

SEARCH FOR KEYWORDS IN A HYBRID TECHNOLOGIES FIELD, BASED ON ULTRASONICALLY AIDED EDM-ECM USING THE ONLINE ENVIRONMENT

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ABSTRACT: In the present study we established for the “Nonconventional Technologies” research field, the composition of a keyword vector (terms specific to the analyzed field) = {advanced materials, electrical-discharge machining, hybrid machining, electrochemical machining, micro EDM, micro-ECM, hybrid ultrasonic machining} to carry out a research based on two main directions/components. The first component consists in the process of identifying the works that address the specific terms in the composition of the above vector in Web of Science. The second component is the analysis of the interest of Google users, in searches based on the keyword vector. The emergence, development and diversification of the technologies that make up the keyword vector in this paper is mainly due to their use in the processes of advanced materials machining. The importance, and the key role played by advanced materials and technologies is emphasized by utmost personalities from the academic, research and industry fields.

KEYWORDS: advanced materials, electrical-discharge machining, hybrid machining, electrochemical machining, micro EDM/ECM, hybrid ultrasonic machining

1. INTRODUCTION

The implementation of nonconventional technologies for machining continuously growing characteristics of advanced materials that cannot be processed by classic mechanical technologies, suppose one or more types of combined technologies, such as: laser, electron and ion beam machining, electrical-discharge and electrochemical machining, water jet, ultrasound and microwave, plasma cutting etc. Therefore, the keyword vector $V_{word} = \{\text{advanced materials, electrical-discharge machining, hybrid machining, electrochemical machining, micro EDM, micro-ECM, hybrid machining ultrasonic}\}$ contains a pack of nonconventional technologies, used in various advanced material machining processes.

These processes can be classic, e.g. electrical-discharge (EDM) or electrochemical machining (ECM) [1]) or hybrid [2], e.g. ultrasonically aided electrical discharge machining (EDM+US). EDM is one of the large scale applied advanced technology, based on concentrated energy transfer from the tool to machined workpiece, in which the removal of the material takes place due to the melting, vaporization and even boiling, through thermal energy produced by successive electric sparks. EDM has the capability to process advanced materials like very hard super-alloys, metal matrix composites, coated ceramics, with high grade of complexity shapes at

both macro and micro levels. But the application of this type of machining is very restricted to electrically conductive materials. Other constraints refer to the low machining rate, i.e. volume of removed material per time unit, the high wear rate of the tool-electrode, the thermally influenced and modified superficial layer and the geometric inaccuracy in the form of inclined surfaces and over machining. To surmount these weaknesses, the researchers from the field introduced combined machining operated simultaneously or sequentially, leading to hybrid machining process. Hence this study is organized into five sections, addressing the following issues: (i) Introduction in hybrid nonconventional technologies (ii) Justification of such types of machining to advanced materials processing, (iii) Keyword vector analysis in some data bases, (iv) Mahalanobis’ distance and (v) Conclusions.

2. ADVANCED MATERIALS AND MACHINING

Hybrid manufacturing processes are based on the simultaneous applied types of energy, corresponding to components of the combined technology, which is transferred to material removal mechanism that becomes obviously more intricate than ones of classic technological variants. The performance of hybrid machining processes is much improved, comparing to its contributive processes [3]. The combination could imply conventional and

nonconventional technologies, and different types of energy: mechanical, electrical, thermal, and chemical [4]. The purpose of hybrid machining is to combine different removal mechanisms in order to increase their performance. In other words, the objective of the hybridization processes is to obtain the "1 + 1 = 3" effect. This can be explained by *synergy* meaning that its effect is more than arithmetic sum of single processes [5]. The development of hybrid processes is the result of the major technological challenges generated by advanced materials with extraordinary and contradictory properties, e.g. toughness and fragility, non-precedent increasing of machining accuracy in the nanometric domain, and machined surface complexity, e.g. sculptural. Hence the existing conventional and nonconventional separate technologies have major difficulties. Consequently, the term "hybrid process" means a combination of different process energies or the aiding / assistance of other specific process by using a different process environment.

