INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 04, April 2025, pp : 3363-3368
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

NON-CONVENTIONAL MACHINING OF METAL MATRIX COMPOSITES PARAMETRIC APPRAISAL AND MULTI-OBJECTIVE OPTIMIZATION

Kriti Sahu[1], Takeshwar Kaushik[2]

[1]M. Tech scholar, ISBM University Gariyaband Chhattisgarh India.

[2]Assistant Professor, ISBM University, Gariyaband, Chhattisgarh, India.

DOI: https://www.doi.org/10.58257/IJPREMS40380

ABSTRACT

Al, SiCp MMCs have wide range of applications in aerospace, automotive and electronics engineering due to its excellent properties compared to other conventional materials. Conventional machining process shows difficulties in machining of these advanced materials due to several reasons like high tool wear, poor surface roughness, high machining cost etc. Therefore, different researchers have utilized several advanced machining methods like electro discharge machining, electrochemical machining, ultrasonic machining etc. for effective machining of these composites. In this present work, ECM and EDM have been selected for machining of MMCs towards obtaining high product quality and satisfactory process performance yield. It is utmost important that several process parameters of ECM and EDM need to be precisely controlled as well as optimized. Taguchi method is generally used only for optimizing single response. As these processes are involved with multiple response characteristics; exploration of an appropriate multi-objective optimization technique is indeed essential. Therefore, this thesis work represents case study on selection of optimal machining parameters in ECM of Al/15%SiC composites using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) integrated with Taguchi method and further utilizing another hybrid method Grey-Fuzzy Logic coupled with Taguchi's optimization philosophy. The performance characteristics: Material Removal Rate (MRR) and surface roughness have been considered for optimizing the machining parameters (feed rate, voltage and electrolytic concentration).

1. INTRODUCTION

A composite material comprises of two or more chemically and/or physically apparent phases. Composite materials, also termed as composition materials or known as composites, are naturally or engineered appearing materials produced from two or more composing materials with considerably different chemical or physical properties which persist distinct and separate within the finished structure. The constituent elements, mainly comprises of a reinforcing elements, fillers, and a composite matrix binder which differ in composition or form on a macro-scale. The constituent elements preserve their own characters means they do not merge or dissolve completely into one another although they act in concert. Normally, the constituents exhibit an interface between one another and can be physically identified.

Composites which are of heterogeneous structures accommodate the necessities of specific function and design, infused with ambitious properties which limit the scope for classification. However, this blunder is made up for, by the reality new varieties of composites are being invented, each with their own specific characteristics and purpose like the particulate, flake, laminar and filled composites. Particles or fibers entrenched in matrix of another material are the most suitable example of modern-day composite materials, which are mostly structural. The present study deals with machining and machinability aspects of Metal Matrix Composites (MMCs) (Hybrid Composites) emphasizing parametric appraisal and multi-objective optimization in relation to machining performance features. The following sections accumulate basic knowledge on MMCs.

2. METAL MATRIX COMPOSITES

A **metal matrix composite** (**MMC**) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a **hybrid composite**. An MMC is complementary to a cermet.

2.1 Composition

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminum matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminum to generate a brittle and water-soluble compound Al_4C_3 on the surface of the fiber. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride.

2.2 Matrix

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

2.3 Reinforcement

The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

Applications of Metal Matrix Composites

- Carbide drills are often made from a tough cobalt matrix with hard tungsten carbide particles inside.
- Some tank armors may be made from metal matrix composites, probably steel reinforced with boron nitride. Boron nitride is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.
- Some automotive disc brakes use MMCs. Early Lotus Elise models used aluminum MMC rotors, but they have less than optimal heat properties and Lotus has since switched back to cast-iron. Modern high-performance sport cars, such as those built by Porsche, use rotors made of carbon fiber within a silicon carbide matrix because of its high specific heat and thermal conductivity. 3M sells a preformed aluminum matrix insert for strengthening cast aluminum disc brake calipers, allowing them to weigh as much as 50% less while increasing stiffness. 3M has also used alumina preforms for AMC pushrods.
- Ford offers a Metal Matrix Composite (MMC) driveshaft upgrade. The MMC driveshaft is made of an aluminum matrix reinforced with boron carbide, allowing the critical speed of the driveshaft to be raised by reducing inertia. The MMC driveshaft has become a common modification for racers, allowing the top speed to be increased far beyond the safe operating speeds of a standard aluminum driveshaft.
- Honda has used aluminum metal matrix composite cylinder liners in some of their engines, including the B21A1, H22A and H23A, F20C and F22C, and the C32B used in the NSX.
- Toyota has since used metal matrix composites in the Yamaha-designed 2ZZ-GE engine which is used in the later Lotus Elise S2 versions as well as Toyota car models, including the eponymous Toyota Matrix. Porsche also uses MMCs to reinforce the engine's cylinder sleeves in the Boxster and 911.
- The F-16 Fighting Falcon uses monofilament silicon carbide fibers in a titanium matrix for a structural component of the jet's landing gear.
- Specialized Bicycles has used aluminum MMC compounds for its top of the range bicycle frames for several years. Griffen Bicycles also makes boron carbide-aluminum MMC bike frames, and Univega briefly did so as well.
- Some equipment in particle accelerators such as Radio Frequency Quadrupoles (RFQs) or electron targets use copper MMC compounds such as Glidcop to retain the material properties of copper at high temperatures and radiation levels.
- Copper-silver alloy matrix containing 55 vol. % diamond particles, known as Dym alloy, is used as a substrate for high-power and high density multi-chip modules in electronics for its very high thermal conductivity.
- Ford offers a Metal Matrix Composite (MMC) driveshaft upgrade. The MMC driveshaft is made of an aluminum matrix reinforced with boron carbide, allowing the critical speed of the driveshaft to be raised by reducing inertia. The MMC driveshaft has become a common modification for racers, allowing the top speed to be increased far

