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Artificial Intelligence in Plasma Electrolytic Micro-oxidation for Surface Hardening - Insights from Scholarly Citation Networks and Patents.

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Artificial Intelligence in Plasma Electrolytic Micro-oxidation for Surface Hardening - Insights from Scholarly Citation Networks and Patents.

Abstract -

Objective - The purpose of this article is to analyze the top work areas and patent domains in the field of surface hardening by micro-arc oxidation. Also, it is directed on the opportunities of data analysis by different machine learning tools.

Material and methods - The www.lens.org database is used to collect articles from Elsevier, Trans tech publications, Springer New York, MDPI, etc. to review the relevant articles as well as patents related to the topic.

The result - A total of 1057 articles were published in 60 different journals and 756 patents in the area of research under various jurisdictions. The top-cited article has 119 scholarly articles citations as well as 19 cited patents. The machine learning analysis is implemented at the testing level for image evaluation in a few articles and to the parameter monitoring of the process in other few articles. The present analysis provides the trend in the area of Plasma Electrolytic Micro-oxidation (PEMO)coating and areas of patentability.

Keywords: - Plasma Electrolytic Micro-oxidation, Machine learning, Bibliometric, Surface Hardening

Introduction -

Various surface modification techniques improve the surface properties without altering the base material. Hence these methods are encouraging in industrial applications due to cost-saving and effectiveness of the process.

The multifunctional composite type of coatings is the trending vicinity of the researcher for production applications. New types or finding new uses for already known coatings, development of application technology of hard, wear-resistant coatings, the search for new methods of deposition, and modernization of existing techniques of deposition are a few areas for the research. An extensive range of coatings needs for suitable selection of the coating relying on the application, the method of deposit, and substrate material [1]–[8]. The protective kind of coatings identified based on the material that develops the type of metallic chemical bond like nitride, carbide; silicates are some examples[9], [10]. These surfaces show high hardness as well as wear resistance properties due to the presence of covalence of the metallic bond. In another type are based on the ion bonds like in oxide coatings[11].

Various surface modification techniques improve the surface properties without altering the base material. Hence these methods are encouraging in industrial applications due to cost-saving and effectiveness of the process.

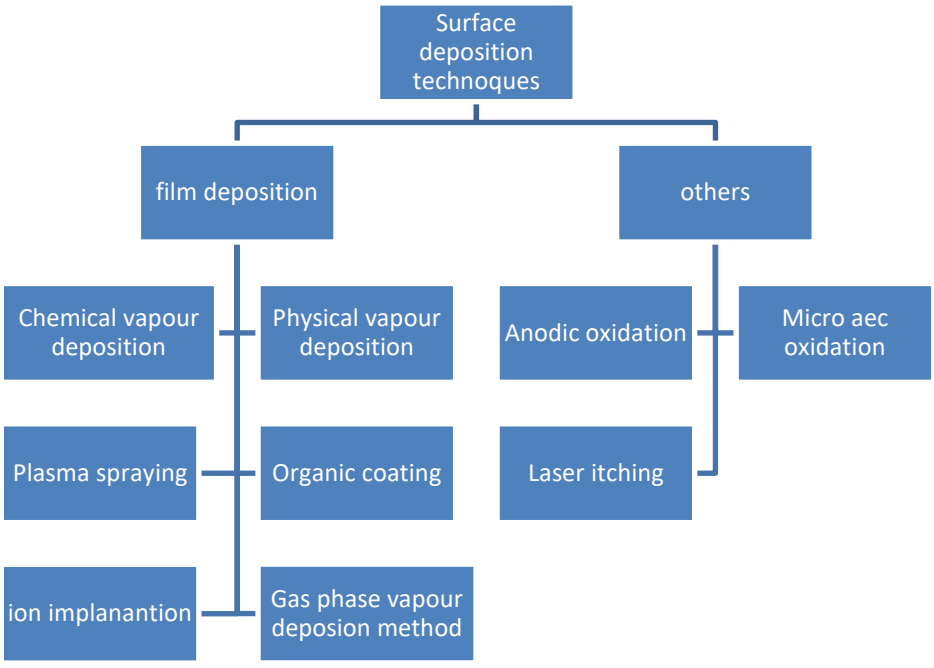

Figure 1Surface modification techniques for surface hardening

Literature Review

The article is focused on the method of micro-arc oxidation and its relevance in coating and surface hardening applications. Plasma electrolytic method oxidation (PEMO) is durable, forming more adherent and uniform coatings on the critical shaped surface of the light alloys without subjecting it to elevated temperature. In the PEMO or micro-oxidation process, the workpiece is placed in the electrolytic bath, and voltage is applied between it and an inert cathode. With certain metals like Al, Mg, Ti, the surface produced is highly porous, and in recent developments, it can be nano-scaled microstructures also. The plasma electrolytic method is more widely used as the composition of the outer coating is based on the composition of the electrolyte and additives particles. The desired mechanical properties on the coating surface can be obtained by controlling the electric parameters as well as the composition of the electrolyte used[12]–[15]. The properties like wear resistance, corrosion resistance, wear, hardness can be improved using the micro-arc oxidation method. The plasma arc method is a mixture of the plasma chemical and electrochemical reactions with the use of a high electric-powered field. The process is based on three main steps of the formation of the oxide layer, dissolution, and reaction with the spark. The following sections give the review for the few papers focused on the process improvement.