A hybrid process can be expressed in different terms, such as [6]: combining different active energy at the same time in the working spot (e.g. laser-turning); processes that combine successively process stages, two or more steps (e.g. laser hardening-grinding); hybrid machines that integrate different types of processes within a single technological system (e.g. successive milling and EDM).

Micro-machining had an explosive development due to micro-components/products, e.g. microsensors, microactuators, integrative microsystems, in such different industries like automotive, aerospace, optoelectronics, green energy, medical instruments etc. Since these micro products are made from advanced materials, with complex micro-structures, they require precision to achieve micro and even nanomachining. According to the specialists, hybrid micro-machining processes are classified into two major categories: assisted and combined hybrid micro-machining techniques [7]. Therefore, e.g. ultrasonically assisted electrical-discharge micro-machining (μ EDM+US) is a solution to deliver concentrated thermal energy produced by electric discharge in ultrasonic environment, according to above conditions. Numerous researchers emphasize the needed relation between advanced materials and hybrid machining/micro-machining [8-15].

3. KEYWORD VECTOR ANALYSIS IN WEB OF SCIENCE AND GOOGLE

To determine the trends occurring in the field of nonconventional technologies, our study analyzed from the Web of Science database (<https://www.webofscience.com>) the evolution of citations and publications in the period 2010-2021 for the articles that contain the following keywords in the title:

- advanced materials;
- electrical-discharge machining;
- hybrid machining;
- electrochemical machining;
- micro-EDM;
- micro-ECM;
- hybrid ultrasonic machining.

Web of Science is a strong support for any PhD Aspirant, researcher or any people interested in the process of identifying relevant publications for a certain analyzed or researched subject. For this reason, we have developed Top 5 Web of Science Categories, for the vector of the keywords that are the basis of our study, for the period 2010-2021 (Table 1).

Table 1. Web of Science categories related to keyword vector

Keywords	Web of Science Categories
advanced materials	Materials Science Multidisciplinary; Chemistry Multidisciplinary; Chemistry Physical; Physics Applied; Nanoscience Nanotechnology.
electrical-discharge machining	Engineering Manufacturing; Materials Science Multidisciplinary; Engineering Mechanical; Automation Control Systems; Multidisciplinary Engineering
hybrid machining	Engineering Electrical Electronic, Computer Science Artificial Intelligence, Manufacturing Engineering, Energy Fuels, Computer Science Information Systems
electrochemical machining	Manufacturing Engineering, Multidisciplinary Materials Science, Mechanical Engineering, Electrochemistry, Automation Control Systems
micro-EDM	Manufacturing Engineering, Mechanical Engineering, Multidisciplinary Materials Science, Automation Control Systems, Industrial Engineering
micro-ECM	Manufacturing Engineering, Industrial Engineering, Mechanical Engineering, Multidisciplinary Materials Science, Nanoscience, Nanotechnology
hybrid ultrasonic machining	Manufacturing Engineering, Industrial Engineering, Mechanical Engineering, Multidisciplinary Materials Science, Nanoscience, Nanotechnology

In Table 2, we present for the Top 5 Web of Science Categories, the frequency of the appearance of the categories of journals that contain papers in whose titles the analyzed key expressions are found. Basically, it provides information on the most relevant categories of journals that correspond to certain terms or expressions for an article published in Web of Science.

Table 2. Frequency of occurrence of the categories of Web of Science publications containing papers with phrases from the keyword vector

Fields	Number
Manufacturing Engineering	6
Multidisciplinary Materials Science	6
Mechanical Engineering	5
Automation Control Systems	3
Industrial Engineering	3
Nanoscience Nanotechnology	3
Multidisciplinary Chemistry	1
Chemistry Physical	1
Computer Science Artificial Intelligence	1
Computer Science Information Systems	1
Electrochemistry	1
Energy Fuels	1
Electrical Electronic Engineering	1
Multidisciplinary Engineering	1
Applied Physics	1

It can be observed that "Manufacturing Engineering" and "Multidisciplinary Materials Science" appear six times in the seven components of the vector, followed by "Mechanical Engineering", with a number of five occurrences. The first two positions are because materials represent the starting point or the base in all manufacturing industries, in the physical sciences and engineering. Materials, energy, infrastructure, and information generate what is called "technology". The materials are processed by manufacturing technologies. The design of a product cannot be separated from the manufacturing processes. The approach of researchers to "Manufacturing Engineering" differs, depending on the characteristics and goals of each RDI project. Manufacturing engineers deal with what production requires: technological processes, and systems, rough materials, process/tool optimization, cost reduction, quality assurance etc.

