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Bibliometric analysis of machining of titanium alloy research

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ABSTRACT

This paper aims to acquaint the readers about the research trends in machining of titanium alloy related literature based on the data collected from Web of Science (WoS) databases using bibliometric analysis. A total of 1291 results were obtained from WoS database. The results were analyzed based on aspects like distribution of the obtained research documents based on language, type, subject areas covered, total publications of authors, and citation counts of authors over the years in WoS database. Most of the publications are either in the engineering and material science domain. Further, lists of most productive authors, institutions, countries (along with geographical representation) are presented. China is the leading country in this research field but the Nanjing University of Aeronautics and Astronautics of China have the highest number of publications among all other institutes around the world. The author's keywords co-occurrence analysis network is visualized using VOS viewer. The study shows that 'Minimum quantity lubrication (MQL)', 'nanofluid', 'cryogenic machining', 'cutting temperature', 'CFD', 'microstructure', 'sustainable machining', 'green machining', 'tool wear', 'micromachining', 'optimization parameters', 'tool life' with major machining process like turning, milling, grinding, drilling, EDM and WEDM, etc. are the most recent keywords that indicate the hot topics and future research directions in the machining of titanium alloy field. This study also shows that the annual growth rate in machining of titanium alloy research is 16.94%, which indicates that machining of titanium alloy research has gained rapid attention since 2016 and gradually evolved over the years. By referring to this paper, researchers will be able to make calculated decisions and will get useful information for future research directions.

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1. Introduction

In many industrial applications, the continuous development of new materials and the continuous requirements for engineers to manufacture complex parts within tighter tolerances are growing substantially [1]. From this perspective, Machining of rare materials, such as titanium alloy is show high significance. Titanium alloys are widely used in medical instruments, aerospace industry, and defence applications due to their excellent properties such as high strength to weight ratio, high-temperature resistance, and resistance to corrosion and biocompatibility [2]. However, the Machining of titanium alloys has gained attention due to their low thermal conductivity, extensive application of these alloys and high chemical reactivity with cutting tool materials results in poor machinability. Therefore, various techniques such as dry machining, flood Lubrication, cryogenic cooling, and MQL has been

used for machining of these alloys [3]. During Machining of Titanium alloy, most of the heat generated is conducted to the cutting tool because these alloys have low thermal conductivity results in poor surface quality and high tool wear [4]. Therefore, it is necessary to use suitable cutting fluid to prevent rapid tool wear [5]. In recent decades, many researchers have been working to improve the machinability of titanium alloy (Ti-6Al-4 V) by testing different lubrication strategies such as flood lubrication [6], cryogenic cooling [7], multi-point injection MQL [8]. To address the key difficulties in the machining of titanium alloys, study over the last few decades has paid careful attention to the production of new cutting tool materials and the enhancement of existing tool designs [4,5,9–15]. Moreover, comprehensive machinability studies have also been carried out to investigate the correct combination of cutting instruments, machine tools, and cutting parameters. Also, many researchers have developed and implemented new technology and method such as minimum quantity lubrication (MQL), cryogenic cooling, different cooling, and lubrication systems, minimum quantity cooling lubrication (MQCL), multi-point injection

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MQL, nanofluid lubrication, sustainable cooling method, sustainable lubrication fluid, and laser-assisted machining, etc to address the key difficulties in the machining of titanium alloys [13–29]. Most of the previous review studies use qualitative methods to analyze the existing literature, so they failed to describe the overall paradigm of the research field. To the best of our knowledge, few studies have combined quantitative methods with visualization methods to explore the machining of titanium alloy research. This is essential to demonstrate the progress of the machining of titanium alloy literature. Therefore, there is an urgent need to critically review the research in the field of machining of titanium alloy and to suggest a way forward. To fill this gap, Two-level analysis including bibliometric and visualization analysis has been used. In this paper, a detailed bibliometric analysis of the research field of machining of titanium alloy was discussed. The main objective of this article is to explore the ideas and opportunities of the selected literature through bibliometric and visualization analysis for the period from 1st January 2000 to 31st December 2019. The selected articles have been analysis related to trend analysis, author analysis, discipline wise analysis, source analysis, country-wise analysis, institution wise analysis, and keyword analysis.