Aluminium is reactive material with excellent corrosion resistance with a thin film of 2-5 nm passive film stable in PH values 4 to 8.5[16]. The composition of the material is an important parameter to improve corrosion resistance. Surface modification methods can modify the secondary phases of oxide formed on the outer layer with the surface for strong, durable bonds. The oxide coatings can repair cracks in metallic structures for automobile industries. The oxide layers have a notable improvement in fatigue resistance as compared to the hard anodic coatings[17]. The oxidation method of coating on the surface of any metal is a surface modification

method that enhances the characteristics of the outer layer of metal. Few methods that are promising and effective are physical and chemical vapour deposition, anodizing, oxidation method, sol-gel, thermal spray, ceramic coating.[18]. The scanning micro-arc oxidation method also shows improvement in microstructure and corrosion resistance with the variation of lubrication time and discharge distribution[19].

With heat treatment, the phase change of the alloying material was achieved to improve the characterization of the biomaterial like Mg-2Zn-0.5Nd-0.5Zr alloy. The increase in the solution temperature up to 500 ^{o}C changes the phase increases grain size 4-5µm. Due to the homogeneous material structure, the material shows uniform degradation behaviour [20].

The study on the addition of Gd in Mg alloy was done by Yao et al. by varying percentage content of Gd in Mg-2 Zn-0.5 Zr-xGd for the parameters of the coating surface. Gd is proven to be a material adding good corrosion resistance. Hence the different proportion of material was tested for improvement in mechanical properties and anti-corrosive performance. A particular weight percentage of the nanoscale rod-like phases of (Mg Zn) $_{3}$Gd found that give better ultimate strength and yield strength. Also, significant corrosion resistance with the uniform rate of corrosion was observed [21].

Current applied during oxidation and time of process were found to be significant parameters for the quality of the coating. The researcher investigated the formation of a ceramic coating by micro-arc oxidation method on Aluminium foil with silicate-based electrolyte. For current value less than 4A the arc failed while at a higher value of current, more than 9A the ablation started. On the other hand, the insufficient time of oxidation results in the low thickness of the coating, and longer duration increased the coating thickness on account of reduction in the

quality of the coating. The power frequency and duty cycle of power inputs affect the ceramic coating considerably[22]. The effect of plasma spray was studied by Cihan et al. about the input variables current and spray distance on magnesium alloy in the oxidation method. The hardness and wear resistance of Mg alloy increased due to the coating of Cr_2O_3. Amongst input variables of oxidation spray, as the distance goes on increasing and increase in values for current, the hardness and abrasion resistance decreases. However, the friction coefficient also gets reduced [23].

The fundamental trouble that researchers face in it is countless variables that all things with influence on coatings properties, and, therefore, the quality of coated components varies. The primary area of tool development is to provide coatings with high mechanical properties. It could be achieved by automation of the method and optimizing cutting parameters. The automation system in material science is based on genetic algorithms, fuzzy logic, and an artificial neural network that will monitor controlling the process wherever multiples parameters are needed to fine-tune the process.

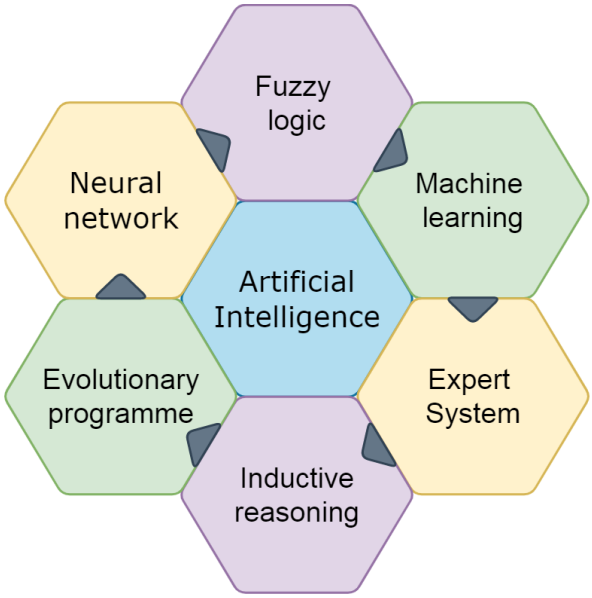

Figure 2 Different types of algorithms for artificial intelligence[1].

The machine learning algorithm developed for data of the X-ray absorption spectroscopy. The data from XAS analyzed using a data-driven model using a logical regression algorithm. The objective to identify descriptors responsible for determining the oxide state. Eight different approaches were used for algorithm implementation, with results of 80 % of validated results [24]. The machine learning model is often applied at the chemical process level wherever the various chemical compound formation and functional similarity can be captured using the algorithm. It facilitates to improve the accuracy of the method and parameters monitoring; therefore, improvement within the chemical synthesis process can be achieved[25].

The research work is carried out on the Aluminium alloy for heat-treated 7N01 series is optimized using a machine learning approach. The experimental data are analyzed using multiple regression and regression neural network, along with machine learning techniques like GRNN and SVM. Specified geometry for the deposited metal rate was optimized using the machine learning technique [26].

Methodology -

Area of research -

The research work mentioned is mainly focused on the method of the surface hardening by Plasma Electrolytic micro-arc oxidation for aluminium alloy series and high-temperature applications.

Data source -

The data is taken from the 'Lens.org ' under the section of the research scholar article section. From given keywords, 1057 articles are published. The data is taken on date 05.11.2020. The articles are from different sources like Elsevier, Springer New

York, BioMed Central, Trans Tech, IEEE, Wiley, etc. which covers various fields of application from manufacturing to bio medicals.