The main Web of Science domains for which the percentage of publications containing in the title the expression "advanced materials" with a frequency of appearance higher than 10% in the period 2010-2021, is represented in figure 1. Thus, it can be observed that the field "Materials Science

Multidisciplinary" contains most publications for the expression "advanced materials".

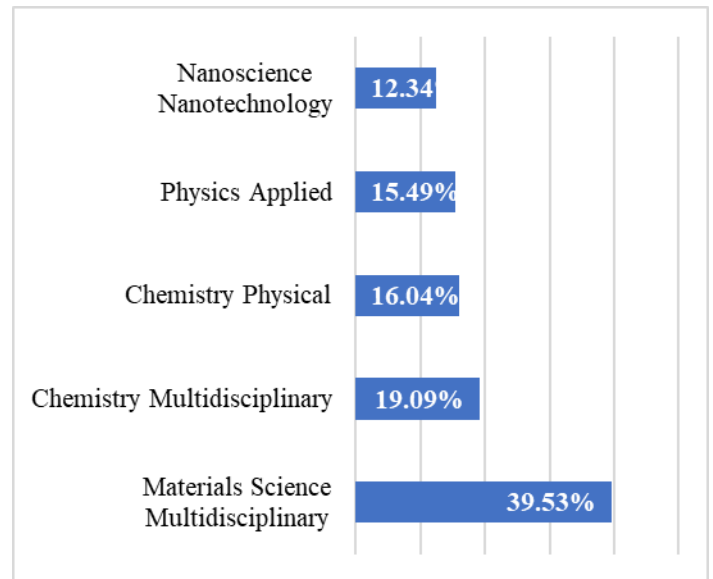


Figure 1. Frequency of occurrence of the term "advanced materials" in the Web of Science

Next, it could be identified the fact that in 2020 there were the most **citations** for the phrases "advanced materials; electrical-discharge machining; hybrid machining; electrochemical machining; micro EDM; micro-ECM", as can be seen in Fig. 2 – Fig. 7.

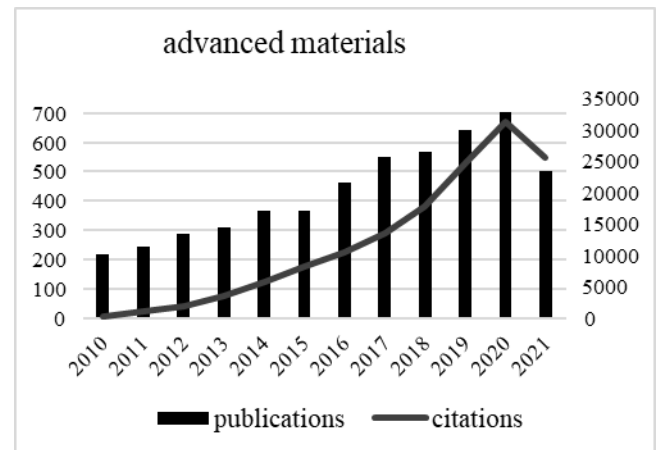


Figure 2. Number of citations and publications for "advanced materials"

