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"NON-CONVENTIONAL MACHINING OF COMPOSITE METALS WITH MULTI OBJECTIVE OPTIMIZATION TO IMPROVE EFFICIENCY"

Sushil Kumar[1]
Research Scholar , Shri Venkateshwara University, Gajraula, Amroha , India
dnsushilclasses@gmail.com

Dr. Nitin Agarwal[2]
Research Guide, Shri Venkateshwara University, Gajraula, Amroha, India

ABSTRACT

The role of non-conventional machining processes (NCMPs) in today's manufacturing environment has been well acknowledged. For effective utilization of the capabilities and advantages of different NCMPs, selection of the most appropriate NCMP for a given machining application requires consideration of different conflicting criteria. This paper presents the application of a recent MCDM method, i.e., the multi-objective optimization on the basis of ratio analysis (MOORA) method to solve NCMP selection which has been defined considering different performance criteria of four most widely used NCMPs. In order to determine the relative significance of considered quality criteria a pair-wise comparison matrix of the analytic hierarchy process was used. The results obtained using the MOORA method showed perfect correlation with those obtained by the technique for order preference by similarity to ideal solution (TOPSIS) method which proves the applicability and potentiality of this MCDM method for solving complex NCMP selection problems.

KEYWORDS: Non-conventional machining processes, Multi-criteria decision making, Selection, MOORA method.

1. INTRODUCTION

In today's industry, a number of non-conventional machining processes (NCMPs) are increasingly being used for processing of different engineering materials. it has been observed that different multi-criteria decision making (MCDM) methods have been applied for solving NCMP selection problems. MCDM is concerned with those situations where a decision maker has to rank a set of competitive alternatives and select the best alternative while considering a set of conflicting criteria [4]. In order to evaluate the overall performance of the competitive alternatives, the primary objective of an MCDM method is to identify the relevant selection problem criteria, assess the alternative's information relating to those criteria and develop methodologies for determining the relative significance of each criterion. It has been observed that the performance of this method is comparable with other popular and widely used MCDM methods. Moreover, computationally the method is very simple and can be easily implemented. In this paper, firstly a MCDM model which can be used to select the most suitable NCMP considering different performance criteria has been defined. A pair-wise comparison matrix of the AHP method was then used to determine the relative significance of considered quality criteria, and finally the competitive NCMPs were ranked by using the MOORA method. In order to validate the obtained complete rankings of NCMPs of the MOORA method, the NCMP selection problem was solved also by using the TOPSIS method.

2. LITERATURE REVIEW

Most of the past work is related to the development of expert systems, decision support systems and particularly to the application of different MCDM methods for solving NCMPs selection problems. It has to be noted that the majority of the previous studies considered decision matrices from the literature, and only few studies, such as one presented by Temuçin et al. (2013), were focused on the development of decision models for NCMP selection. Yurdakul and Cogun (2003) proposed a selection procedure for NCMPs based on a combination of analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) methods. AHP method is used to determine the criteria weights, i.e. relative importance of the criteria, whereas TOPSIS method is used to rank each of the feasible NCMPs. Chakraborty and Dey (2006) presented a systematic methodology for selecting the best NCMP under constrained material and machining conditions. The authors also presented the design of an AHP based expert system with a graphical user interface to ease the decision-making process. Chakladar and Chakraborty (2008) proposed the use of a combined approach using the TOPSIS and AHP methods to select the most appropriate NCMP for a specific work material and shape feature combination.

2.1 LITERATURE ON MACHINING

A detailed study of different tooling systems has been made by Manna and Bhattacharya [2]. Results showed that the rotary circular tooling exhibits good wear resistance, the rhombic fixed tool is effective at high speed and low depth of cut, the fixed circular tooling provides better results at high depth of cut, and high speed and RCT produce low surface finish. The Sic particles in MMCs are harder than tungsten carbide and that warrants the need for poly crystalline diamond (PCD) in turning operations, and the effect of cutting parameters is studied by Paulo Davim [3]. Tomac and Tonnessen [4] have reported that PCD tools are better than carbide tools (K10), but results in high machining cost. Hung et al. [5] have concluded that the cubic boron nitride and diamond tools, being the best among other conventional materials, suffer from high tool cost and restricted shape. Ding et al. [6] have claimed that PCD tools are better than PCBN ones because of their high resistance to abrasion and fracture. But according to Brun and Lee [7] the PCD also has relatively shorter tool life at moderate speed. Teti [8] found that the tools coated with diamond using CVD may be superior to PCD in machining the brake drum made of aluminum MMC. According to his findings, the machinability is critically affected by the reinforcement and matrix hardness rather than cutting parameters. Machining MMCs with different nonconventional methods have been carried out by Muller and Monaghan [9,10].