Analysis of keywords -

The area of the research is more precisely defined by the keywords which are divided into three major groups of primary keyword, secondary keyword, and master keyword.

Table 1 Keyword list for scholarly article search(Source: https://www.lens.org (Data on November 5, 2020))

Master keyword	Plasma Electrolytic Micro-oxidation	
Primary keyword	(AND)	"corrosion "
Secondary Keyword	(OR)	"ArtificialIntelligence", "machine learning", "Aluminium alloy", "high-temperature coating."

Research work

Even though the search query is not constrained for the duration but most of the work is done from year 2000. Hence the 1009 articles have been analyzed for period of 2000 to 2020.The initial count of publications shows that the significant research articles were published in 2015 and 2016, as shown in the figure. Most of the research papers are in the journal category, which is 995, while other types are negligible.

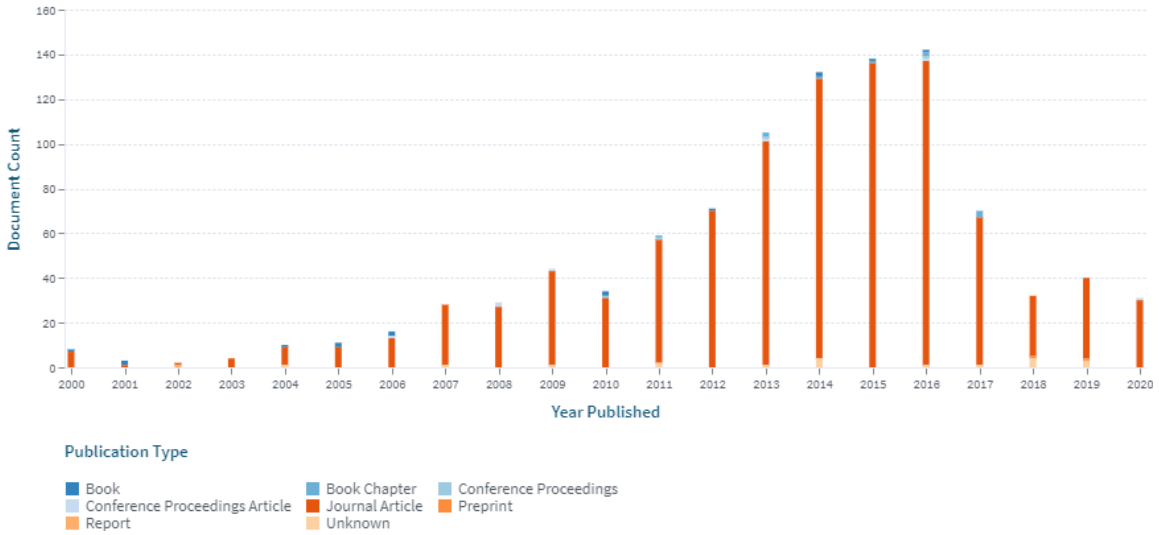

Figure 3 Year-wise Trend analysis of research articles

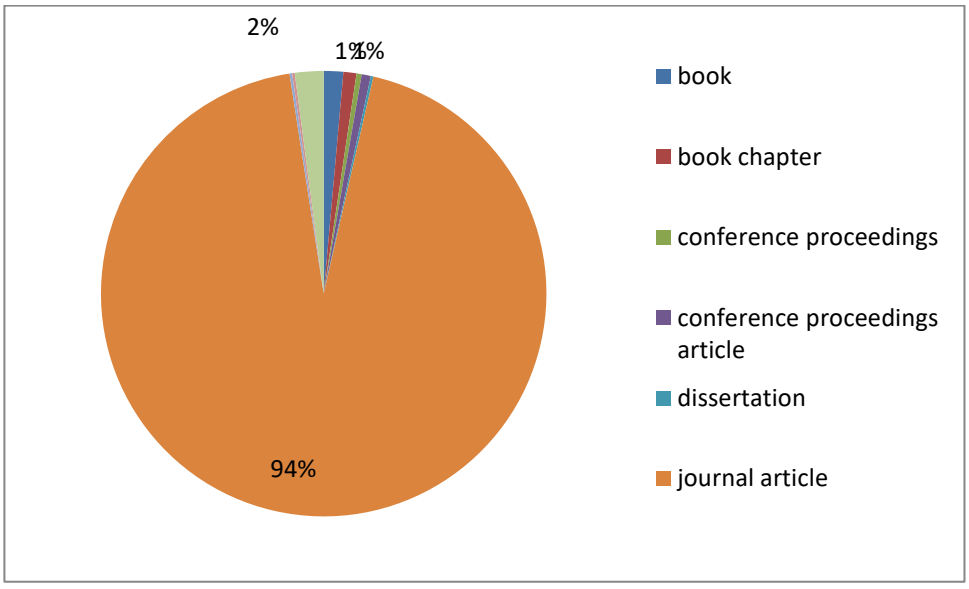

Figure 4 Type of the research articles

Table 2 Count of publications in the area of micro-arc oxidation

Type of articles	Count of Title
journal article	995
book	15
book chapter	10
conference proceedings	4

conference proceedings article	7
dissertation	2
preprint	2
report	2

As depicted in figure 7, most of the research articles are in Elsevier while publishers are with the negligible count. The fields of study covered by the most active top 5 research institutes, as shown in figure 8. The leading institute is Chinese academy of engineering with various domains like materials, metallurgy, chemical engineering, nanotechnology, composite materials etc.