2. Research data collection and methodology

This study uses a mixed approach that integrates bibliometric and visualization analysis. Bibliometric is a statistical analysis of books, articles, or other publications. This term was first coined by Prichard in 1969 [30]. Bibliometric analysis is a systematic method that can quantitatively discover the trend of publication and investigate the critical points of emerging issues, and assess academic research quality from diverse viewpoints [31]. For bibliometric analysis, data were extracted in CSV and plain text file format from the Web of Science (WoS) database from the year 1st January 2000 to 31st December 2019. The WoS produced by the Institute for Scientific Information (ISI) and maintained by Clarivate Analytics and also known for the comprehensive and quality sources of data for bibliometric analysis in the area of science and technology. To carry out this research web of science core collection database was selected. The search strategy used to retrieve the data on machining of titanium alloy is tabulated in table 1. The search string was so selected that it could cover every title containing fully or partly the terms connected to machining of titanium alloy. The search field was set to article title only at the time of searching from WoS database.

Microsoft Excel, Bibliometrix [33], and VoS viewer [32] were used to analyze the results imported from WoS databases because of its high degree of visualizing bibliometric networks and flexibility in adjusting the input data. The results using search strings were analyzed based on aspects like distribution of the obtained research documents based on language, type, subject areas covered, total publications of authors, and citation counts of authors over the years. Further, lists of most productive authors, institutions, countries (along with geographical representation) are presented. The main Information about the extracted data is

Table 1
Search Criteria.

Database and Date of search	WoS and 27/09/2020
Search String	("Titanium alloy" OR "Titanium" OR "Ti-6Al-4 V" OR "Ti6Al4V") AND ("Turning" OR "Milling" OR "Grinding" OR "Drilling" OR "Tapping" OR "Boring" OR "Reaming" OR "Machining")
Search in fields	Article Title
Document Type	All

tabulated in table 2. The extracted information is divided into five parts i.e. key details regarding data, document types, document contents, authors, and author's collaboration. A total of 1291 records were found from WoS database based on the matched the above-mentioned search criteria. It is observed that articles 1174 (90.9%) have the main contribution in document types in WoS database due to its broader coverage of technical and scientific literature.

3. Result and discussion

3.1. Annual production and citation trend analysis

The literature on machining of titanium alloy has been receiving rapid attention since 2016 and gradually evolved over the years. The annual growth rate in machining of titanium alloy research is 16.94%. Publications trend from 1st January 2000 to 31st December 2019 based on the annual production and citations count is shown in Fig. 1. As can be seen from Fig. 1, the number of publications has increased significantly since 2000. From the year 2000 to 2014 research growth related to machining of titanium alloy was slow. The growth in this research field was increased rapidly since 2016 till it reaches its highest peak in the year 2019 with 215 articles. From this trend, it is visible that the number of machining of titanium alloy related publications will grow in the forthcoming years.

Table 3 shows the total annual production and citation count. From Fig. 1, it is seen that there is a serious downfall in the citation count from the year 2000 to 2019. However, mean total citations (TC) per year is not much affected and almost constant around 4. Where 'N' stands for no of publications.

3.2. Top productive authors impact analysis

Recognizing authors with the highest production and impact is a significant consideration for obtaining an overview of machining

Table 2
Main information extracted from WoS database.

Main Information About Data	
Timespan	2000:2019
Sources (Journals, Books, etc)	255
Documents	1291
Average years from publication	5.82
Average citations per documents	22.37
Average citations per year per doc	3.074
References	19,765
Document Types	
Article	1174(90.9%)
Article; Proceedings Paper	81(6.3%)
Correction	2(0.2%)
Editorial Material	2(0.2%)
Meeting Abstract	3(0.2%)
News Item	10(0.8%)
Retraction	1(0.1%)
Review	18(1.4%)
Document Contents	
Keywords Plus (ID)	1422
Author's Keywords (DE)	2711
Authors	
Authors	2830
Author Appearances	4875
Authors of single-authored documents	29
Authors of multi-authored documents	2801
Authors Collaboration	
Single-authored documents	45
Documents per Author	0.456
Authors per Document	2.19
Co-Authors per Documents	3.78
Collaboration Index	2.25

Fig. 1. Annual Production and Citation.

Table 3
Annual production and citation.

Year	N	Mean TC per Article	Mean TC per Year	Citable Years
2000	11	64.00	3.20	20
2001	21	82.57	4.35	19
2002	18	48.50	2.69	18
2003	12	36.50	2.15	17
2004	18	33.11	2.07	16
2005	27	53.52	3.57	15
2006	27	37.85	2.70	14
2007	28	50.43	3.88	13
2008	22	48.32	4.03	12
2009	38	43.26	3.93	11
2010	36	47.81	4.78	10
2011	43	52.14	5.79	9
2012	53	34.28	4.29	8
2013	68	26.66	3.81	7
2014	98	19.80	3.30	6
2015	92	22.86	4.57	5
2016	130	16.71	4.18	4
2017	158	11.54	3.85	3
2018	176	7.51	3.76	2
2019	215	4.62	4.62	1

of titanium alloy research. The top 20 list of most productive authors is shown in Table 4. Liu Z.Q with 29 number of publications (NP) has the highest number of documents published by him whereas Dargusch M.S is the highest contributor as well as an influential author with a total of 24 NP and a total of 4270 total citation (TC). Both authors (Liu Z.Q and Dargusch M.S) have the same h_{index} i.e 15 but publication start year (PY_start) are different i.e 2010 and 2007 respectively. Where 'R' stands for rank.