3. NCMPS SELECTION PROBLEM

Ability to machine advanced materials and fulfill the requirements of high dimensional accuracy and surface finish, made NCMPs one of the most used machining processes in today’s industry. Quality performances are very important aspect for NCMPs because it helps to achieve proper tolerance and the required quality of cut, thus eliminating the need for post-processing. These are dependable not only on the machining process itself, but also on the machine tool and its control capabilities, thickness and type of material being cut and also the machining process parameter settings. Process performances are also important aspect while selecting the most suitable NCMP. It can be considered by taking into account either individually or collectively several indicators such as the specific cutting energy, cutting speed, specific cutting power and the like. Among these, cutting speed is one of the most important factors, and at the same time represents one of the major technoeconomic performances of NCMPs.

3.1. FORMULATION OF THE NCPM SELECTION MODEL

The present MCDM problem is based on the evaluation of four NCMPs i.e. LBM, PAM, EDM and AWJM considering 9 criteria. The NCMPs selection problem was defined considering:

i. Work piece material (WM): This criterion is concerned with the ability of a given NCMP to machine a given work piece material. It is preferable that a given NCMP has the ability to machine a wider range of materials.

ii. Temperature of the cut (TC): This criterion incorporates the fact that during different NCMPs there exist temperature effects which may have important impacts on metallurgical properties of the work piece material.

iii. Economical work piece thickness (EWT): Although the considered NCMP can machine a wide spectrum of material thicknesses, for each NCMP there is an interval range of material thickness for which the given NCMP is particularly suitable. In other words, the use of a given NCMP within this range is economical.

iv. Machining accuracy (MA): The machining accuracy is determined by the characteristics of the coordinate worktable (positioning accuracy) and the quality of the control unit of machine tool.

v. Kerf taper (KT): Kerf taper is a special and undesirable geometrical feature inherent to all NCMPs. Kerf taper is normally expressed by kerf taper angle. Reduced kerf taper angle is very important since it allows better positioning of parts, elimination of post-processing and finally saving of material.

vi. Kerf width (KW): Kerf width and kerf taper are one of the most important quality performance criteria that directly affect final dimensions of the workpiece. It can be defined as the width of material that is removed by a given NCMP. Each NCMP removes a different amount of material i.e. creates different kerf width. The more precise process, the smaller the kerf width is. Generally, it is mainly influenced by the cutting speed.

vii. Quality of surface roughness (QSR): Assessment of the surface roughness includes the shape and size of irregularities and in practice comes down to analysis of particular sections on the cut surface. Surface roughness parameters defined by international standards are related to the characteristics of the irregularities profiles. Most frequently used parameters for surface roughness are maximum height of the assessed profile (Rz) and the arithmetic mean deviation of the profile (Ra).

4 . THE MOORA METHOD

It can simultaneously take into account any number of criteria and offer a very simple computational procedure. As this method is based on simple ratio system, it involves the least amount of mathematical computations. This has the double benefit for decision makers. On the one hand, the implementation of the MOORA method does not necessarily requires strong background in mathematics and operational research. On the other hand, unlike many other MCDM methods, which require software packages in order to efficiently solve a given MCDM problem, all mathematical calculations of the MOORA can be easily worked in MS Excel. Regarding required application steps for solving decision making problems, the MOORA method has advantage over other MCDM methods. While only five steps are needed to solve a particular decision making method using the MOORA method, TOPSIS method requires nine steps [22]. Also, unlike many other MCDM methods, the normalization of decision matrix is done by vector normalization procedure using only one normalization equation regardless of the nature of criterion (beneficial or non-beneficial). In such way there is no need to use additional normalization equations or to transform non-beneficial to beneficial criteria and vice versa. As noted by Chakraborty [12], another major advantage of this method is that its calculation procedure is not affected by the introduction of any additional parameters as it happens in case of other MCDM methods.