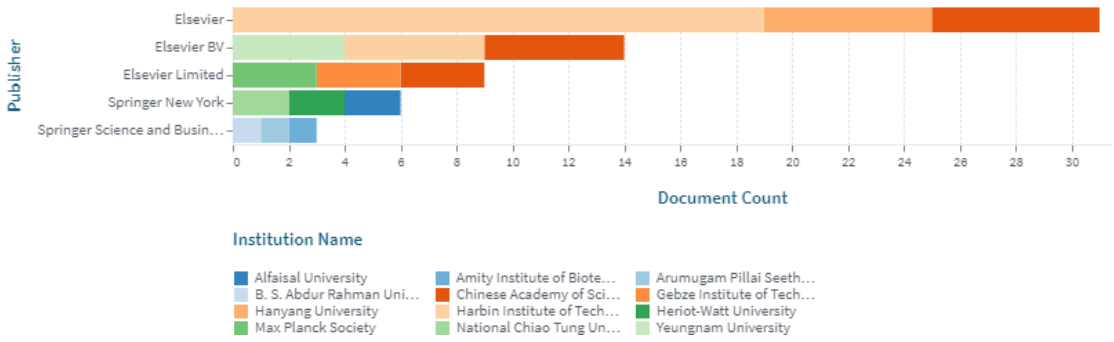

Figure 5 top five publisher with the most active Institutions,
(Source: https://www.lens.org (Data on November 5,2020))

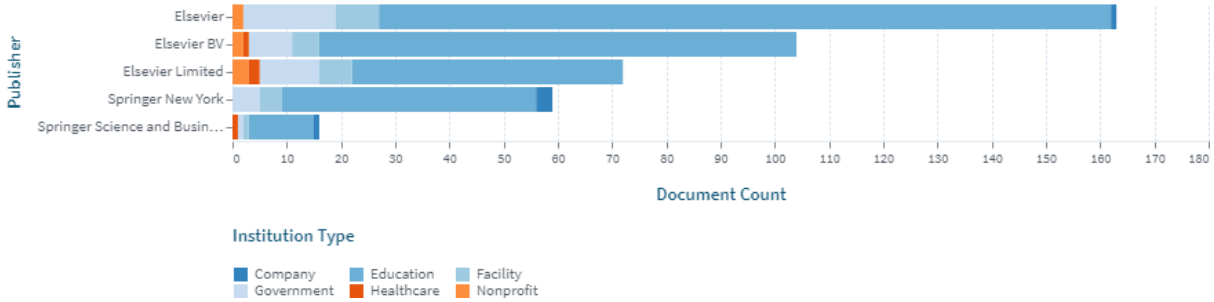

Figure 8 Top five publishers in the research area with the journal name (Source: https://www.lens.org (Data on November 5,2020))

