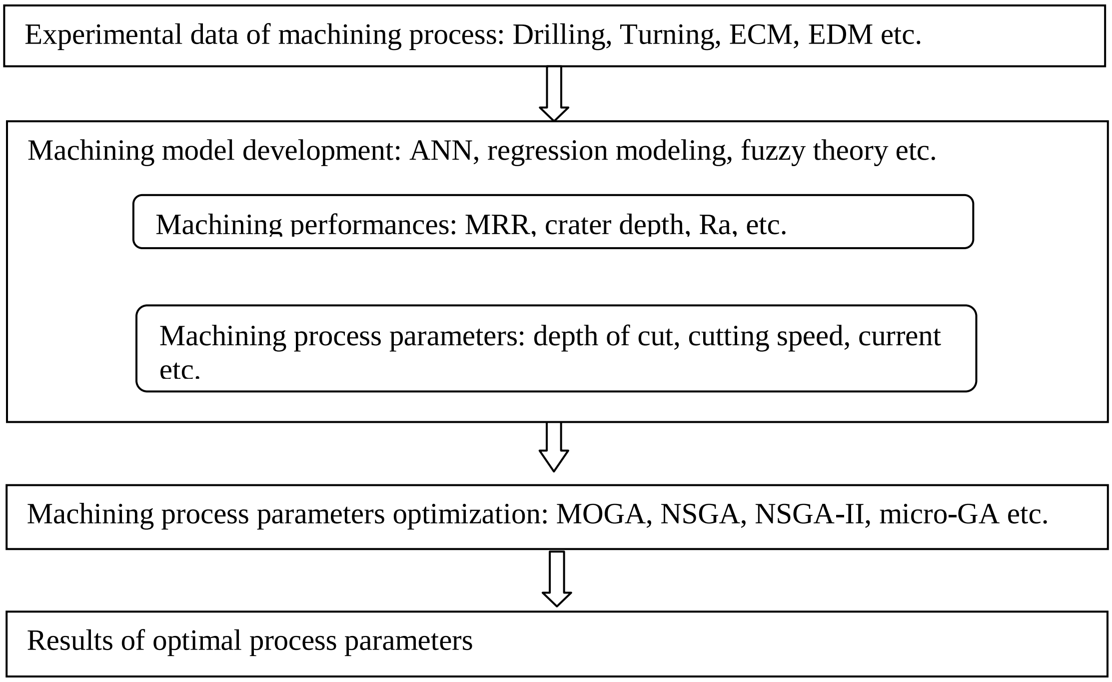

Figure 1.1: Flow of optimizing process parameters using MoGA

1.3 Problem Statement

Although GA is well established, it is subjected to solve one objective function only. The intention of multi objectives optimization is to obtain optimal values of multiple machining performances, such as MRR and Ra simultaneously. In the era of conventional machining tools, many experimental trials at different combination of value need to be done to estimate the optimal value of process parameters and fully depend to machinist experience who conducts the experiment. According to Cooper and DeRuntz (2007), "*The lack of formal procedure was a problem, especially for the new machinists who had no past experience with which to base a judgement on call*". Therefore, multi objective optimization such as MoGA is one of the efforts done by researchers to assist in the development of manufacturing world.

Getting information on the optimal process parameters that influence the machining performances is very important. Moreover, the relationships among various process parameters and machining performances are unclear and difficult to quantify particularly when the information is not clear, incomplete and uncertain. It is also difficult to get the practical and experimental data of various machining processes resulted to a vague in machining optimization. Those complications guided to an innovation and changes in machining model and optimization.

These days, known as one of the most popular MoGA, non dominates sorting genetic algorithm II (NSGA-II) has taken wide interests among the researchers in machining optimization. However, there are three major problems in machining optimization using NSGA-II that need to be faced:

(i) Difficulties in merging the machining model and optimization technique
(ii) One objective leads to a poorer value of the other objective.
(iii) Too many optimal solutions to be chosen

Thus, machining optimization should be able to encounter the problems so that the users have confidence of employing the technique proposed. Therefore the problem statement for this study is, "***E-NSGA-II (enhanced NSGA-II) is able to***

search the best optimal solutions for multi objectives machining performances”. The followings are the research questions that are addressed to answer the above problem statement:

(i) How to modify existing machining model and NSGA-II?

(ii) How to find the stable factors that can represent the algorithm in order to maintain high machining performance?

(iii) How to obtain machining process optimization result when dealing with various types of data?

(iv) Can the proposed E-NSGA-II outperform the existing NSGA-II?

These research questions are answered through the empirical results obtained throughout this study. This study is an extension of case study by Kanagarajan *et al.* (2008) and Garg and Ojha (2012). Regression modeling technique is proposed. NSGA-II by Deb *et al*. (2002) and reference point based NSGA-II (R-NSGA-II) by Deb and Sundar (2006) optimization technique are utilized to improve the optimal searching of best process parameters (Deb *et al.*, 2002; Deb and Sundar, 2006).

1.4 Aim of the Research

The aim of this study is to modify NSGA-II to satisfy the machining performances and machining process parameters demand on real machining applications of cobalt bonded tungsten carbide EDM (WC/Co EDM) and powder mixed EDM (PMEDM).

1.5 Objective of the Research

The objectives of this study are:

(i) To investigate a proper model of EDM to be combined with NSGA-II and E-NSGA-II optimization technique.

