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A four-decade of abrasive waterjet processing technology (1980-2023): a scientometric analysis

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Abstract. The field of abrasive waterjet (AWJ) machining has seen growing interest over the past decade, reflected in the increasing number of related research publications. Despite significant progress, uncertainties remain regarding the future direction and performance of AWJ technology. This paper aims to deliver a structured, in-depth, dynamic, quantitative, and objective analysis of research in the abrasive waterjet field. By examining the existing body of knowledge and identifying emerging trends, this review seeks to enhance and refine research within the domain of manufacturing. This study employs bibliometric and text mining analyses using R-tool Biblioshiny and VOSviewer to quantitatively assess and visualize key concepts, themes, and research dynamics in AWJ. The dataset, sourced from the Scopus database (1980–2023) following PRISMA guidelines, includes 1,666 articles from 504 sources, involving 3,062 authors across 80 countries and 2,776 affiliations. Findings reveal a significant growth rate of 228.57% in AWJ-related publications in 1993, marking a pivotal increase in scientific output. India and China emerged as the most productive countries in AWJ research. The results provide valuable insights for academics and policymakers, offering a benchmark for evaluating research efforts and guiding future developments in AWJ technology.

Keywords: Abrasive waterjet / bibliometric / performance analysis / network analysis / thematic analysis

1 Introduction

The continued growth of the manufacturing sector, characterized by the utilization of advanced and highly competitive technology, necessitates machining and production techniques to achieve products of high-quality and precision. The current state of materials science has led to a increasing tendency to design and produce of intricate mechanical components. Consequently, there is a corresponding demand to integrate novel machining techniques and enhance existing ones within the manufacturing process. Advanced machining engineering processes are extensively employed as a means to address diverse challenges encountered in manufacturing operations. These challenges include the use of high-strength materials, fabrication of intricately profiled components, and demand for enhanced surface characteristics. Moreover, these methods are suitable for achieving high accuracy, miniaturisation, waste reduction, and process streamlining subsequent operations, all while permitting shorter production times. Due to its wide operational capabilities and high precision, abrasive waterjet (AWJ) machining has attracted significant interest from researchers and engineers in the manufacturing industry when compared to alternative machining techniques [1,2].

The commercialization of abrasive waterjet (AWJ) cutting began in the early 1970s, marking its initial commercial release. The first application of AWJ was developed in the 1970s with the aim of minimising production time and reducing thermal weaknesses commonly found in other non-conventional manufacturing techniques. The commercialisation of abrasive waterjet cutting was completed in the late 1980s [3]. AWJ machining initially faced limitations in the early 1980s. At its beginning, the technique was primarily applied on materials of lower hardness. However, due to technological advancements and the emergence of high-pressure waterjet generation, AWJ cutting is now capable of effectively

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cutting various materials while preserving their internal characteristics [4]. The utilisation of AWJ technology is presently observed in multiple industrial sectors, including automotive [5], electronic devices [6], geotechnical engineering [7], food manufacturing [8], marine applications [9], medical and surgical devicesf milling operation [10,11], and aerospace [12]. AWJ possesses a range of capabilities, enabling the utilisation of various AWJ operations such as milling [13–15], drilling [16–18], turning [19–21], threading and cleaning [22,23], peening [24–26], and hybrid machining [27].

The workpieces subjected to the AWJ process frequently display diverse shapes and dimensions, and possess the capacity to efficiently sever a broad spectrum of materials. The AWJ possesses the capability to perform cutting operations on both metal and non-metal materials. It exhibits proficiency in cutting various materials, including those that are soft and flexible such as glass [28] and plastic [29], as well as those that are considerably harder, such as titanium alloy [30–32], tool steel [33,34], and tungsten carbide [35]. The AWJ method is also employed for cutting advanced materials, including composites [36–38], ceramics [39,40], and other materials with magnetic properties.