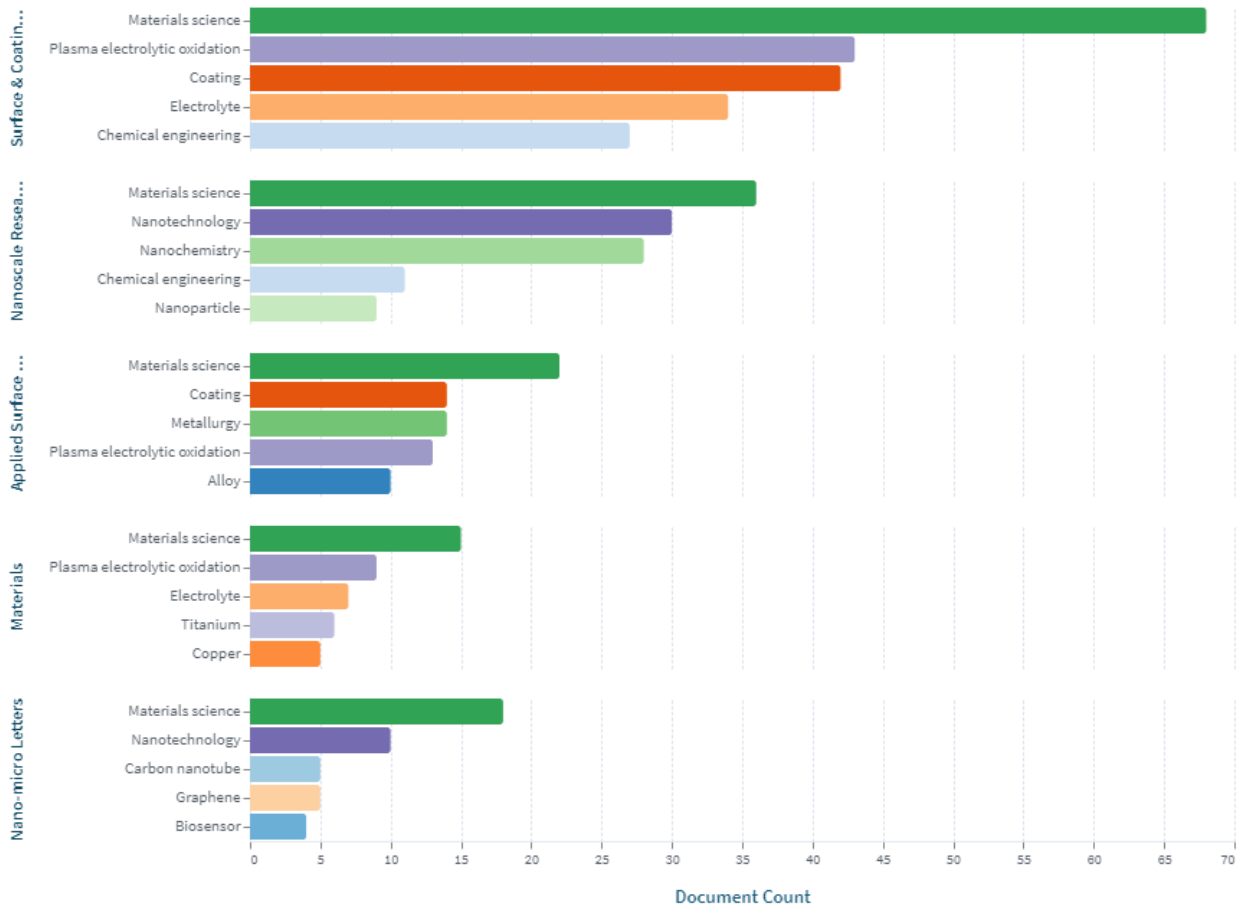

Figure 9 Fields of Study covered by the most active Institutions, (Source: https://www.lens.org (Data on November 5,2020))

The analysis of the key area of research is, as shown in the word cloud in figure 9.Most of the research work is focused on coating properties and characteristics. Following trending area is the study of the electrolyte material science are 736, plasma electrolytic oxidation 231 in document count. At the same time, significantly less work is done on the data analysis of the process. Hence tools of the data analysis can be applied.

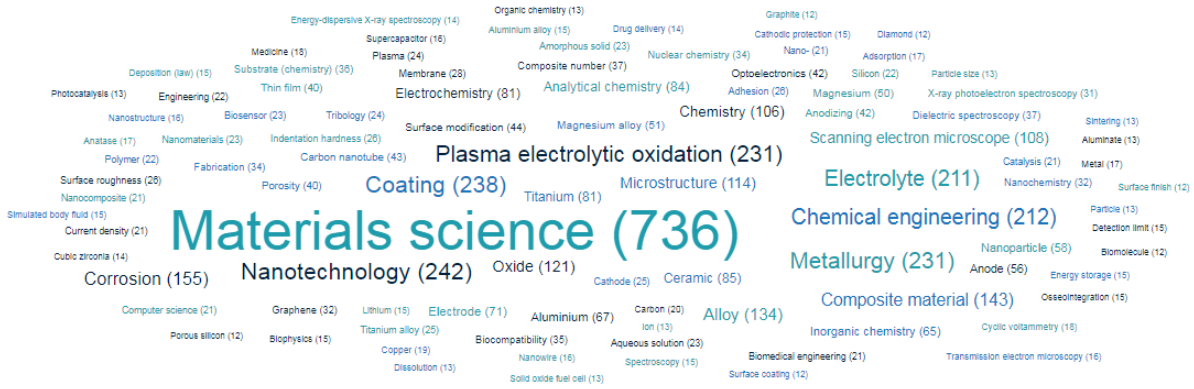

Figure 6 Word cloud map of key areas for micro-arc oxidation

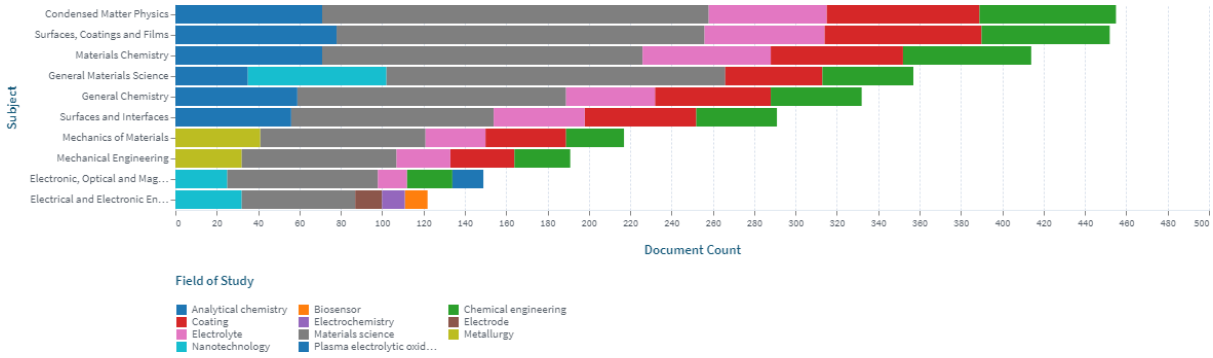

Figure 7 Top ten publishers with trending sections in the area of micro-arc oxidation.(Source: https://www.lens.org (Data on October 30,2020))

As per figure 10 of the top ten publishers, the Elsevier has the most extensive scholarly articles in surface and coating technology, followed by the applied surface sciences. The materials and nanoparticles characteristics are significant areas of work, as observed from the document count of data from figure 8 and 10. The data analysis is having a scope in the process monitoring by fine-tuning and optimizing the parameters [26]–[28]. The data generated in the process as well as from the microstructure analysis can be analyzed using a machine learning algorithm. To identify the work done in this area using the different techniques of artificial intelligence like machine learning, image analysis, artificial neural network etc. ; the search is also carried out using keywords " micro-arc oxidation" AND " Artificial intelligence ".It shows the breakdown of

scholarly articles from 2015-2020 as below. There are 18 research articles published in the area which majorly focused on industrial manufacturing and AI.