(ii) To test and evaluate the efficiency of NSGA-II and E-NSGA-II in process parameters optimization.

(iii) To classify preference point advantages in E-NSGA-II for better optimization performances.

1.6 Scope of the Research

The scopes of this study are:

(i) Machining model is based on regression modeling.

(ii) WC/Co EDM and PMEDM as part of EDM are the considered machining processes.

(iii) MRR and Ra are machining performances considered.

(iv) Process parameters of WC/Co EDM include rotational speed (*R*), pulse current (*I*), pulse on time (*T*) and flushing pressure (*P*).

(v) Process parameters of PMEDM are rotational current (*A*), duty cycle (*B*), powder concentration (*C*) and tool diameter (*D*).

(vi) The development of E-NSGA-II is based on NSGA-II (Deb *et al.*, 2002) and R-NSGA-II (Deb and Sundar, 2006).

(vii) Spread of solutions, maximum MRR and minimum Ra values, ability to search for best sets of optimal solutions, width interval, probability value, optimization time and dominant process parameters derivation are the performance measurement considered.

1.7 Research Significant

This study is to investigate the performances of modified NSGA-II named as E-NSGA-II in optimizing EDM performances. To indicate the effectiveness of this technique, the final results are compared with experimental results and optimal results by Kanagarajan *et al*. (2008) and Garg and Ojha (2012). NSGA-II is modified and implemented according to the machining processes requirements. Figure 1.2

summarizes the research significant which lead to the requirement of a new optimization technique that can produce accurate, robust and highly reliable machining optimal solutions.

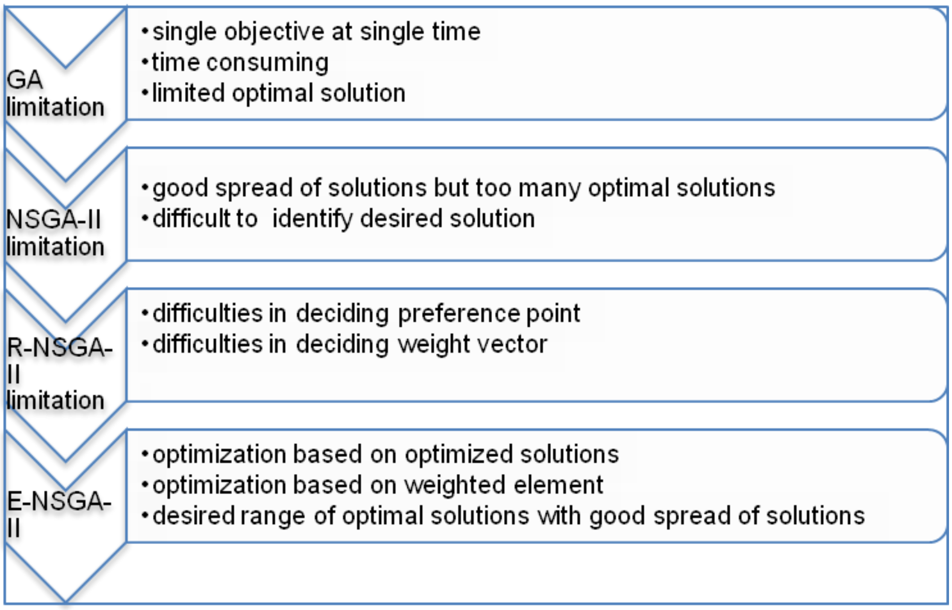

Figure 1.2: Research significant

1.8 Contributions of the Study

Contributions of this study can be divided into two categories:

(i) Contribution to machining processes

Basically, this study assists in getting optimal values of process parameters by considering multiple objectives simultaneously. The objectives are to maximize MRR and minimize Ra for WC/Co and PMEDM in order to obtain the optimal solutions. Combination of regression modeling and E-NSGA-II is proposed to get best optimal solutions of EDM.

(ii) Contribution to artificial intelligence

Modifications on NSGA-II, known as E-NSGA-II are developed to search the best optimal solutions. The variety set of preference points is trusted to leads to a better NSGA-II performance. This idea generally, is a way of getting the best among the best solutions in solving multi objective optimization problem of machining processes.

1.9 Summary

This chapter discussed several topics related to the brief idea of research implementation. Problem background, statement, aim of research, objectives and scopes are precisely mentioned in this chapter. Importance of the research and contributions of the study have also been described. As a guideline and references of this study, literature reviews are discussed in the next chapter.

REFERENCES

Ahmad, N., Tanaka, T., and Saito, Y. (2006). Cutting parameters optimization and constraints investigation for turning process by GA with self-organizing adaptive penalty strategy. *JSME International Journal, Series C: Mechanical Systems, Machine Elements and Manufacturing, 49*(2), 293-300.

Ali, M. Y., Atiqah, N., and Erniyati. (2011). Silicon carbide powder mixed micro electro discharge milling of titanium alloy. *International Journal of Mechanical and Materials Engineering, 6*(3), 338-342.

Ali-Tavoli, M., Nariman-Zadeh, N., Khakhali, A., and Mehran, M. (2006). Multi-objective optimization of abrasive flow machining processes using polynomial neural networks and genetic algorithms. *Machining Science & Technology, 10*(4), 491-510.

Amini, H., Soleymani Yazdi, M. R., and Dehghan, G. H. (2011). Optimization of process parameters in wire electrical discharge machining of TiB 2 nanocomposite ceramic. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225*(12), 2220-2227.