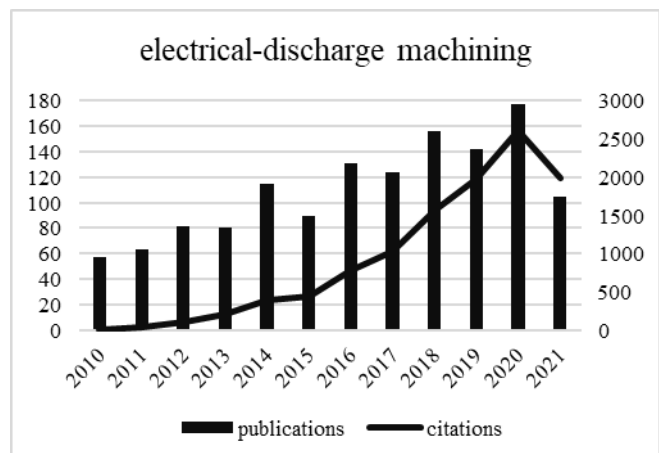


Figure 3. Number of citations and publications for "electrical-discharge machining"

allow the combination of two or more processes leading to synergy.

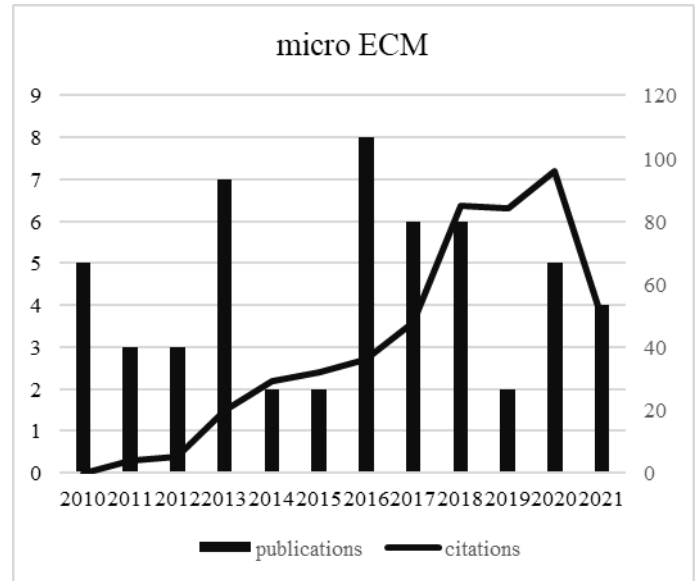


Figure 7. Number of citations and publications for “micro-ECM”

In the case of EDM type machining, to increase the capability of this technology, its hybridization with other processes was accomplished. The effects of a hybrid process consist in the machining time decrease while surface quality increase. In hybrid process, the mechanism of two processes is applied concurrently or consecutively. Thus, the output technological performance of the combined process is increased, but hybridization also grows the complexity of the process. For example, the combination of the EDM process with the ultrasonic oscillation of electrode leads to significant stability of the process, avoiding its degeneration, and implicitly increase the discharge efficiency, growing the material removal rate (MRR) [16]. In the case of subtractive machining, the most used are CNC machines, which generally perform classic mechanical machining as milling, turning and drilling operations. Due to technology flexibility, the parts obtained are very diverse, so they are used in different industries from automotive to aeronautical. Concerning the materials used, in the case of additive technologies, e.g. 3D printing, they differ depending on the technological system utilized. Relatively small polymer parts are used at fused filament fabrication, and larger parts are used at injection molding pellets and reinforced polymers [17]. Being interested in finding relevant information on the Internet about the elements of the vector $V_{word} = \{\text{advanced materials, electrical-discharge machining, hybrid machining, electrochemical machining, micro EDM, micro-ECM, hybrid machining ultrasonic}\}$, we have grouped in Table 3 the number of indexed web

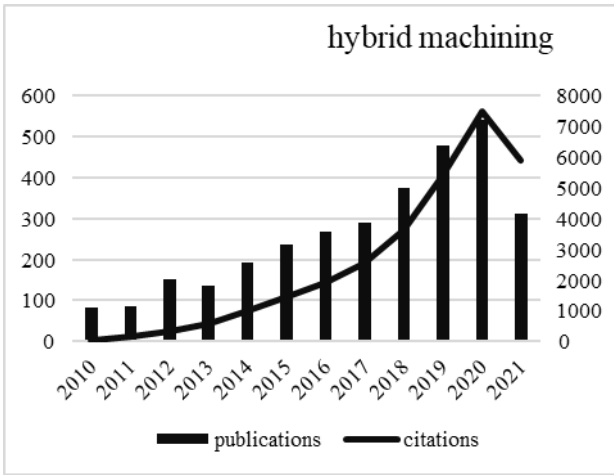


Figure 4. Number of citations and publications for “hybrid machining”