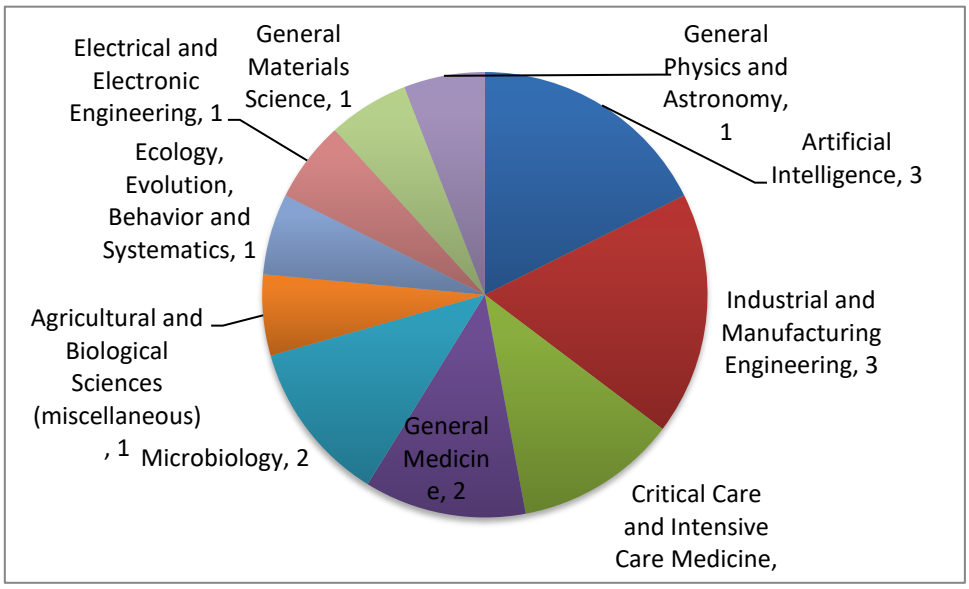

Figure 8 Work analysis in the area of the micro-arc oxidation using AI techniques.(Source: www.lens.org)

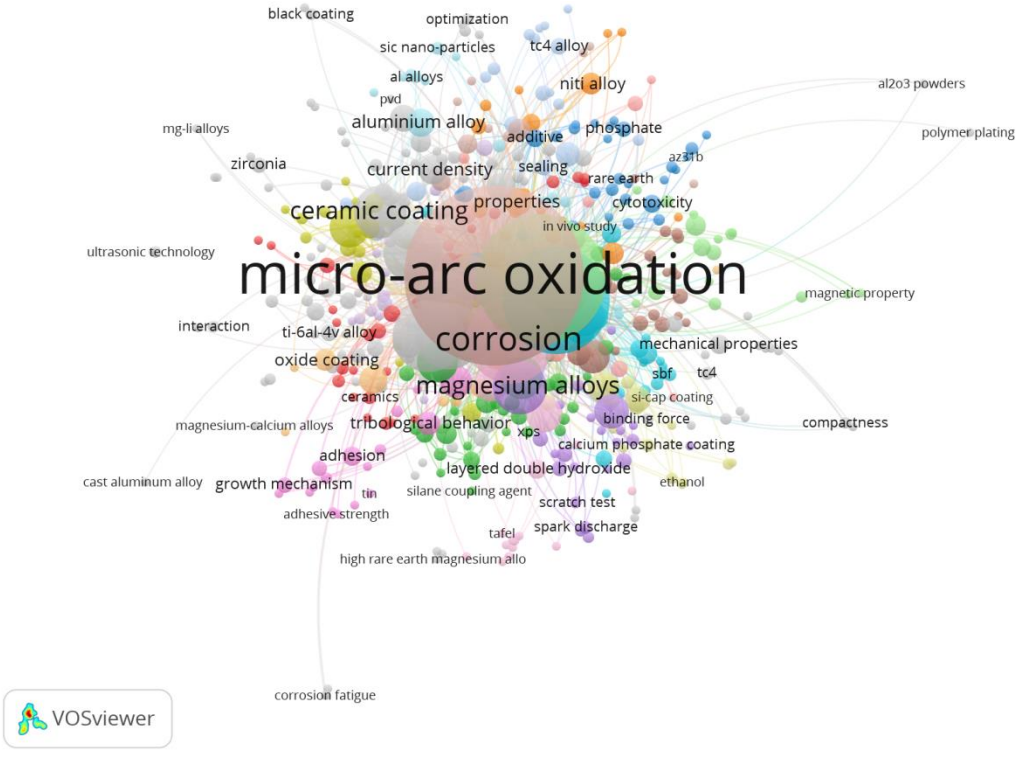

Figure 9 Network cluster of the keywords related to the micro-arc oxidation process.(Source: VOSviewer.com)

Figure 12 shows the network visualizations of the key area for research under the process of micro-arc oxidation. More giant the bubble highlights the most popular keywords.All together, the parameter analysis is more prominent for the study of the process in close virtue. Figure 13 shows the contribution of the different researchers in the area of the process. Still there are emerging area like black coating , optimisation of the process and additives which contains huge potential for research work to be done[29]–[33].