beyond the safe operating speeds of a standard aluminum driveshaft.

- Honda has used aluminum metal matrix composite cylinder liners in some of their engines, including the B21A1, H22A and H23A, F20C and F22C, and the C32B used in the NSX.
- Toyota has since used metal matrix composites in the Yamaha-designed 2ZZ-GE engine which is used in the later Lotus Elise S2 versions as well as Toyota car models, including the eponymous Toyota Matrix. Porsche also uses MMCs to reinforce the engine's cylinder sleeves in the Boxster and 911.
- The F-16 Fighting Falcon uses monofilament silicon carbide fibers in a titanium matrix for a structural component of the jet's landing gear.
- Specialized Bicycles has used aluminum MMC compounds for its top of the range bicycle frames for several years. Griffen Bicycles also makes boron carbide-aluminum MMC bike frames, and Univega briefly did so as well.
- Some equipment in particle accelerators such as Radio Frequency Quadrupoles (RFQs) or electron targets use copper MMC compounds such as Glidcop to retain the material properties of copper at high temperatures and radiation levels.
- Copper-silver alloy matrix containing 55 vol. % diamond particles, known as Dym alloy, is used as a substrate for high-power and high density multi-chip modules in electronics for its very high thermal conductivity.

While a variety of matrix materials has been used for making MMCs, the major emphasis has been on the development of lighter MMCs using aluminum and titanium alloys, due to the significant potential of improvement in the thrust to-weight ratio for the aerospace, space and automotive engines.

Aluminium alloy matrix composites are suited to applications below the temperatures of 400°C (750°F). Aluminium and its alloys have attracted the most attention as matrix material in metal matrix composites. Commercially, pure aluminium has been used for its good corrosion resistance. Aluminium alloys, such as 201, 6061, and 1100, have been used for their higher tensile strength to weight ratios. Amore common reinforcement for aluminium alloys is Silicon Carbide (SiC).

Continuous silicon carbide fibre reinforced metals have been successfully applied on aerospace development programs fulfilling primary design objective of high specific strength over

Al,SiC$_p$ COMPOSITES

conventional monolithic materials. The high specific strength of silicon carbide metal matrix composites has generated significant interest for the' aircraft industry. The principal areas of interest are for high performance structures such as aircraft, missiles and engines.

PROCESSING OF METAL MATRIX COMPOSITES

Metal-matrix composites can be processed by several techniques. Some of these important techniques are described below.

Liquid-State Processes

- **Casting or liquid infiltration** involves infiltration of a fibrous or particulate reinforcement preform by a liquid metal.
- **Squeeze casting or pressure infiltration** involves forcing a liquid metal into a fibrous or particulate preform .Pressure is applied until solidification is complete.