Amorim, F. L., Weingaertner, W. L., and Bassani, I. A. (2010). Aspects on the optimization of die-sinking EDM of tungsten carbide-cobalt. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 32*(5 SPEC. ISSUE), 496-502.

Aouici, H., Yallese, M. A., Chaoui, K., Mabrouki, T., and Rigal, J.-F. (2012). Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization. *Measurement, 45*(3), 344-353.

Asiltürk, İ., and Neşeli, S. (2012). Multi response optimisation of CNC turning parameters via Taguchi method-based response surface analysis. *Measurement, 45*(4), 785-794.Bannard, J. (1977). Electrochemical machining. *Journal of Applied Electrochemistry, 7*(1), 1-29.

Bannard, J. (1977). Electrochemical machining. *Journal of Applied Electrochemistry, 7*(1), 1-29.

Baraskar, S. S., Banwait, S. S., and Laroiya, S. C. (2011). Multi-objective optimisation of electrical discharge machining process using Derringer's desirability function approach. *International Journal of Materials Engineering Innovation, 2*(3-4), 203-221.

Baskar, N., Asokan, P., Prabhaharan, G., and Saravanan, R. (2005). Optimization of machining parameters for milling operations using non-conventional methods. *International Journal of Advanced Manufacturing Technology, 25*(11-12), 1078-1088.

Beri, N., Kumar, A., Maheshwari, S., and Sharma, C. (2011a). Optimisation of electrical discharge machining process with CuW powder metallurgy electrode using grey relation theory. *International Journal of Machining and Machinability of Materials, 9*(1-2), 103-115.

Beri, N., Maheshwari, S., Sharma, C., and Kumar, A. (2011b). Multi-objective parametric optimisation during electrical discharge machining of Inconel 718 with different electrodes. *International Journal of Materials Engineering Innovation, 2*(3-4), 236-248.

Bhattacharya, A., Batish, A., and Singh, G. (2012). Optimization of powder mixed electric discharge machining using dummy treated experimental design with analytic hierarchy process. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *226*(1), 103-116.

Bouzakis, K. D., Paraskevopoulou, R., Giannopoulos, G. (2008). Multi-objective optimization of cutting conditions in milling using genetic algorithms. *Proceedings of the 3rd International Conference on Manufacturing Engineering (ICMEN), Chalkidiki, Greece*, 763-774.

Chandrasekaran, M., Muralidhar, M., Krishna, C., and Dixit, U. (2010). Application of soft computing techniques in machining performance prediction and optimization: a literature review. *The International Journal of Advanced Manufacturing Technology, 46*(5), 445-464.

Chatterjee, S. (1990). A review of: “non traditional machining process” E.J. Weller SME, Dearborn, Michigan Second Edition, 273 pages, hardcover, 1984. *Materials and Manufacturing Processes, 5*(1), 139-140.

Choudhuri, K., Pratihar, D. K., and Pal, D. K. (2001). Multi-objective optimization in turning - Using a genetic algorithm. *Journal of the Institution of Engineers (India), Part PR: Production Engineering Division, 82*(2), 37-44.

Coello, C. A. C., and Cortés, N. C. (2005). Solving Multiobjective Optimization Problems Using an Artificial Immune System. *Genetic Programming and Evolvable Machines*, *6*(2), 163-190.

Coello, C. A. C., and Pulido, T. G. (2001). A Micro-Genetic Algorithm for Multiobjective Optimization. In E. Zitzler, L. Thiele, K. Deb, C. Coello Coello and D. Corne (Eds.), *Evolutionary Multi-Criterion Optimization* (Vol. 1993, pp. 126-140): Springer Berlin / Heidelberg.

Çoğun, C., Özerkan, B., and Karaçay, T. (2006). An experimental investigation on the effect of powder mixed dielectric on machining performance in electric discharge machining. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 220*(7), 1035-1050.

Corne, D., Jerram, N., Knowles, J., Oates, M., and Martin, J. (2001). PESA-II: Region-based Selection in Evolutionary Multiobjective Optimization. *Proceedings of the Genetic and Evolutionary Computation Conference GECCO’2001*, 283-290.

Corne, D., Knowles, J. D., and Oates, M. J. (2000). The Pareto Envelope-Based Selection Algorithm for Multi-objective Optimisation. *Proceedings of the 6th International Conference on Parallel Problem Solving from Nature,* 839-848.

Cus, F., and Balic, J. (2003). Optimization of cutting process by GA approach. *Robotics and Computer-Integrated Manufacturing, 19*(1-2), 113-121.

Cus, F., Balic, J., and Kopac, J. (2002). Optimization of milling parameters by GA approach. *Proceedings of Asian Simulation Conference/the 5th International Conference on System Simulation and Scientific Computing, Vol.II,* 974-979.

Datta, D., and Das, A. (2010). Tuning Process Parameters of Electrochemical Machining Using a Multi-objective Genetic Algorithm: A Preliminary Study. In K. Deb, A. Bhattacharya, N. Chakraborti, P. Chakroborty, S. Das, J. Dutta, S. Gupta, A. Jain, V. Aggarwal, J. Branke, S. Louis and K. Tan (Eds.), *Simulated Evolution and Learning* , Vol. 6457, pp. 485-493: Springer Berlin / Heidelberg.