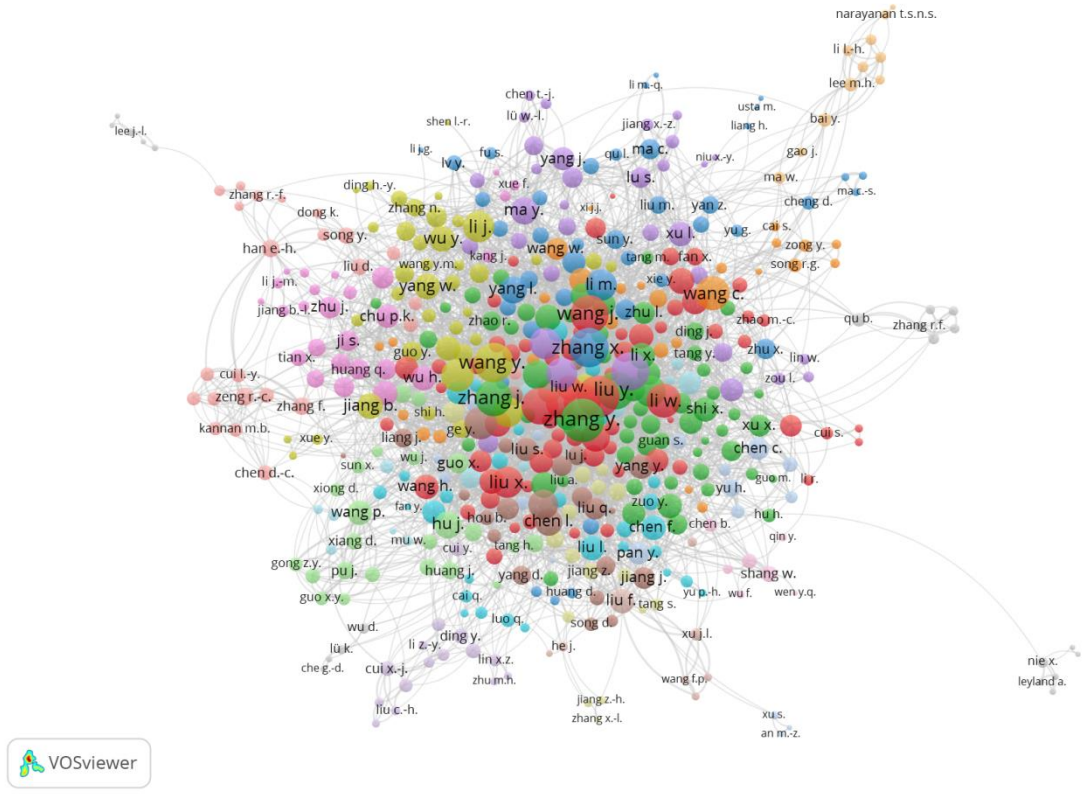

Figure 10 Author contribution to the research area.(Source: https://www.VOSviewer.com (Data on October 30,2020))

As explained in the figure no . 7 which gave tope institutes working in the field , mostly the universities in China contributed in research article. Hence the network analysis of the author in area of research is prominently headed by authors from China.

Table 3 Highest cited scholarly articles with citation counts of publications and patents from 2015-2020 .(Source: https://www.lens.org (Data on Novmber 5,2020))

Sr. No.	**Title (Publication Year)**	**Source Title**	**Author/s**	**Cites Patent Count**	**Scholarly Citation Count**
1	High-rate aluminium yolk-shell nanoparticle anode for Li-ion battery with long cycle life and ultrahigh capacity (2015)	Nature Communications	Li; Junjie Niu; Yu Cheng Zhao; Kang Pyo So; Chao Wang; Chang-An Wang; Ju Li	19	119
2	Electrochemical oxygen reduction catalysed by Ni3(hexaiminotriphenylene)2 . (2016)	Nature Communications	Elise M. Miner; Tomohiro Fukushima; Dennis Sheberla; Lei Sun; Yogesh Surendranath; Mircea DincÄ*f*	5	238
3	Facile Formation of High-Quality InGaN/GaN Quantum-Disks-in-Nanowires on Bulk-Metal Substrates for High-Power Light-Emitters.(2016)	Nano Letters	Chao Zhao; Tien Khee Ng; Nini Wei; Aditya Prabaswara; Mohd Sharizal Alias; Bilal Janjua; Chao Shen; Boon S. Ooi	5	57
4	Microneedle arrays as transdermal and intradermal drug delivery systems: Materials science, manufacture and commercial development(2016)	Materials Science & Engineering R-reports	Eneko LarraÃ±eta; Rebecca E. M. Lutton; A. David Woolfson; Ryan F. Donnelly	3	185
5	Artificial opal photonic crystals and inverse opal structures â€“ fundamentals and applications from optics to energy storage(2015)	Journal of Materials Chemistry C	Eileen Armstrong; Colm O'Dwyer	3	127

6	Effect of Postetch Annealing Gas Composition on the Structural and Electrochemical Properties of Ti2CTx MXene Electrodes for Supercapacitor Applications(2015)	Chemistry of Materials	Raghavan Baby Rakhi; Bilal Ahmed; Mohamed N. Hedhili; Dalaver H. Anjum; Husam N. Alshareef	3	301
7	Graphene based metal and metal oxide nanocomposites: synthesis, properties and their applications(2015)	Journal of Materials Chemistry	Mujeeb Khan; Muhammad Nawaz Tahir; Syed Farooq Adil; Hadayat Ullah Khan; M. Rafiq H. Siddiqui; Abdulrahman Al-Warthan; Wolfgang Tremel	3	281
8	Stimulus-active polymer actuators for next-generation micro fluidic devices(2016)	Applied Physics A	Wolfgang Hilber	3	33
9	Perspectives on oblique angle deposition of thin films: From fundamentals to devices (2015)	Progress in Materials Science	Angel Barranco; Ana Borras; AgustÃn R. GonzÃ¡lez-Elipe; Alberto Palmero	3	285
10	High capacity group-IV elements (Si, Ge, Sn) based anodes for Lithium-ion Batteries (2015)	Journal of Materiomics	Huajun Tian; Fengxia Xin; Xiao-Liang Wang; Wei He; Wei-Qiang Han	2	105

Table 1 shows the highest cited work in a given area which contains the count of citing articles, patents for the year 2015-2020. The area covered by the top cited articles are fuel cell, Biomaterials, composites and nanotechnology. However there are more higher count of the patents in the area of fuel cell development which is 19 with citation by 119 different articles [34]. The material at nano level can be developed more and with more

numbers of patents generated[35][36]. Figure 15 shows that US Jurisdiction has highest number of the patents registered flowed by China and other European countries.