Over the past three decades, many countries have undertaken extensive research on AWJ, resulting in the broadening of its application sector and scope. In recent years, the quantity of research articles in the AWJ field has significantly increased. Numerous researchers have undertaken early-stage investigations on AWJ and have derived numerous insightful findings. Emerging trends and themes are currently emerging. However, the existing body of study primarily emphasizes engineering applications. Nevertheless, there is a lack of analysis regarding the challenges encountered throughout research endeavors and prevailing trends in this field. Bibliometrics is a powerful technique and an effective tool for analyzing the general state of scientific research and examining the wealth of information contained in multiple publications. This approach leverages the interconnectedness of bibliographic networks to assess the scholarly merit and scientific influence of publications, as well as to forecast future trends in their growth. Furthermore, it is imperative to assess and critically assess the current literature to review research advances and identify possible avenues for future investigation. Hence, bibliometric analysis emerges as a valuable approach for assessing large-scale publication datasets due to its capacity to identify areas of knowledge deficiency, evaluate research quality, and identify recent advances within a specific domain.

This paper presents an extensive review of AWJ through the utilisation of bibliometric analysis indicators. This type of bibliometric analysis distinguishes itself from other types of literature reviews, such as thematic reviews, by employing objective quantitative and statistical methods, as well as utilising technological advancements like databases and software. Unlike thematic reviews, which rely on subjective manual processes and typically cover a limited number of articles (usually tens to hundreds), this bibliometric review offers a broader scope. Enabled by the use of advanced data analysis and machine learning techniques [41]. Bibliometric analysis indicators primarily attempt to quantitatively evaluate the quantity and significance of publications by taking into account the total number of scientific papers produced and the citations received. To assess the impact and influence of authors, journals, countries, and institutions in a particular research domain, bibliometric indicators are used, which play an important role. Moreover, bibliometric indicators can provide a comprehensive overview of a specific field of study. A number of scholars have presented bibliometric-based assessments in various disciplines with the aim of identifying the most dynamic and influential authors, publications, and institutions.

The purpose of this study is to classify and analyse recent publication trends in AWJ technology, determine the countries that have made the greatest contribution to this field, determine the most important journals and influential publications, and analyse keyword clusters. This study subsequently performed a systematic examination and evaluation of research publications that included case studies, with the objective of categorising their techniques. In addition to the general objectives, the specifics of this paper expand our understanding of the subject, provide context for application trends, suggest practical recommendations, and provide supporting references. In this way, gaps or opportunities for improvement in the unexplored field of AWJ can be identified.

2 Methodology

2.1 Bibliometric analysis

The utilisation of bibliometric analysis is a significant method for understanding and visually representing the accumulated scientific information and complex developments across established academic disciplines. This is accomplished by employing rigorous approaches to systematically analyse significant volumes of unstructured data [42]. The bibliometric review has been widely applied, covering an array of academic disciplines, including science and technology [43], social science [44], economics [45], education [46], business and management [47], health and medicine [48], and engineering [49]. Additionally, bibliometric analysis has been utilized in manufacturing research, including cloud manufacturing [50], additive manufacturing [51,52], sustainable manufacturing [53], lean manufacturing [54], and advanced manufacturing [55].

A bibliometric review involves a thorough assessment of designated databases, including Scopus [56], Web of Science [57], Google Scholar [58], Dimension [59], and PubMed [60], as well as additional literature sources that may not be accessible through these databases. A systematic method is required for the analysis and integration of relevant content in this type of evaluation. Software tools play a vital role in research as it aids researchers in identifying research challenges, displaying outcomes, analyzing data, and distributing knowledge. Regarding bibliometric analysis, numerous software packages for scientific atlases with varying capabilities and limitations have been developed. The information contained in publications can be extracted to the greatest

extent by combining multiple software such as VOSviewer, Biblioshiny (tools inside the bibliometric package R), Histcite, CiteSpace, Gephi, and Leximancer. The presence of this software facilitates the analysis of data in a user-friendly and practical manner, hence leading to a recent increase in scholarly attention towards bibliometric analysis. The the software tools are open-source programs, provided at no cost and is designed with a user-friendly interface.

In bibliometric research, there are two primary methodologies for conducting bibliometric analysis. The initial step involves conducting a performance analysis, which assesses the productivity and impact of publications through the utilisation of diverse bibliometric indicators. These indicators encompass the number of publications, citations received, and average annual citations for publications that have attracted significant attention. Additionally, this analysis evaluates the influence of authors, nations, and journals within the scholarly community. Furthermore, the utilisation of scientific mapping analysis [61] encompasses components include clustering, visualisation of keyword co-occurrence analysis, bibliographic coupling, co-authorship analysis, citation analysis, and co-citation analysis. This comprehensive approach aids in mapping the knowledge structure in a particular area of study or journal [42].