Datta, R., and Deb, K. (2009). A classical-cum-evolutionary multi-objective optimization for optimal machining parameters. *Nature & Biologically Inspired Computing, 2009. NaBIC 2009* , 607-612.

Datta, R., and Majumder, A. (2010). Optimization of turning process parameters using Multi-objective Evolutionary algorithm. *Evolutionary Computation (CEC*), 1-6.

Deb, K., Agrawal, S., Pratap, A., and Meyarivan, T. (2000). A Fast Elitist Non-dominated Sorting Genetic Algorithm for Multi-objective Optimization: NSGA-II. In M. Schoenauer, K. Deb, G. Rudolph, X. Yao, E. Lutton, J. Merelo and H.-P. Schwefel (Eds.), *Parallel Problem Solving from Nature PPSN VI* (Vol. 1917, pp. 849-858): Springer Berlin / Heidelberg.

Deb, K., and Datta, R. (2011). Hybrid evolutionary multi-objective optimization and analysis of machining operations. *Engineering Optimization*, 1-22.

Deb, K., and Sundar, J. (2006). Reference point based multi-objective optimization using evolutionary algorithms. *Proceedings of the 8th annual conference on Genetic and evolutionary computation*, 635-642.

Deb, K., Pratap, A., Agarwal, S., and Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *Evolutionary Computation, IEEE Transactions on, 6*(2), 182-197.

Dhavamani, C., and Alwarsamy, T. (2011). Optimization of cutting parameters of composite materials using genetic algorithm. *European Journal of Scientific Research, 63*(2), 279-285.

Dönmez, S., and Kentli, A. (2011). Optimization of WEDM process parameters of γ-TiAl alloy using SVM method. *Technics Technologies Education Management, 6*(4), 1225-1234.

Dubey, A. K. (2008). A hybrid approach for multi-performance optimization of the electro-chemical honing process. *The International Journal of Advanced Manufacturing Technology*, 1-12.

Dubey, A. K., and Yadava, V. (2008). Laser beam machining—A review. *International Journal of Machine Tools and Manufacture, 48*(6), 609-628.

El-Hofy, H. (2006). Fundamentals of machining processes: conventional and nonconventional processes, Vol. 978, Issues 0-7289*: CRC/Taylor & Francis*.

Engineering Department of Computer Scianece (2002), www.ee.pdx.edu/~mperkows / temp/ 0101.genetic-algorithm.ppt

Figueira, J. R., Liefooghe, A., Talbi, E. G., and Wierzbicki, A. P. (2010). A parallel multiple reference point approach for multi-objective optimization. *European Journal of Operational Research, 205*(2), 390-400.

Fonseca, C. M., and Fleming, P. J. (1993). Multiobjective genetic algorithms. *Genetic Algorithms for Control Systems Engineering, IEE Colloquium*, 6/1-6/5.

Furutani, K., Sato, H., and Suzuki, M. (2009). Influence of electrical conditions on performance of electrical discharge machining with powder suspended in working oil for titanium carbide deposition process. *International Journal of Advanced Manufacturing Technology, 40*(11-12), 1093-1101.

Garg, R. K., and Ojha, K. (2011). Parametric optimization of PMEDM process with Nickel Micro Powder suspended dielectric and varying triangular shapes electrodes on EN-19 steel. *Journal of Engineering and Applied Sciences, 6*(2), 152-156.

Garg, R. K., and Ojha, K. (2012). Parametric optimization of PMEDM process with chromium powder suspended dielectric for minimum surface roughness and maximum MRR. *Advanced Materials Research*, Vol. 383-390, pp. 3202-3206.

Geem, Z. W., Kim, J. H., and Loganathan, G. V. (2001). A new heuristic optimization algorithm: Harmony search. *Simulation, 76*(2), 60-68.

Golshan, A., Gohari, S., and Ayob, A. (2011a). Comparison of intelligent optimization algorithms for wire electrical discharge machining parameters. *Computational Intelligence, Modelling and Simulation (CIMSiM),* 134-140.

Golshan, A., Gohari, S., and Ayob, A. (2011b). Modeling and optimization of cylindrical wire electro discharge machining of AISI D3 tool steel using non-dominated sorting genetic algorithm. doi: 10.1117/12.914614.

Golshan, A., Gohari, S., and Ayob, A. (2012). Modeling and optimization of wire electrical discharge machining of cold-work steal 2601. *Manufacturing Science and Technology*, Vol. 383-390, pp. 6695-6703.

Gutowski, T. (2009). Machining Processes from http://web.mit.edu/2.810/www/ lecture09/ 4.pdf

Hajela, P., and Lin, C. Y. (1992). Genetic search strategies in multicriterion optimal design. *Structural and Multidisciplinary Optimization, 4*(2), 99-107.

Hill, T., Lewicki, P. (2008). Statistics: methods and applications : a comprehensive reference for science. StatSoft, Inc.

Ho, K. H., and Newman, S. T. (2003). State of the art electrical discharge machining (EDM). *International Journal of Machine Tools and Manufacture, 43*(13), 1287-1300.

Ho, K. H., Newman, S. T., Rahimifard, S., and Allen, R. D. (2004). State of the art in wire electrical discharge machining (WEDM). *International Journal of Machine Tools and Manufacture, 44*(12-13), 1247-1259.