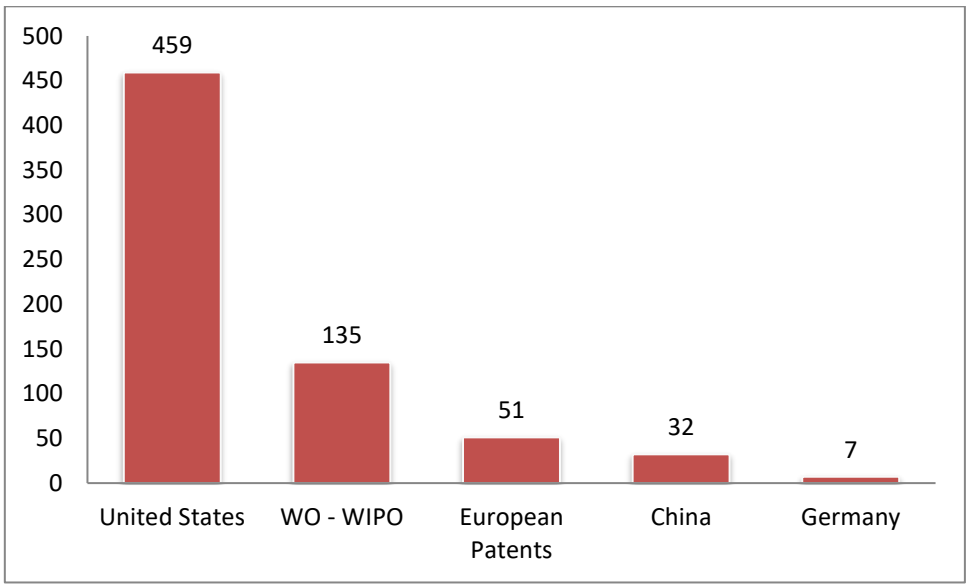

Figure 11Top Jurisdiction of patents count

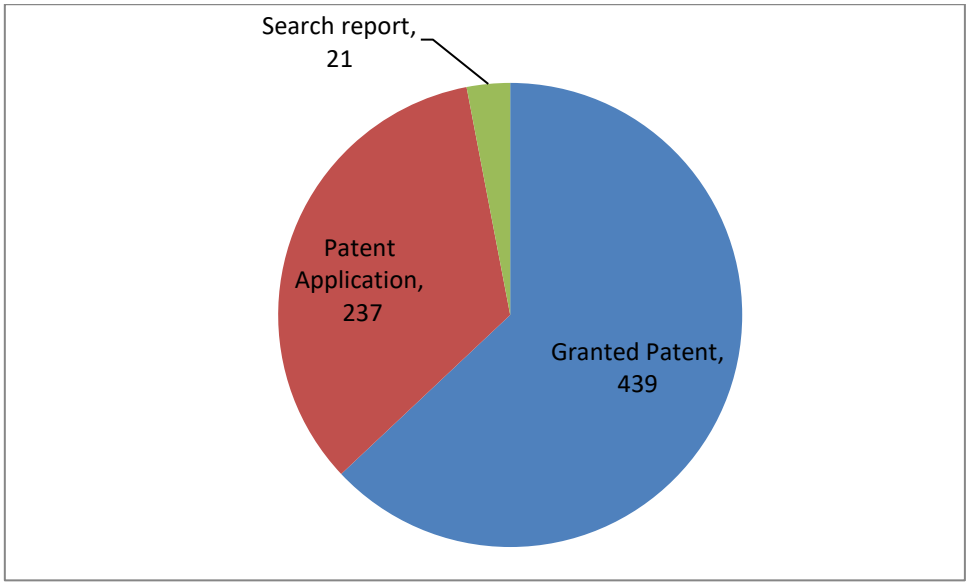

Figure 12 Patent analysis in the area of micro-arc oxidation

There are more number of patents are granted stage around 439 while 237 are at application stage. Also figure 17 shows what are the different area of research as well as

the number of patents filed on different research domain. Renewable energy , Acta material , Surface coating technology are few of the highest and trending area in field of Plasma electrolytic micro oxidation method. While applied Physics has higher in patent work.

Figure 13 Citing patents in area of Micro-arc oxidation method.

Conclusion-

The work done in the area of the coating by plasma electrolytic micro-arc oxidation is primarily focused optimization of electrolyte composition and surface characterization. The process monitoring of the process can be more effective if the data analysis techniques are applied. Significantly less work is done till now to study, analyze and use the learning algorithm for data monitoring. In-process monitoring by sensors can be applied to get a large number of data and apply machine learning and image analysis.

The present analysis of work gives a brief idea about the area to be explored based on applications. The micro-arc coating method is applied in the applications like high temperature, high tool ear conditions and in biomaterial devices as well. The patent potential s also increased in this area that can be explored.

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