2.2 Selection of bibliographic database

The dataset was compiled from the results obtained from subject search queries conducted on the Scopus core collection. The data covers the time period from 1980 to December 31, 2023. The aforementioned search query design is general enough that allows for its use to a science mapping investigation, unless, of course, the researcher possesses unrestricted access to the complete database. The dataset utilized in this investigation comprises articles and reviews that have been published in the English language. Researchers use the keywords “abrasive waterjet”, “abrasive water jet”, or “abrasive water-jet” within the “Title, Abstract, and Keywords” field on the Scopus search database to screen papers related to AWJ. However, irrelevant papers may have been inadvertently included in the data collection procedure. In order to reduce this circumstance, a manual screening process was conducted to exclude articles that lack relevance to AWJ. A comprehensive collection of 3022 documents was acquired, consisting primarily of articles (61%), conference papers (31%), book chapter (3%), conference review (2%) and a small percentage of other types of publications, as illustrated in Figure 1.

In the year 2023, the the dataset included 5,328 total subject classifications. Table 1 displays a thorough collection of the top nine study categories in the field of AWJ, as noticed in different scholarly journals. The field of engineering is the predominant category, with 2,312 articles. The subject areas include materials science (19.3%), computer science (9.0%), physics and astronomy (7.01%), chemical engineering (4.1%), earth and planetary sciences (3.2%), environmental science (2.9%), energy (2.6%), and mathematics (2.6%).

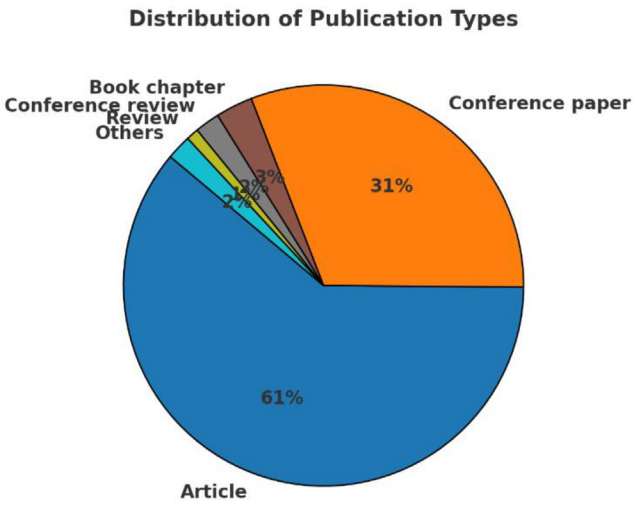

Fig. 1. The document category obtained from the Scopus database.

2.3 Inclusion criteria for literature selection

A total of 1,666 articles were identified in the previous methodological step (Tab. 2). Examining each article against a set of inclusion and exclusion criteria is essential for determining its suitability. The selection of these criteria aligns with the viewpoints of this review and is designed to be comprehensive to identify all relevant papers, while also clearly defining the research question. The research evaluated only peer-reviewed journal articles to ensure the quality of the selected sample, excluding other document categories such as books, chapters, conference proceedings, and editorial notes. During the screening procedure, irrelevant (i.e., publications that are outside the scope of this work) and non-English articles were eliminated. The dataset exhibits an annual growth rate of 12.67% over the full time span, including a mean of 18.74 references per document and a total of 34,958 references. Furthermore, the retrieved data unveiled an overall amount of 6,991 keywords and 3,062 author keywords that were categorized as either plus or index keywords from the 1,666 articles.

The investigation of the retrieved documents revealed that a total of 3,064 authors were engaged in performing research within this specific topic. Notably, single authors contributed to the authorship of 116 documents, indicating a significant level of individual productivity. On average, each article had 3.55 co-authors, suggesting a collaborative approach to research. Furthermore, foreign co-authorship accounted for 16.57% of the overall authorship, highlighting co-authorship contributed to the total international collaborations.

Table 1. The top 9 groups for the subject areas of the study (data from Scopus database).

Subject Area	Publications	Percentage (%)
Engineering	2,312	43.40
Materials Science	1027	19.27
Computer Science	481	9.02
Physics and Astronomy	374	7.01
Chemical Engineering	218	4.10
Earth and Planetary Sciences	173	3.25
Environmental Science	152	2.86
Energy	140	2.63
Mathematics	137	2.58

Table 2. The datasets collected.