Solid-State Processes

ADVANTAGES OF NONCONVENTIONAL MACHINING OVER CONVENTIONAL MACHINING FOR MMCs

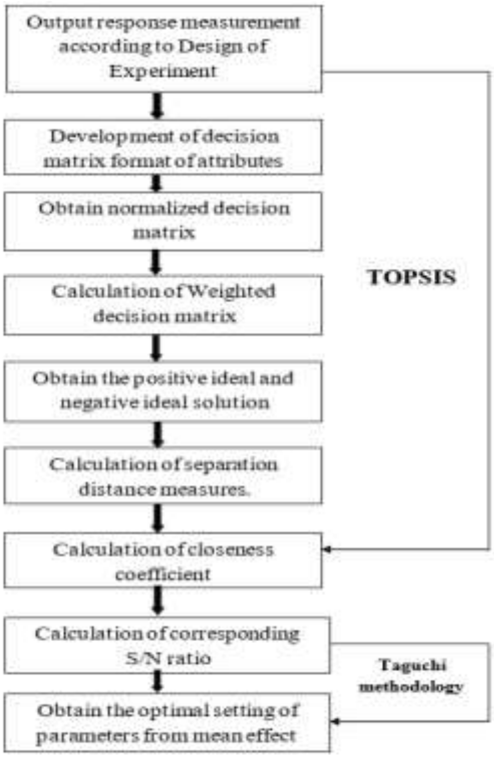
Metal matrix composites (MMC) possess higher stiffness and specific strength than that of conventional structural materials that are used in aerospace and automotive industries. MMCs generally consist of light weight metal as matrix element, and the fibers, whiskers or particles as the reinforcing elements. In MMC reinforcement helps in improving the material properties which otherwise the metal does not have. Metal Matrix Composites show considerable improvement in stiffness, elastic limit, tensile strength and fatigue strength when compared to matrix material, Apart from this they also possess high creep strength even at elevated temperature and adequate thermal fatigue resistance. Conventional machining such as turning, milling, drilling etc. shows ineffectiveness in advanced materials, since it results in a poor material removal rate, excessive tool wear and increased surface roughness.

INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 04, April 2025, pp : 3363-3368
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

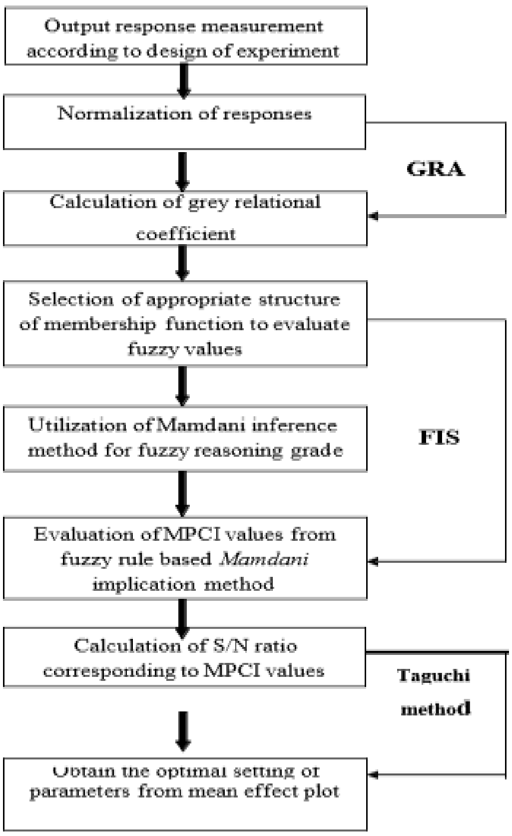
controllable variable(s) at their optimal operatingconditions with minimum variability in the output(s) and effect of uncontrollable variables on the levels. Todesign and implement an effective process control for metal cutting operation by parameter optimization, amanufacturer seeks to balance between cost and quality at each stage of operation. The Taguchi method is a systematic methodology of design and analysis of experiments for the intention of designing and improving product quality.

Proposed Methodology for Analysis of ECM Data

TOPSIS Combined with Taguchi Methodology



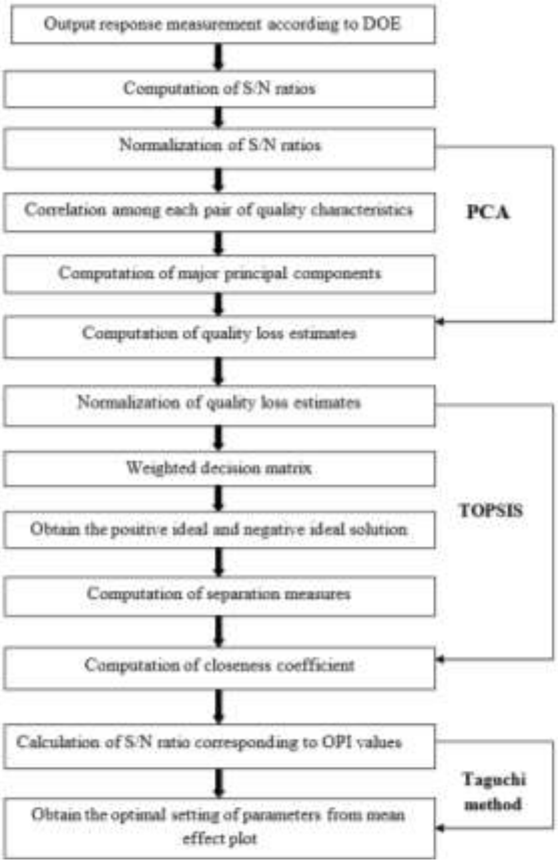
Grey-Fuzzy Combined with Taguchi Methodology