3.3. Country wise publication analysis

Authors from various institutions from different countries have published papers relating to machining of titanium alloy research. Table 5 shows the lists of top 20 most productive counties with TP- Total publication, TC- Total Citation, AAC- average article citation on machining of titanium alloy research. The most productive

country is China with 678 TP and 6333 TC, followed by India with 346 TP and 3965 TC. Other productive countries publishing on machining of titanium alloy include developed countries as well as developing countries, suggesting that the research topic is receiving global attention. Again, the one new entrant in the analysis is Bangladesh ranked at number 20 in WoS with 1.16% of TP and 205 TC.

This analysis can be best visualized on the world map. Fig. 2 shows the global geographical distribution of machining of titanium alloy research outputs. This map is created by using Microsoft excel 2016 software. The map uses color-coding, where the dark orange world region has the largest number of publications, and the light pink world region has the least number of publications. Areas without color indicate that no publication is available in these areas. In this map, it can be seen that South Asian countries such as China, India are leading the research, followed by

Table 4
Author production and impact.

R	Author	h_index	g_index	m_index	TC	NP	PY_start
1	Liu Z.Q	15	25	1.364	636	29	2010
2	Dargusch M.S	15	24	1.071	1109	24	2007
3	Sun J	13	23	0.867	669	23	2006
4	Xu J.H	11	17	0.647	326	23	2004
5	Fu Y.C	10	16	0.588	283	20	2004
6	Li J.F	12	18	1	365	18	2009
7	Chen M	9	17	0.5	332	17	2003
8	An Q.L	8	16	0.533	308	16	2006
9	Ding W.F	9	15	0.9	251	16	2011
10	Singh R	8	14	0.533	278	14	2006
11	Li L	7	14	0.412	606	14	2004
12	He N	6	13	0.4	537	13	2006
13	Palanisamy S	10	13	0.714	513	13	2007
14	Wang B	9	13	1.286	241	13	2014
15	Bruschi S	8	12	1.333	235	12	2015
16	Mia M	9	12	2.25	298	12	2017
17	Ozel T	12	12	1.091	1358	12	2010
18	Balazinski M	6	11	0.6	142	11	2011
19	Brandt M	9	11	0.643	656	11	2007
20	Ghiotti A	7	11	1.167	226	11	2015

Table 5
Top 20 Countries publication.

R	Countries	Frequency of TP	%	Country	TC	AAC
1	China	678	27.20	China	6333	15.75
2	India	346	13.88	USA	5103	45.97
3	USA	225	9.03	India	3965	21.20
4	Australia	142	5.70	Australia	1971	31.79
5	UK	119	4.77	UK	1531	26.40
6	France	82	3.29	France	1393	38.69
7	Turkey	81	3.25	Malaysia	1142	43.92
8	Japan	63	2.53	Turkey	899	23.05
9	Germany	59	2.37	Italy	868	27.12
10	Canada	58	2.33	Brazil	665	23.75
11	Italy	55	2.21	Spain	655	32.75
12	Poland	53	2.13	Germany	628	21.66
13	Brazil	52	2.09	Japan	412	16.48
14	Malaysia	50	2.01	Canada	393	15.12
15	Spain	42	1.68	Singapore	388	55.43
16	South Korea	41	1.64	Iran	371	21.82
17	South Africa	34	1.36	Korea	257	11.68
18	Sweden	34	1.36	Ireland	220	110.00
19	Iran	30	1.20	South Africa	218	12.82
20	Bangladesh	29	1.16	Bangladesh	205	25.62

North American countries like the USA, Canada. The Middle East countries and the African continent lag far behind other regions in this research field. Fig. 3 shows the country collaboration map on machining of titanium alloy research. In this figure, it is seen that China –USA has the strongest collaboration with 22 collaboration followed by China –the UK with 10 collaboration and India – China with 7 collaboration receptively.