Description	Results
Key Elements Regarding Data	
Documents	1666
Timespan	1980:2023
Sources (Journals, Books, etc)	504
References	34958
Average citations per doc	18.74
Annual Growth Rate %	12.67
Document Average Age	11.2
References	34958
AUTHORS	
Authors	3064
Authors of single-authored docs	116
TABLE OF CONTENTS	
Author's Keywords (DE)	3020
Keywords Plus (ID)	7000
DOCUMENT TYPES	
Articles	1666
COLLABORATION AMONG AUTHORS	
Single-authored docs	198
Co-Authors per Doc	3.55
International co-authorships %	16.57

2.4 Construction of citation and keyword networks

The chosen articles for the data collection procedure were imported into Biblioshiny and VOSviewer software in order to generate source-, country-, and author-level citation networks. This analysis aims to identify the authors and regions that have had the greatest impact on the field of AWJ research. Furthermore, keyword classification was also performed using the co-occurrence of keywords.

2.5 Visualisation of bibliometric data

Numerous software packages with diverse functionalities and limits were created for use in bibliometric analyses and science mapping. The integration of many software applications enables the comprehensive extraction of information from publications [62]. This study employed two distinct software bibliometric algorithms which is widely recognized as the most prominent software for conducting bibliometric analyses One notable package in R Studio is Biblioshiny, used to analyse the annual growth in publication frequency and changes in citation patterns. Furthermore, a collaborative technique was employed to perform a multi-country network analysis. This research focused on the co-citation of authors and the co-occurrence of keywords throughout various evaluation periods. The research was conducted utilising VOSviewer 1.6.18. The data given in Biblioshiny primarily relies on command-line execution, unlike VOSviewer, which provides a graphical interface.

2.6 Analytical procedure

To gain deeper insight into AWJ technology, a two-phase methodology was applied [63]. The research investigation centered on two distinct categories of bibliometric indicators. The first category included conventional bibliographic information, encompassing details such as affiliations, authors, publication year, and sources (e.g. journal titles). The second group comprised terms obtained from the abstracts and titles of research articles using machine learning methods. The R software tool was used in both phases of the investigation. The second phase involves the identification of clusters, which are crucial in deciding the articles that will be incorporated for inclusion in the review section. The purpose of this investigation was to obtain social insight, intellectual framework, and conceptual of the subject's study. The review process followed in this work is depicted in Figure 2.

3 Results

3.1 Trends in annual publication volume

This study examines the research on AWJ by analyzing the documents generated on the subject across a span of four decades, beginning in 1980 with one article by Griffiths and Godding [64]. The frequency of published articles has demonstrated a gradual increase from 1980 to 2023, as depicted in Figure 3. Between the years 1980 and 2008, there was a marked lack of growth in scientific publications, resulting in a tendency towards a state of stagnation. This was particularly evident in the fewer than fifty publications per year. The quantity of published articles shown a substantial growth over the years 2015 and 2022, and has steadily risen during the preceding five-year period. The annual growth rate in publications corresponds to 12.67%. Furthermore, in recent years, there has been a notable rise in the quantity of citations for publications, indicating a heightened level of scholarly interest in the subject matter.