Horn, J., Nafpliotis, N., and Goldberg, D. E. (1994). A niched Pareto genetic algorithm for multiobjective optimization. *Evolutionary Computation, 1994. IEEE World Congress on Computational Intelligence., Proceedings of the First IEEE Conference*, 82-87 vol.81.

Jahan, M. P., Rahman, M., and Wong, Y. S. (2011). A review on the conventional and micro-electrodischarge machining of tungsten carbide. *International Journal of Machine Tools and Manufacture, 51*(12), 837-858.

Jain, P. V. K. (2010). Advanced Machining Processes: *Allied Publishers Private Limited*.

Jianling, C. (2009). Multi-Objective Optimization of Cutting Parameters with Improved NSGA-II. *Management and Service Science, 2009. MASS '09. International Conference*, 1-4.

Jones, P., Tiwari, A., Roy, R., and Corbett, J. (2004). Multi-objective optimisation with uncertainty, Proceeding (451) Artificial Intelligence and Soft Computing, 114-119.

Joshi, S. N., and Pande, S. S. (2011). Intelligent process modeling and optimization of die-sinking electric discharge machining. *Applied Soft Computing, 11*(2), 2743-2755.

Kackar, R. N. (1985). Off-line quality control, parameter design, and the Taguchi method *Journal of Quality Technology, Vol. 17*, pp. 176-188.

Kalpakjian, S. (1995). Manufacturing engineering and technology (Vol. 3rd Edition): *Addison-Wesley*.

Kanagarajan, D., Karthikeyan, R., Palanikumar, K., and Davim, J. P. (2008). Optimization of electrical discharge machining characteristics of WC/Co composites using non-dominated sorting genetic algorithm (NSGA-II). *International Journal of Advanced Manufacturing Technology, 36*(11-12), 1124-1132.

Kanović, Ž., Rapaić, M. R., and Jeličić, Z. D. (2011). Generalized particle swarm optimization algorithm - Theoretical and empirical analysis with application in fault detection. *Applied Mathematics and Computation, 217*(24), 10175-10186.

Kansal, H. K., Singh, S., and Kumar, P. (2007). Effect of silicon powder mixed EDM on machining rate of AISI D2 die steel. *Journal of Manufacturing Processes, 9*(1), 13-22.

Khan, M. A. R., Rahman, M. M., Noor, M. M., Kadirgama, K., and Maleque, M. A. (2011). Current research trends on dry, near-dry and powder mixed electrical discharge machining. *Advances in Materials and Processing Technologies II*, Vol. 264-265, pp. 956-961.

Kim, M., Hiroyasu, T., Miki, M., and Watanabe, S. (2004). SPEA2+: Improving the Performance of the Strength Pareto Evolutionary Algorithm 2 Parallel Problem Solving from Nature. *Lecture Notes in Computer Science,* Vol. 3242.

Knowles, J., and Corne, D. (1999, 1999). The Pareto archived evolution strategy: a new baseline algorithm for Pareto multiobjective optimisation. *Evolutionary Computation, 1999. CEC 99. Proceedings of the 1999 Congress,* 105 Vol. 101.

Kodali, S. P., Kudikala, R., and Deb, K. (2008). Multi-Objective Optimization of Surface Grinding Process Using NSGA II. *Emerging Trends in Engineering and Technology, 2008. ICETET '08. First International Conference,* 763-767.

Kondayya, D., and Krishna, A. G. (2011). An integrated evolutionary approach for modelling and optimization of wire electrical discharge machining. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225*(4), 549-567.

Krishnamoorthy, A., Rajendra Boopathy, S., Palanikumar, K., and Paulo Davim, J. (2012). Application of Grey Fuzzy Logic for the Optimization of Drilling Parameters for CFRP composites with Multiple Performance Characteristics. *Measurement, 45*(5), 1286-1296.

Kung, K.-Y., Horng, J.-T., and Chiang, K.-T. (2009). Material removal rate and electrode wear ratio study on the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide. *The International Journal of Advanced Manufacturing Technology, 40*(1), 95-104.

Kuriakose, S., and Shunmugam, M. S. (2005). Multi-objective optimization of wire-electro discharge machining process by Non-Dominated Sorting Genetic Algorithm. *Journal of Materials Processing Technology, 170*(1-2), 133-141.

Latha, B., and Senthilkumar, V. S. (2009). Simulation optimization of process parameters in composite drilling process using multi-objective evolutionary algorithm, *Advances in Recent Technologies in Communication and Computing, 2009. ARTCom '09. International Conference*, 154-159.

Li, W., Man, Y., and Li, G. (2008). Optimal parameter design of input filters for general purpose inverter based on genetic algorithm. *Applied Mathematics and Computation, 205*(2), 697-705.

Lin, C. L., Lin, J. L., and Ko, T. C. (2002). Optimisation of the EDM process based on the orthogonal array with fuzzy logic and grey relational analysis method. *International Journal of Advanced Manufacturing Technology, 19*(4), 271-277.

Lin, S. (2011). NGPM -- A NSGA-II Program in Matlab v1.4. 23 Apr 2011 (Updated 26 Jul 2011) from http://www.mathworks.com/matlabcentral/fileexchange /31166-ngpm-a-nsga-ii-program-in-matlab-v1-4

Luque, M., Miettinen, K., Eskelinen, P., and Ruiz, F. (2009). Incorporating preference information in interactive reference point methods for multiobjective optimization. *Omega, 37*(2), 450-462.