3.4. Top institutions publishing work on machining of titanium alloy

The list of top organizations publishing on machining of titanium alloy is shown in Table 6. Nanjing University of Aeronautics Astronautics is on the top with h-index of 10 with the highest number of publications (71 TP), followed by the Shandong University have the h-index of 9 with 55 TP. Indian Institute of Technology System (IIT System) India is in the third position with h-index of 8 and 54 TP. Northwestern Polytechnical University is on the last in the list of institutions with h-index of 2. As can be seen from Table 6, most of the publications from the institution of China.

3.5. Top source impact analysis

Most sources of high impact are also closely related to engineering disciplines. Table 7 lists the 20 most influential and most productive journals related to machining of titanium alloy. The progress and impact of research on reputable sources/journals are also reflected in Table 7. IJAMT is on the top of the list with 273 NP getting 4615 TC followed by the journal of materials processing technology with 4038 TC from 70 NP. Interestingly, the journal of materials processing technology has the highest impact with 39 h_index on the research on machining of titanium alloy followed by IJAMT.

3.6. Research discipline wise analysis

In WoS database, most of the publications related to machining of titanium alloy research belong to the fields of engineering, materials science, business, automation control systems, metallurgy metallurgical engineering, and science technology. Table 8 lists

Distribution of Literature Publication

Fig. 2. Global Geographical Distribution of Machining of Titanium Alloy Research outputs.

Fig. 3. Global Collaboration Map of Machining Research of Titanium Alloy.

the publications count in different research disciplines. It can be seen from Table 8 that there are 958 (73.46%) and 470 (39.08%) publications related to machining of titanium alloy in the engineering fields and materials science, respectively. Through this analysis, we can easily conclude that machining of titanium alloy is a comprehensive field of all disciplines.

3.7. Most frequent author keywords used in Machining of titanium alloy research

To understand the key areas of a topic in a specific field for a specific period, it is necessary to study the keywords of the research paper, because they can provide important details of the

Table 6

Top Institutions publishing work on machining of titanium alloy.

Institutions	Country	TP Record	%
Nanjing University of Aeronautics and Astronautics	China	71	5.445
Shandong University	China	55	4.218
Indian Institute of Technology System (IIT System)	India	54	4.141
Shanghai Jiao Tong University	China	37	2.837
University of Queensland	Australia	28	2.147
Arts Et Metiers Institute of Technology	France	26	1.994
Royal Melbourne Institute of Technology	Australia	23	1.764
Anna University	India	21	1.610
Swinburne University Of Technology	Australia	19	1.457
Beihang University	China	18	1.380
Georgia Institute Of Technology	USA	18	1.380
Harbin Institute Of Technology	China	18	1.380
University System Of Georgia	USA	18	1.380
Indian Institute Of Technology IIT Bombay	India	17	1.304
Northeastern University of China	China	16	1.227
Northwestern Polytechnical University	China	16	1.227

current research field [34]. In WoS database, most of the extracted author keywords are linked to machining of titanium alloy. Table 9 shows the author keywords with keyword frequency. There are different types of keywords found from which the author keyword was considered for co-occurrence analysis. Where 'F' stands for the frequency of occurrence.

The author's keyword search can help to identify major research areas. For visual analysis, VoS Viewer was used to visualizing author keywords and co-occurrence networks. Different research topics are coloured in various colours so that corresponding keywords can be linked together. Certainly, over the past few years, keywords have changed dramatically. Fig. 4 shows the network visualization of author keywords in the field of machining of titanium alloy. From the analysis, it is clearly visible that different clusters are formed from the author keywords and each cluster showed a particular research theme. In cluster 1 the keywords are cutting fluid, minimum quantity lubrication (MQL), lubrication, Nanofluid, cutting forces, cryogenic machining, temperature, cutting parameters and surface morphology, etc. In cluster 2 the keywords are roughness, optimization, EDM, Taguchi method, FEM, MRR, residual stress, and Numerical Simulation, etc. In cluster 3 the keywords are Flank Wear, crater wear, wear mechanism, PCD

Table 8

Top research discipline on machining of titanium alloy.

Research discipline	Record Count	%
Engineering	958	73.466
Materials Science	470	36.043
Automation Control Systems	275	21.089
Metallurgy Metallurgical Engineering	124	9.509
Science Technology Other Topics	78	5.982
Physics	44	3.374
Chemistry	41	3.144
Instruments Instrumentation	36	2.761
Mechanics	33	2.531
Computer Science	16	1.227
Electrochemistry	14	1.074
Environmental Sciences Ecology	14	1.074
Thermodynamics	14	1.074
Dentistry Oral Surgery Medicine	12	0.920
Energy Fuels	8	0.613
Optics	7	0.537
Operations Research Management Science	6	0.460
Mathematics	5	0.383
Acoustics	4	0.307
Orthopedics	4	0.307

tool, tool life, and cutting tool. In cluster 4 the keyword is chip formation, chip mechanism, chip formation, microstructure, and serrated chip formation. In cluster 5 the keywords are drilling, hole quality, composite, and optimization.