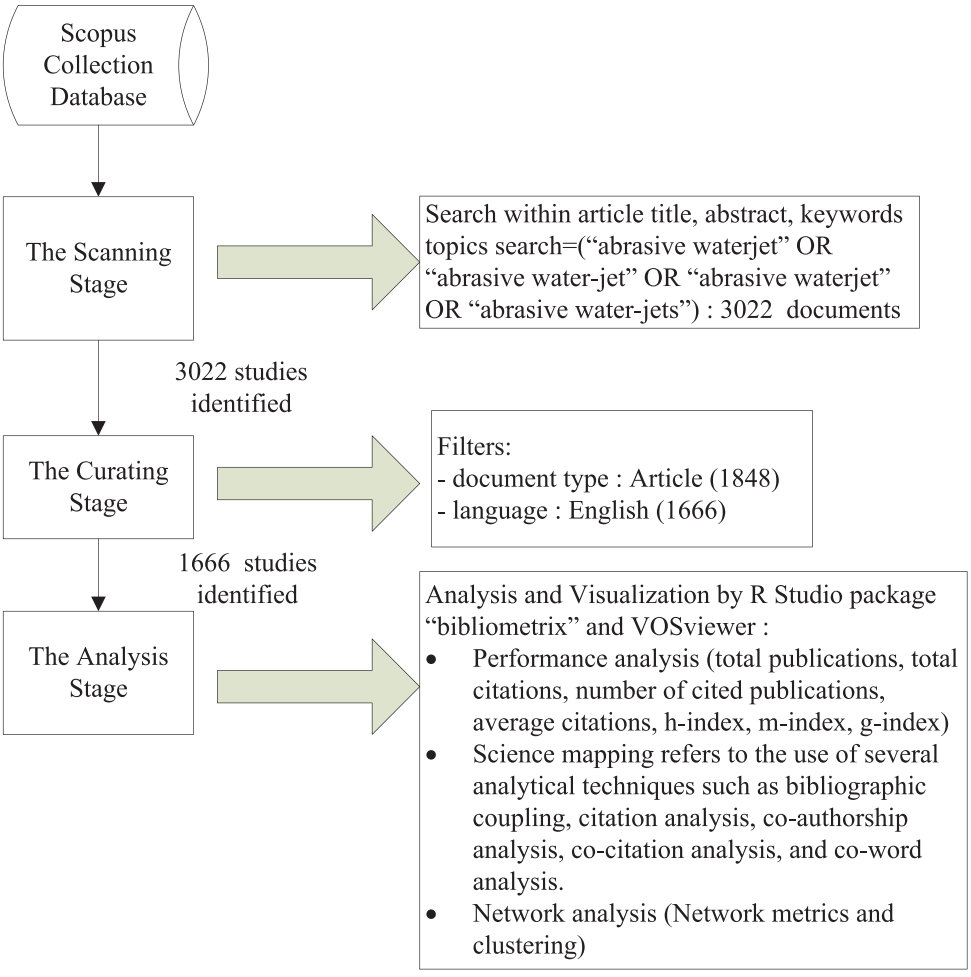

Fig. 2. A bibliometric review's methodology.

The year 1993 had a notable surge in research output, with a growth rate of 228.57% compared to the preceding year. A comparable pattern is also observed in the proportion of publications as the years ago. Four distinct characteristics were observed in the AWJ research articles, as indicated in Table 3. During the initial decade spanning from 1980 to 1990, a 87 papers were analysed, which represented a consistent pattern. Following that, a total of 167 articles (indicative of a consistent pattern) were recorded between 1991 and 2000, whereas 256 articles were recorded between 2001 and 2010. Subsequently, a additional 1,156 documents were examined from 2011 to 2023. The final characteristic of the research output demonstrated a significant increase in publications, a trend that is expected to persist as the recognition of the advantages associated with the utilisation of AWJ becomes more widespread. Consequently, this is likely to stimulate research interest and foster further advancements in various fields of study. Figure 4 illustrates the mean number of citations accumulated annually. The phenomenon of citations is currently experiencing a growing trend, although the growth rate is non-uniform.

3.2 Leading journals in AWJ research

A comprehensive review leading journal titles is presented in Table 4. This includes the number of publications, citations, CiteScore, total link strength, impact factors (IF), h-index, and quartile rankings associated with each title. The aforementioned data was acquired through the utilisation of the VOS viewer software, which performs citation analyses on sources. The IJAMT achieved the most prominent ranking among the top 20 journals, accumulating a total citation count of 4,038. The journal is well regarded for its significant impact factor of 3.4, a cite score of 6.2, an H-index of 145, and a Q1 ranking. It is widely recognized as the leading journal in the field of abrasive waterjet research, offering a comprehensive collection of scientific articles. Its reputation extends globally, solidifying its position as the foremost publication in this discipline. The observed result can be attributed to the alignment between the journal's specific emphasis on manufacturing and the primary research focus on abrasive waterjet technology across various applications within the field of AWJ study.