Mahdavinejad, R. (2010). Optimizing of Turning parameters Using Multi-Objective Genetic Algorithm. *Advanced Materials Research*, Vol. 118-120, pp. 359-363.

Maji, K., and Pratihar, D. K. (2011). Modeling of electrical discharge machining process using conventional regression analysis and genetic algorithms. *Journal of Materials Engineering and Performance, 20*(7), 1121-1127.

Mandal, D., Pal, S. K., and Saha, P. (2007). Modeling of electrical discharge machining process using back propagation neural network and multi-objective optimization using non-dominating sorting genetic algorithm-II. *Journal of Materials Processing Technology, 186*(1-3), 154-162.

Mandal, N., Doloi, B., Mondal, B., and Das, R. (2011). Optimization of flank wear using Zirconia Toughened Alumina (ZTA) cutting tool: Taguchi method and Regression analysis. *Measurement, 44*(10), 2149-2155.

Manolas, D. A., Gialamas, T. P., Frangopoulos, C. A., and Tsahalis, D. T. (1996). A genetic algorithm for operation optimization of an industrial cogeneration system. *Computers and Chemical Engineering, 20*(SUPPL.2), S1107-S1112.

Meleka, A. H., and Glew, D. A. (1977). Electrochemical machining. *International Metals Reviews, 22*(1), 229-252.

Mitra, K. (2009). Multiobjective optimization of an industrial grinding operation under uncertainty. *Chemical Engineering Science, 64*(23), 5043-5056.

Mitra, K., and Gopinath, R. (2004). Multiobjective optimization of an industrial grinding operation using elitist nondominated sorting genetic algorithm. *Chemical Engineering Science, 59*(2), 385-396.

Mohd Abbas, N., Solomon, D. G., and Fuad Bahari, M. (2007). A review on current research trends in electrical discharge machining (EDM). *International Journal of Machine Tools and Manufacture, 47*(7-8), 1214-1228.

Murata, T., and Ishibuchi, H. (1995). MOGA: multi-objective genetic algorithms. *Evolutionary Computation, 1995., IEEE International Conference,* 289.

Narula, S. C., and Wellington, J. F. (2002). Multiple Objective Optimization Problems in Statistics. *International Transactions in Operational Research, 9*(4), 415-425.

Natarajan, N., and Arunachalam, R. M. (2011). Optimization of micro-EDM with multiple performance characteristics using taguchi method and grey relational analysis. *Journal of Scientific and Industrial Research, 70*(7), 500-505.

Neşeli, S., Yaldız, S., and Türkeş, E. (2011). Optimization of tool geometry parameters for turning operations based on the response surface methodology. *Measurement, 44*(3), 580-587.

Ojha, K., Garg, R. K., and Singh, K. K. (2011). The effect of nickel micro powder suspended dielectric on EDM performance measures of EN-19 steel. *Journal of Engineering and Applied Sciences, 6*(1), 27-37.

Okuda , T., Hiroyasu, T., Miki, M., Watanabe, S. (2002). *DCMOGA:* Distributed Cooperation Model of Multi-Objective Genetic Algorithm. *Proceedings of the PPSN/SAB Workshop on Multiobjective Problem Solving from Nature II (MPSN-II).*

Palanikumar, K. (2011). Experimental investigation and optimisation in drilling of GFRP composites. *Measurement, 44*(10), 2138-2148.

Palanikumar, K., Latha, B., Senthilkumar, V. S., and Karthikeyan, R. (2009). Multiple performance Optimization in machining of GFRP composites by a pcd tool using Non-dominated Sorting Genetic Algorithm (NSGA-II). *Metals and Materials International, 15*(2), 249-258.

Pandey, P. C., and Shan, H. S. (2008). Modern Machining Processes: *Tata McGraw-Hill Education*.

Peças, P., and Henriques, E. (2008a). Effect of the powder concentration and dielectric flow in the surface morphology in electrical discharge machining with powder-mixed dielectric (PMD-EDM). *International Journal of Advanced Manufacturing Technology, 37*(11-12), 1120-1132.

Peças, P., and Henriques, E. (2008b). Electrical discharge machining using simple and powder-mixed dielectric: The effect of the electrode area in the surface roughness and topography. *Journal of Materials Processing Technology, 200*(1-3), 250-258.

Prasad, D., and Krishna, A. G. (2009). Empirical modeling and optimization of wire electrical discharge machining. *The International Journal of Advanced Manufacturing Technology, 43*(9), 914-925.

Prihandana, G. S., Mahardika, M., Hamdi, M., Wong, Y. S., and Mitsui, K. (2009). Effect of micro-powder suspension and ultrasonic vibration of dielectric fluid in micro-EDM processes-Taguchi approach. *International Journal of Machine Tools and Manufacture, 49*(12-13), 1035-1041.

Pulido, G. T., and Coello, C. A. C. (2003). The Micro Genetic Algorithm 2: Towards Online Adaptation in Evolutionary Multiobjective Optimization. *EMO'03 Proceedings of the 2nd international conference on Evolutionary multi-criterion optimization*, 252-266.

Rajurkar, K. P., Zhu, D., McGeough, J. A., Kozak, J., and De Silva, A. (1999). New Developments in Electro-Chemical Machining. *CIRP Annals - Manufacturing Technology, 48*(2), 567-579.