4. Implications and limitations of the research

This study appends the literature on machining of titanium alloy. The bibliometric analysis will be used to provide a general outline and overall structure of the research area. For practitioners, this study provides important implications such as where is machining of titanium alloy research is going? The insight gained from this analysis also has implications for industrial peoples and academic scholars. From the industrial person point of view, the findings of this study help in the decision making process for the selection of research in the field of machining of titanium alloy. On the other hand, in the academic scholar point of view, this study gives a direction for starting new future research work in this field.

This research has some limitations. In this study only WoS database is used for bibliometric analysis. Although this database is very comprehensive and valid, it is better to use other databases,

Table 7

Top journals publishing works on machining of titanium alloy research.

Source	h_index	g_index	m_index	TC	NP	PY_start
IJAMT	35	50	2.33	4615	273	2006
Journal of Materials Processing Technology	39	63	1.86	4038	70	2000
Proceedings of The Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture	17	24	0.89	826	62	2002
Materials and Manufacturing Processes	20	30	1.54	1028	48	2008
International Journal of Machine Tools & Manufacture	30	41	1.50	4098	41	2001
Journal of Manufacturing Processes	13	19	1.63	480	35	2013
Machining Science and Technology	15	25	0.83	666	34	2003
Journal of Manufacturing Science and Engineering-Transactions of The ASME	12	17	0.75	346	32	2005
Wear	17	29	0.85	1253	29	2001
Materials	8	10	1.00	146	22	2013
CIRP Annals-Manufacturing Technology	13	17	0.68	867	17	2002
Journal of Alloys and Compounds	11	17	0.52	555	17	2000
Journal of The Brazilian Society of Mechanical Sciences and Engineering	8	12	0.62	153	16	2008
Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing	12	14	0.63	457	14	2002
Tribology International	11	14	0.92	475	14	2009
Journal of Cleaner Production	9	13	1.29	277	13	2014
Precision Engineering-Journal of The International Societies for Precision Engineering and Nanotechnology	10	13	0.50	367	13	2001
International Journal of Precision Engineering and Manufacturing	7	12	0.78	259	12	2012
Measurement	10	12	1.11	416	12	2012
Metals	5	9	0.71	89	12	2014

Top 100 Author Keywords on machining of titanium alloy research.

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including the Scopus database and Google Scholar. Another limitation is that our research includes publications in the English language only, and it is recommended that future research include documents published in other languages.

5. Conclusion

This article presents a bibliometric analysis of machining of titanium alloy research publications from 1st January 2000 to 31st December 2019 from the WoS database. An overview of the research on machining of titanium alloy was presented with the information related to the number of documents published on machining of titanium alloy, their language-wise distribution, type of documents, chronological publications count, top authors, journals, universities, and countries publishing documents. Based on the descriptive finding, the annual growth rate in machining of titanium alloy research is 16.94%, which indicates that machining of titanium alloy research has gained rapid attention since 2016 and gradually evolved over the years. Moreover, most of the research on machining of titanium alloy has been done in the engineering and material science field. From a quantitative perspective, China and India are leading countries but on the other hand in the view of a qualitative perspective, China and the USA are on the top. Consequently, the visualization diagram of keywords created by VoS viewer using WoS data files shows that the field of machining of titanium alloy has a great scope in the future in the directions like minimum quantity lubrication (MQL), nanofluid, cryogenic machining, cutting temperature, CFD, microstructure, sustainable machining, green machining, tool wear, nano machining, optimization, tool life with major machining process like turning, milling, grinding, drilling, EDM and WEDM, etc. From the Journal wise analysis, IJAMT (4615(TC), 273(NP)), and JMPT (h index 39) have a good quality of published publications. It is seen that Liu Z.Q who holds the first position with 29 publications and 15 h-index. Similar is the case with other authors as well. Although China dominates in the machining of titanium alloy research around the world but Nanjing University of Aeronautics Astronautics, china has maximum research outputs than other universities around the world. Country collaborating wise, China-USA is leading in the world as their combined research output is the highest.

CRedit authorship contribution statement

Gaurav Gaurav: Conceptualization, Writing - original draft, W, riting - review & editing. **Abhay Sharma:** Investigation, Methodology. **G.S. Dangayach:** Supervision. **M.L. Meena:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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