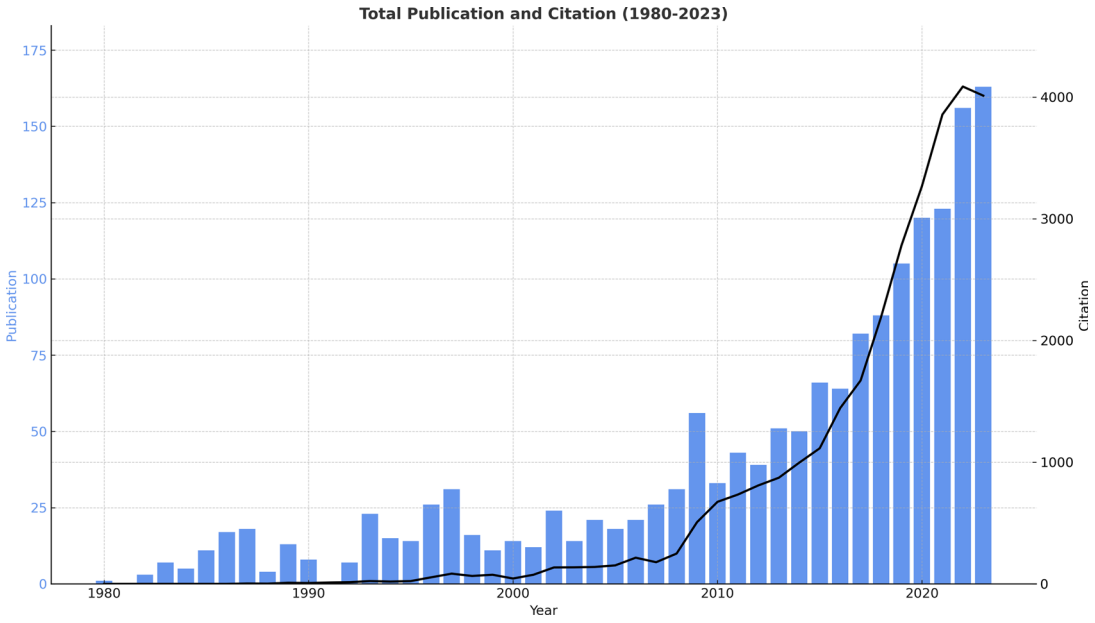

Fig. 3. Annual scientific production.

The study of scientific research published in the leading 20 journals reveals a notable emphasis on sophisticated machining and manufacturing, alongside the use of machining technologies. The data aligns with the scope of AWJ research, which focuses on the use of AWJ, as a highly advanced machining technique derived from the field of manufacturing technology. The findings presented in Table 4 indicate that a significant proportion of the top 20 articles (fourteen out of twenty) place a high emphasis on scientific inquiries pertaining to machining processes. The aforementioned findings provide support for the conclusions drawn regarding the primary subject areas in which engineering achieved the greatest rankings. The data may be attributed to the fact that engineering represents the tangible application of scientific findings. Based on the given criteria, which include the impact factor (IF) range of 1.2–14, the Cite Score range of 2.4–20.9, and the observation that over 50% of the journals possess a Scimago® grade of Q1, it can be inferred that the 20 highest-ranked journals have exceptional quality and significant scientific effect.

The evaluation of the quality of academic journals can be accomplished by using the impact factor, as demonstrated in Table 4. Based on an analysis of publication counts and citation metrics across various academic disciplines, it has been observed that the IJAMT and the JMPT have recorded high publication and citation counts. The IJMTM achieved the greatest impact factor among the 20 journals. Furthermore, it is worth mentioning that the JMPT has recorded the highest h-index (215) in comparison to other prominent and prolific journals across many fields of publication.

3.3 Leading authors in AWJ research

The assessment of an author's productivity can be conducted by the total number of published papers they have generated. Similarly, the evaluation of the impact of their research can be performed by calculating the total number of citations received by their published works. The h-index, also known as the Hirsch index [65], is a composite metric that considers both productivity and effect. The h-index is a metric used to evaluate the scholarly productivity of academics based on the quantity of their publications and the extent to which these publications have been cited [66]. The g-index is a metric that has been developed to assess the overall citation impact of a collection of scholarly papers. The g-index is a metric that reflects high-impact contributions [67]. In order to calculate an individual's m-index, the h-index is divided by the number of years since their first publication. Table 5 shows the twenty authors who have received the greatest number of citations. Wang J was identified as the author who has authored the most publications and received the most citations within a group of 20 authors. Specifically, Wang J received 2,731 citations from 64 articles, with the initial article dating back to 1999. Hashish M ranked second in total citations, with 1,843 citations received from 51 publications. These articles span from the first publication in 1982. Furthermore, it is worth noting that Wang J and Hashish M have achieved the highest h-index scores of 28 and 21, respectively.