Ramachandran, N., and Ramakrishnan, N. (1993). A review of abrasive jet machining. *Journal of Materials Processing Technology, 39*(1-2), 21-31.

Ramesh, S., Karunamoorthy, L., and Palanikumar, K. (2012). Measurement and Analysis Of Surface Roughness In Turning Of Aerospace Titanium Alloy (Gr 5). *Measurement, 45*(5), 1266-1276.

Reza, M. S., Hamdi, M., and Hadi, A. S. (2011). Optimization of control parameters for MRR in injection flushing type of EDM on stainless steel 304 workpiece. *Proceedings of World Academy of Science, Engineering and Technology, 76*, 399-401.

Roy, R., and Mehnen, J. (2008). Dynamic multi-objective optimisation for machining gradient materials. *CIRP Annals - Manufacturing Technology, 57*(1), 429-432.

Sadeghi, M., Razavi, H., Esmaeilzadeh, A., and Kolahan, F. (2011). Optimization of cutting conditions in WEDM process using regression modelling and Tabu-search algorithm. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225*(10), 1825-1834.

Saravanan, R., Asokan, P., and Sachidanandam, M. (2002). A multi-objective genetic algorithm (GA) approach for optimization of surface grinding operations. *International Journal of Machine Tools and Manufacture, 42*(12), 1327-1334.

Sardiñas, R. Q., Santana, M. R., and Brindis, E. A. (2006b). Genetic algorithm-based multi-objective optimization of cutting parameters in turning processes. *Engineering Applications of Artificial Intelligence, 19*(2), 127-133.

Sardiñas, R. Q., Mengana, J. E. A., and Davim, J. P. (2009). Multi-objective optimisation of multipass turning by using a genetic algorithm. *International Journal of Materials and Product Technology, 35*(1-2), 134-144.

Sardiñas, R. Q., Reis, P., and Davim, J. P. (2006a). Multi-objective optimization of cutting parameters for drilling laminate composite materials by using genetic algorithms. *Composites Science and Technology, 66*(15), 3083-3088.

Sarker, R., Liang, K.-H., and Newton, C. (2002). A new multiobjective evolutionary algorithm. *European Journal of Operational Research, 140*(1), 12-23.

Schaffer, J. D. (1985). Multiple Objective Optimization with Vector Evaluated Genetic Algorithms. *Proceedings of the 1st International Conference on Genetic Algorithms*, 93-100.

Senthilkumar, C., Ganesan, G., and Karthikeyan, R. (2010). Bi-performance optimization of electrochemical machining characteristics of Al/20%SiCp composites using NSGA-II. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 224*(9), 1399-1407.

Senthilkumar, C., Ganesan, G., and Karthikeyan, R. (2011). Parametric optimization of electrochemical machining of Al/15 SiC p composites using NSGA-II. *Transactions of Nonferrous Metals Society of China (English Edition), 21*(10), 2294-2300.

Seshadri, A. (2007). A fast elitist multiobjective genetic algorithm: NSGA-II [Electronic Version], from http://www.mathworks.com/matlabcentral/ fileexchange

Singh, S. (2012). Optimization of machining characteristics in electric discharge machining of 6061Al/Al 2O 3p/20P composites by grey relational analysis. *International Journal of Advanced Manufacturing Technology*, 1-12.

Singh, S., and Yeh, M. F. (2011). Optimization of Abrasive Powder Mixed EDM of Aluminum Matrix Composites with Multiple Responses Using Gray Relational Analysis. *Journal of Materials Engineering and Performance*, 1-11.

Solimanpur, M., and Ranjdoostfard, F. (2009). Optimisation of cutting parameters using a multi-objective genetic algorithm. *International Journal of Production Research, 47*(21), 6019-6036.

Srinivas, N., and Deb, K. (1994). Muiltiobjective Optimization Using Nondominated Sorting in Genetic Algorithms. *Evolutionary Computation, 2*(3), 221-248.

Su, C. H., and Hou, T. H. (2008). Using multi-population intelligent genetic algorithm to find the pareto-optimal parameters for a nano-particle milling process. *Expert Systems with Applications, 34*(4), 2502-2510.

Sultana, I., and Dhar, N. R. (2010). GA based multi objective optimization of the predicted models of cutting temperature, chip reduction co-efficient and surface roughness in turning AISI 4320 steel by uncoated carbide insert under HPC condition. *Proceedings of the 2010 International Conference on Mechanical, Industrial, and Manufacturing Technologies (MIMT 2010)*, 161-167.

Surry, P. D., and Radcliffe, N. J. (1997). The COMOGA method: Constrained optimisation by multi-objective genetic algorithms. *Control and Cybernetics, 26*(3), 391-412.

Swain, A. K., Ray, S., and Mandal, N. K. (2012). Study on kerf width in wire-EDM based on Taguchi method. *Applied Mechanics and Materials*,Vol. 110-116, pp. 1808-1816.

Thiyagarajan, S., Sivapirakasam, S. P., Mathew, J., and Surianarayanan, M. (2012). Experimental investigation on manufacturing and environmental aspects of electrical discharge machining process using graphite electrode. *Advanced Materials Research*, Vol. 433-440, pp. 655-659.

Tiwari, S., Fadel, G., and Deb, K. (2011). AMGA2: Improving the performance of the archive-based micro-genetic algorithm for multi-objective optimization. *Engineering Optimization, 43*(4), 377-401.