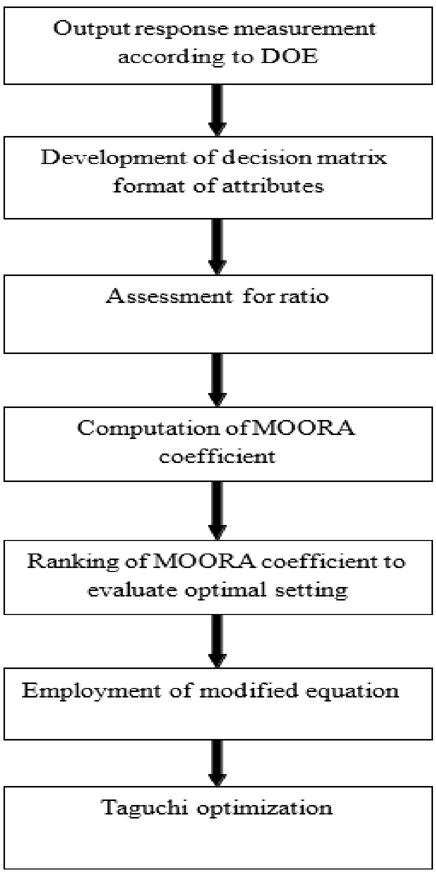
INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 04, April 2025, pp : 3363-3368
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

Proposed Methodology for Analysis of EDM Data

PCA-TOPSIS Combined with Taguchi Philosophy



MOORA Combined with Taguchi Philosophy



INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 04, April 2025, pp : 3363-3368
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

3. CONCLUSIONS AND FUTURE SCOPE

In this study, TOPSIS combined with Taguchi philosophy and grey theory combined with fuzzy rule based model have been developed towards optimizing roughness average and MRR in machining Al, 15%SiC composites. It has been found that both the methods concluded with same result. So the optimal setting for ECM is found to be most beneficent. The proposed procedures are simple, effective in developing a robust, versatile and flexible mass production process. In the context of grey-fuzzy based Taguchi method there is no need for checking the correlation among responses as no individual weight has been assigned to responses. FIS can efficiently take care of these aspects into its internal hierarchy thereby overcoming various limitations of existing optimization approaches. This approach can be recommended for continuous quality improvement and off-line quality control of a process of manufacturing industry.

In order to achieve best quality characteristics and satisfactory process performance yield; the machining parameters in EDM of workpiece material Al, 10%SiCp MMCs need to be optimized. Taguchi's philosophy is primarily concerned with the optimization of single response only. Therefore, in this study a multi-objective hybrid optimization technique combining PCA, TOPSIS integrated with Taguchi method; and another efficient technique MOORA combined with Taguchi method have been employed successfully for optimizing performance parameters of EDM reaching to an optimal parameter setting for machining of advanced materials like Al,SiCp MMCs. These integrated approaches can be applied for product quality and process performance improvement in any production processes which involve multiple response features and can be considered as an efficient tool for continuous process improvement and off-line quality control.

Aforesaid work can be extended in the following directions:

Different material parameters like % of SiC, temperature of sintering, mesh size of powders can also be considered for experimental analysis and further quality improvement. Other machining parameters of ECM like flow rate, different electrolytes etc. can be taken into account for analysis. Similarly other machining parameters like pulse on energy, flushing pressure of dielectric fluid etc. can also be taken into account. Machine tool vibration, cryogenic effect on tools etc. can be adopted for analysis. Different mathematical models can be developed for productivity and quality improvement program as well as for optimization of process parameters of EDM,ECM on MMCs.

4. BIBLIOGRAPHY

[1] D.D.L. Chung (2010) Composite Materials, Science and Applications, Second edition.

[2] B. Harris (1999) Engineering Composite Materials, The institute of materials, London.

[3] M. Rosso (2006) Ceramic and metal matrix composites: Routes and properties. Journal of Materials Processing Technology, vol.175, pp. 364-375.

[4] V.K. Lindoors and M.J. Talvitie (1995) Recent advances in metal matrix composites. Journal of Materials Processing Technology, vol. 53, pp. 273-284.

[5] M. Gupta, M.O. Lai and C.Y. Soo (1995) Effect of type of processing on the microstructural features and mechanical properties of Al-Cu/SiC metal matrix composites. Material Science and Engineering, vol. A210, pp.114-122.