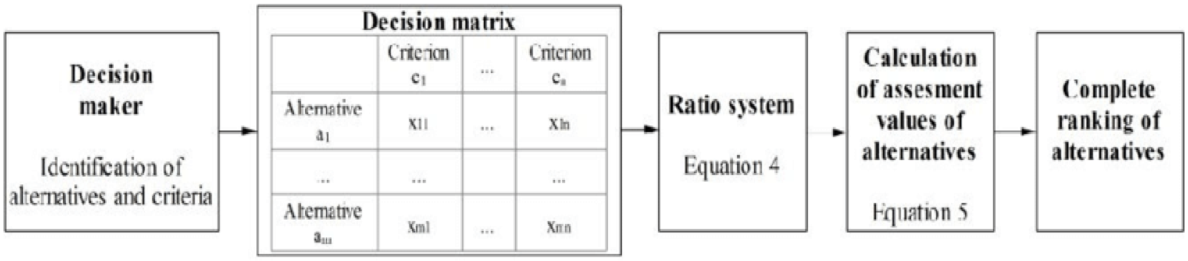

Fig-1 Application Procedure of MOORA method.

4.1 NON-CONVENTIONAL MACHINING METHODS

The so-called non-conventional machining methods can no longer be called “non-traditional”, since they found a wide range of applications. Moreover, these electro-physical and electro-chemical material removal methods often do compete with the more traditional machining techniques.

Those non-conventional machining methods allow the machining of complex shapes, not at least because of the use of advanced CNC-technology. The cutability of material often suggests the use of these techniques, e.g. when hard steel alloys and special composite materials are concerned.

Evidence is given of the growing economical importance and the enlarged scope of applications covered by these non-conventional manufacturing methods. This is illustrated by a number of specific examples. Some recent developments and new trends are highlighted as well.

Some industrial examples illustrate how some of these techniques can be competitive with classical manufacturing methods. In many other cases they are the only efficient solution for realizing specific industrial products. In combination with conventional machining methods Improved performances may be achieved.

Machining of metal matrix composite is a difficult task as compared to monolithic materials due to hard-to-cut reinforced materials. However, metal matrix composites are gaining worldwide importance in the field of manufacturing industries due to their high strength-to-weight ratio, high ultimate tensile strength, temperature resistance, excellent structural stability. To improve the machining conduct of metal network composites, various methods were adopted, including conventional, non-conventional, and hybrid machining processes. This paper centers around the examination and investigation of different machining cycles of metal matrix composites to get the upgraded result and it is observed that hybrid machining plays an important role in machining metal matrix composite as compared to other methods due to its better machining ability. Since the availability of hybrid-machine is not common and also skilled people are required to run hybrid machines so, non-conventional machining also plays a vital role in achieving the goal. Machining of composite materials is difficult due to the heterogeneity and heat sensitivity of the material and the high abrasiveness of the reinforcing fibers. This results in damage being introduced into the work piece and very high tool wear. Here new methods are considered: laser, waterjet, electro-discharge, electro-chemical spark, and ultrasonic machining. These various techniques have been applied to organic matrix composites with aramid, glass, graphite fiber reinforcement but also to metal matrix and ceramic matrix composites.

NON-CONVENTIONAL MACHINING PROCESSES

- The non-conventional machining method involves the use of modern and advanced technology for machine processing.
- There is no physical contact between the tool and the workpiece in such a process.
- Tools used for cutting in unconventional methods are laser beams, electric beam, electric arc, infrared beam, Plasma cutting, and so on depending on the type of working material.

ADVANTAGES OF NON-CONVENTIONAL MACHINING PROCESS

i. It has good accuracy.

ii. It provides a good surface.

iii. Complex shapes can be made easily.

iv. It has longer tool life.

v. The rate of metal removal is high.

DISADVANTAGE OF NON-CONVENTIONAL MACHINING PROCESS

i. The cost of this process is high.

ii. It requires skilled operators.

iii. Its setup is difficult.

4.2 BACKGROUND AND MOTIVATION

composite materials play an important role in the field of engineering as well as advance manufacturing in response to unprecedented demands from technology due to rapidly advancing activities in aircrafts, aerospace and automotive industries. These materials have low specific gravity that makes their properties particularly superior in strength and modulus to many traditional engineering materials such as metals. As a result of intensive studies into the fundamental nature of materials and better understanding of their structure property relationship, it has become possible to develop new composite materials with improved physical and mechanical properties. These new materials include high performance composites such as reinforced composites. Continuous advancements have led to the use of composite materials in more and more diversified applications. The importance of composites as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 200 are composite [1].