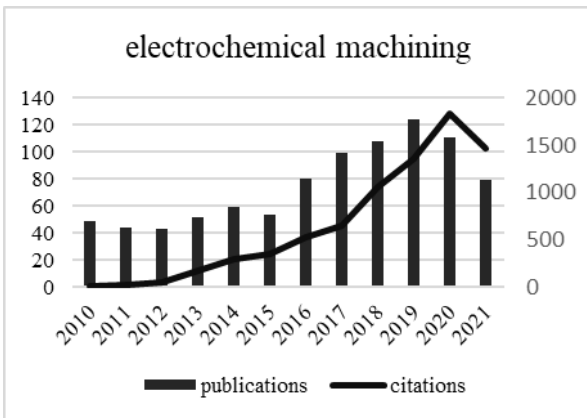


Figure 5. Number of citations and publications for “electrochemical machining”

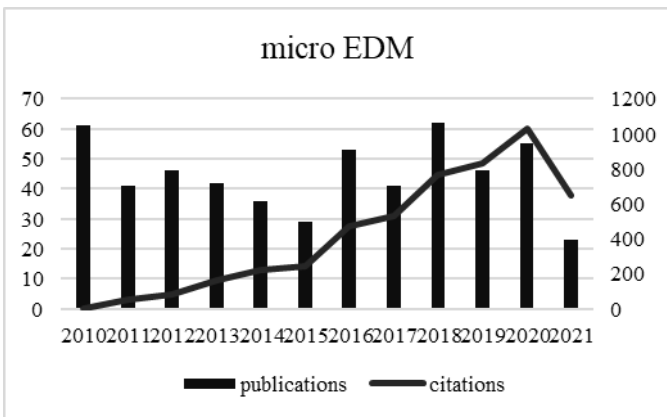


Figure 6. Number of citations and publications for “micro EDM”

It can also be seen that publications and citations for the expression "advanced materials" have the highest values, followed by the expression "hybrid machining". This pointed out the role and importance of "advanced materials" in the context of 2020 scientific environment, which was governed by the need to identify new technologies required in the crisis triggered by the Covid-19 Pandemic. The response to this challenge could be "hybrid machining" because are based on the fact that they

pages that refer to the subject of this paper. This table was based on Google search reports on 26.08.2021.

Table 3. Comparisons between appearances, news and videos

Phrase	Google occurrences	News Results	Videos results
advanced materials	2,020,000,000	12,800,000	42,000,000
micro-ECM	21,400,000	23,400	137,000
micro EDM	25,600,000	17,800	208,000
hybrid machining	16,000,000	23,400	296,000
electrical-discharge machining	6,280,000	5,360	61,000
electrochemical machining	1,290,000	3,340	21,000
hybrid ultrasonic machining	738,000	2,600	13,100

The results related to news have lower values than the results related to video posts. Given the context generated by the Covid-19 Pandemic, the importance of video recordings (education, training, field-specific knowledge etc.) has increased significantly, as sharing this type of information online has become a priority. These items associated with the hybrid technologies leading to increased performances could be a solution for rapid response of human resources to actual challenges in terms of growing requirements of advanced materials, ultra-miniaturization and complexity.

4. THE MAHALANOBIS DISTANCE

There are numerous studies that demonstrate that the Mahalanobis distance is a statistical parameter that has the ability to detect multivariate aberrant values. It also measures the number of standard deviations that an analyzed quantity has from the average of a distribution [18]. The Mahalanobis distance was first proposed by the Indian statistician P.C. Mahalanobis, in 1936. The Mahalanobis distance represents the distance between two points in a multivariate space, being used to discover aberrant values in statistical analyzes involving several variables. In this study, based on the actual data in Table 3, we calculated the Mahalanobis distance for each column in the dataset that displays the number of pages indexed in Google along with the number of web pages that contain "News" and the number of web pages that contain "Videos."