Tiwari, S., Koch, P., Fadel, G., and Deb, K. (2008). AMGA: an archive-based micro genetic algorithm for multi-objective optimization. *Proceedings of the 10th annual conference on Genetic and evolutionary computation*, 729-736.

Tsai, Y. Y., and Masuzawa, T. (2004). An index to evaluate the wear resistance of the electrode in micro-EDM. *Journal of Materials Processing Technology, 149*(1–3), 304-309.

Venkataraman, R. (2012). Multi objective optimization of electro discharge machining of resin bonded silicon carbide. *Applied Mechanics and Materials*, Vol. 110-116, pp. 1556-1560.

Venkatesh, V. C., and Narayanan, V. (1986). Machinability Correlation Among Turning Milling and Drilling Processes. *CIRP Annals - Manufacturing Technology, 35*(1), 59-62.

Venkatesh, V. C., Goh, T. N., Wong, K. H., and Lim, M. J. (1989). An empirical study of parameters in abrasive jet machining. *International Journal of Machine Tools and Manufacture, 29*(4), 471-479.

Vundavilli, P. R., Parappagoudar, M. B., Kodali, S. P., and Benguluri, S. (2012). Fuzzy logic-based expert system for prediction of depth of cut in abrasive water jet machining process. *Knowledge-Based Systems, 27*(0), 456-464.

Wang, D. A., Lin, Y. C., Chow, H. M., Fan, S. F., and Wang, A. C. (2012). Optimization of machining parameters using EDM in gas media based on Taguchi method. *Advanced Materials Research*, Vol. 459, pp. 170-175.

Wang, Z., Wong, Y., Rahman, M., and Sun, J. (2006). Multi-objective optimization of high-speed milling with parallel genetic simulated annealing. *The International Journal of Advanced Manufacturing Technology, 31*(3), 209-218.

Watanabe, S., Hiroyasu, T., and Miki, M. (2002). NCGA: Neighborhood Cultivation Genetic Algorithm for Multi-Objective Optimization Problems. *Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2002)*, 458-465.

Weight function. (2012). From http://en.wikipedia.org/wiki/Weight_function

wiseGEEK. (2003 - 2012). What Is EDM (Electrical Discharge Machining)?, from http://www.wisegeek.com/what-is-edm.htm

Wong, T. N., Chan, L. C. F., and Lau, H. C. W. (2003). Machining process sequencing with fuzzy expert system and genetic algorithms. *Engineering with Computers, 19*(2-3), 191-202.

Xie, S., and Guo, Y. (2011). Intelligent selection of machining parameters in multi-pass turnings using a GA-based approach. *Journal of Computational Information Systems, 7*(5), 1714-1721.

Yang, S., and Natarajan, U. (2010). Multi-objective optimization of cutting parameters in turning process using differential evolution and non-dominated sorting genetic algorithm-II approaches. *The International Journal of Advanced Manufacturing Technology, 49*(5), 773-784.

Yen, G. G., and Haiming, L. (2003). Dynamic multiobjective evolutionary algorithm: adaptive cell-based rank and density estimation. *Evolutionary Computation, IEEE Transactions on, 7*(3), 253-274.

Yildiz, A. R., and Ozturk, F. (2006). Hybrid enhanced genetic algorithm to select optimal machining parameters in turning operation. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 220*(12), 2041-2053.

Zain, A. M., Haron, H., and Sharif, S. (2008). An overview of GA technique for surface roughness optimization in milling process. *Information Technology, 2008. ITSim 2008. International Symposium on, 1-6.*

Zain, A. M., Haron, H., and Sharif, S. (2010a). Application of GA to observe the optimal effect of the radial rake angle for minimising surface roughness in end milling. *International Journal of Machining and Machinability of Materials, 8*(3-4), 283-305.

Zain, A. M., Haron, H., and Sharif, S. (2010b). Application of GA to optimize cutting conditions for minimizing surface roughness in end milling machining process. *Expert Systems with Applications, 37*(6), 4650-4659.

Zain, A. M., Haron, H., and Sharif, S. (2010c). Genetic Algorithm and Simulated Annealing to estimate optimal process parameters of the abrasive waterjet machining. *Engineering with Computers*, 1-9.

Zain, A. M., Haron, H., and Sharif, S. (2011a). Estimation of the minimum machining performance in the abrasive waterjet machining using integrated ANN-SA. *Expert Systems with Applications, 38*(7), 8316-8326.

Zain, A. M., Haron, H., and Sharif, S. (2011b). Optimization of process parameters in the abrasive waterjet machining using integrated SA–GA. *Applied Soft Computing, 11*(8), 5350-5359.

Zhang, L., Jia, Z., Wang, F., and Liu, W. (2010). A hybrid model using supporting vector machine and multi-objective genetic algorithm for processing parameters optimization in micro-EDM. *International Journal of Advanced Manufacturing Technology, 51*(5-8), 575-586

Zitzler, E., and Thiele, L. (1999). Multiobjective evolutionary algorithms: A comparative case study and the strength Pareto approach. *IEEE Transactions on Evolutionary Computation, 3*(4), 257-271.

Zitzler, E., Laumanns, M., and Thiele, L. (2001). SPEA2: Improving the Strength Pareto Evolutionary Algorithm. *Evolutionary Methods for Design Optimization and Control with Applications to Industrial Problems* Athens, Greece: International Center for Numerical Methods in Engineering (2001), 95-100