4.3 COMPOSITES

The typical composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. The constituents retain their identities, that is, they do not dissolve or merge completely into one another although they act in concert. The individual materials that make up composites are called constituents. Most composites have two constituent materials: a binder or matrix (polymers, metals, or ceramics) and reinforcement (fibers, particles, flakes, and/or fillers). The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its good properties. The matrix holds the reinforcements in an orderly pattern. Because the reinforcements are usually discontinuous, the matrix also helps to transfer load among the reinforcements.

4.4 COMPONENTS OF A COMPOSITE MATERIAL

The material, which uses as matrix must bind and hold firmly the reinforcing phase in position within. The matrix isolates the materials from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the materials in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the materials and evenly distributive stress concentration. A few inorganic materials, polymers and metals have found applications as matrix materials in the designing of structural composites, with commendable success. These materials remain elastic till failure occurs and show decreased failure strain, when loaded in tension and compression. Some generally used as matrices are Polymer matrices [4, 5], Ceramic matrices [6] and Metal matrices [7]. Reinforcing constituents in composites indicates to provide the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements. A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimal or even nil the composite must behave as brittle as possible.

4.5 APPLY RESEARCH METHODOLOGY

It is widely used in engineering, in electronic design automation, automatic control systems, and optimal design problems arising in civil, chemical, mechanical, and aerospace engineering. Since the late 1940s, a large effort has gone into developing algorithms for solving various classes of optimization problems, analyzing their properties, and developing good software implementations. In this contest, the task is to find a model, from a family of potential models, which best fits some observed data. Here the variables are the parameters in the model. In order to determine the factor level settings that optimize the performance of the quality characteristics in a single setting, a hybrid optimization technique namely principal component analysis (PCA) coupled with fuzzy inference system are used for combining multiple responses into a single response known as multi-response performance characteristics index (MPCI). Finally, empirical relationship between process parameters and MPCI is derived using Taguchi methodology. To check the soundness of this hybrid optimization technique, another solo optimization technique called weighted principal component analysis (WPCA) is used. In this context optimal settings from both the techniques are compared and analyzed. Development of a valid model helps to search the optimization landscape to find out best possible parametric combination resulting best quality characteristics, which has not been explored during experimentation.

5. OBJECTIVES OF RELATED RESEARCH

i) To Complex shapes can be made easily.
ii) To make the work-piece is free from any stress after machining.
iii) To Extremely hard and brittle materials can be easily removed.
iv) To provides good surface finishing with excellent accuracy.

6. RESULTS AND FUTURE SCOPE

In this thesis, a MCDM model for the selection of the most appropriate NCMP considering different criteria, particularly related to quality performance, has been defined and solved by using the MOORA method. The obtained results suggested that AWJM is the best alternative, while EDM is the second one. LBM and PAM were the third and fourth alternatives in the rank. In order to validate the obtained rankings of NCMPs obtained by the application of the MOORA method, the considered NCMPs selection problem was solved by using the TOPSIS method.

THE ADVANTAGES AND BENEFITS of the MOORA method over other available MCDM methods are reflected in the following facts:

(i) the application of the MOORA method for solving a particular decision making problems requires fewer application steps,
(ii) single equation is required for the purpose of decision. Most of the researchers were tried their work in only EDM and ECM. There is lot of scope to machine composite materials in other non-traditional machining process.

CONCLUSION

The research work of the last 20 years has been discussed. Of the many of non-traditional machining methods reviewed in this article, MOORA method is currently used extensively in industry for machining of NCMPs. This is reflected in the number of publications concerned with these processes. For each and every method introduced and employed in machining process, the objectives are the same: to enhance the capability of machining performance i.e. more material removal rate and better surface finish and to get better output product. It was observed that ranking of competitive NCMPs exactly match. The main advantage of the MOORA method is that it can take into account any number of criteria, both quantitative and qualitative, and offer a very simple computational procedure. Moreover, the implementation of MOORA method does not necessarily requires strong background in mathematics and operational research as well the use of specialized software packages. The performance of the reference point approach and full multiplicative MOORA method are also tested for the considered problems. It is observed that all these three methods are very simple to understand, easy to implement and provide almost exact rankings to the material alternatives.

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