The dataset looks like this: `df = data.frame(google = c(2020000000, 21400000, 25600000, 16000000, 6280000, 1290000, 738000), news=c(12800000, 23400, 17800, 23400, 5360, 3340, 2600), videos=c(42000000, 137000, 208000, 296000, 61000, 21000, 13100))`

Using the mahalanobis() function in the R programming language, we determined the Mahalanobis distance for each field/column. The mahalanobis function has the following syntax: **mahalanobis(x, center, cov)** where: x represents the data matrix; center-> is the average vector of the distribution, and cov is the covariance matrix of the distribution. For our case the function is of the following form: **mahalanobis(df,colMeans(df), cov(df))**. For each Mahalanobis distance, the p value is calculated to determine whether any of the distances are statistically significant. The p-value for each distance is calculated as a value corresponding to the Chi-Square statistics of the Mahalanobis distance with k-1 degrees of freedom, where k = number of variables. In our example, we have a number of degrees of freedom equal to 2. A p value that is less than 0.001 is considered an aberrant value. It is observed that in the data set that there is no aberrant value, because the value of p is greater than 0.001 in all cases (Figure 4).

```

> df = data.frame(google = c(2020000000, 21400000, 25600000, 16000000, 6280000, 1290000, 738000),
+ news=c(12800000, 23400, 17800, 23400, 5360, 3340, 2600),
+ videos=c(42000000, 137000, 208000, 296000, 61000, 21000, 13100))
>
> df$dist_Mahalanobis <- mahalanobis(df,colMeans(df), cov(df))
> df$p <- pchisq(df$dist_Mahalanobis, df=2, lower.tail=FALSE)
> df
  google      news  videos dist_Mahalanobis      p
1 2.02e+09 12800000 42000000      5.1428535 0.07642643
2 2.14e+07    23400    137000      2.3594718 0.30735990
3 2.56e+07    17800    208000      2.5052778 0.28574974
4 1.60e+07    23400    296000      4.6330049 0.09861791
5 6.28e+06     5360     61000      0.4547556 0.79661975
6 1.29e+06     3340     21000      1.3813056 0.50124876
7 7.38e+05     2600     13100      1.5233309 0.46688820
  
```

Figure 8. Mahalanobis distance calculation

5. CONCLUSIONS

The current state of any research can be established based on analyzes performed using existing tools in the Internet service, such as: Web of Science, Scopus, ResearchGate, Google, Google Scholar etc. Manufacturing technologies must give a response to the challenges generated by actual development of Industry 4.0, implying ultra-miniaturization, based on capacity to generate complex shapes from advanced materials with highest known characteristics, and surfaces with dimensions belonging to micro and nano domains, like technologies subjected by this research. Therefore, this could be possible only by using nonconventional technologies / concentrated energies technologies, able to create highest density energy on machined surface. But in the current conditions of sustainable development, Materials Science and Engineering (MSE) specialists must also consider the context of global warming, the effects of technological change, energy consumption and environmental quality. To

successfully address these major challenges, research will need to develop new innovative process that operate with less pollutant materials during machining processes that induce no harm for the human resources and the environment. The present study has the following limitations: **a)** It uses the words vector (advanced materials, electrical-discharge machining, hybrid machining, electrochemical machining, micro EDM, micro-ECM, hybrid ultrasonic machining) in the analysis, which, in certain conditions, can prove to be restrictive for the Hybrid Technologies field, based on ultrasonically aided EDM-ECM; **b)** It uses for the research only the papers which correspond to the words vector chosen from Web of Science base, not from other data bases such as Scopus, IEEE Explore, JSTOR, ScienceDirect, ERIC etc; **c)** The Google searches of the users are only for the content indexed by the search engine, although relevant content for the analysed field can also exist and hasn't been indexed in the search engine.

6. ACKNOWLEDGEMENTS

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