3.4 Most cited articles in AWJ research

The classification of influential papers in the subject of abrasive waterjet has been carried out using articles that

Table 3. Research publication growth.

Year	Publications	% Publication	% Growth
2023	169	10.230	8.33
2022	156	9.443	26.83
2021	123	7.446	2.5
2020	120	7.264	14.29
2019	105	6.356	19.32
2018	88	5.327	7.32
2017	82	4.964	28.13
2016	64	3.874	-3.03
2015	66	3.995	32
2014	50	3.027	-1.96
2013	51	3.087	30.77
2012	39	2.361	-9.3
2011	43	2.603	30.3
2010	33	1.998	-41.07
2009	56	3.390	80.65
2008	31	1.877	19.23
2007	26	1.574	23.81
2006	21	1.271	16.67
2005	18	1.090	-10
2004	21	1.271	42.86
2003	14	0.847	-41.67
2002	24	1.453	100
2001	12	0.726	-14.29
2000	14	0.847	27.27
1999	11	0.666	-31.25
1998	16	0.969	-48.39
1997	31	1.877	19.23
1996	26	1.574	85.71
1995	14	0.847	-6.67
1994	15	0.908	-34.78
1993	23	1.392	228.57
1992	7	0.424	-30
1991	10	0.605	25
1990	8	0.484	-38.46
1989	13	0.787	225
1988	4	0.242	-77.78
1987	18	1.090	5.88
1986	17	1.029	54.55
1985	11	0.666	120
1984	5	0.303	-28.57
1983	7	0.424	133.33
1982	3	0.182	300
1981	0	0.000	-100
1980	1	0.061	0

have the highest citation counts. The work that possesses a greater number of citations is considered more influential owing to the presence of novel and valuable ideas incorporated within its contents. Table 6 displays the 20 most frequently most-cited publications in AWJ over the full time span. The articles that received the greatest amounts of citations was authored by Hashish M in 1984.

3.5 Country-level publication output and collaborations

Among the 80 countries analysed in Figure 5, India is the leading contributor with 381 articles, accounting for approximately 22.85% of total publications in this study area. China ranks second with 314 items, representing 18.88% of the total output, while the United States comes third with 199 items, representing 11.96%. Figure 6 displays the worldwide production of publications in AWJ distribution. The country collaboration structure demonstrates a plenty of cross-continent collaborative relationships in general (Fig. 7). The global network of scientific partnerships is highlighted in the country collaboration map for AWJ research, with the United States, China, and India contributing the most, as shown by the connecting lines and darker shades. The Asia-Pacific region leads in research output, which includes China, India, and Australia. Australia maintains links with Asian and European countries. European nations also exhibit active research partnerships, especially Germany, the UK, and Italy. Cross-border partnerships are indicated by the numerous connections between Europe and North America (USA, Canada). Several countries appear to have no recorded collaboration in AWJ research, including most African nations, selected South American nations (e.g. Bolivia, Paraguay), and Central Asian countries like Kazakhstan and Uzbekistan. Additionally, some Middle Eastern countries and a few Eastern European nations show limited or no research connections. This indicates that AWJ research is concentrated in specific regions, with limited participation from developing or less industrialised regions.

3.6 Network keyword analysis

Co-occurrence refers to the occurrence of certain items simultaneously, such as author keywords, index of words, or entity features, within an article. It is a quantifiable analysis of keyword relationships to uncover the implicit significance of evidence and concealed information linked to a specific object. Keywords help define, map, and trace both popular and emerging fields of study. The minimal threshold for the occurrence of a keyword was set at 10 instances. A total of 85 keywords, out of a pool of 3,023 keywords, met the occurrence threshold. The node's size in the visualisation map is proportional to the keyword's contribution, with larger nodes representing higher occurrences of the keyword.

The characterisation of the eight groupings of cooccurrences is illustrated in Figure 8. They were divided into the following clusters: Cluster 1 consisted of 19 elements in red, Cluster 2 consisted of 18 elements in green, Cluster 3 consisted of 16 elements in blue, Cluster 4 consisted of 10 elements in yellow, Cluster 5 consisted of 10 elements in purple, cluster 6 of 6 elements in cyan, cluster 7 of 5

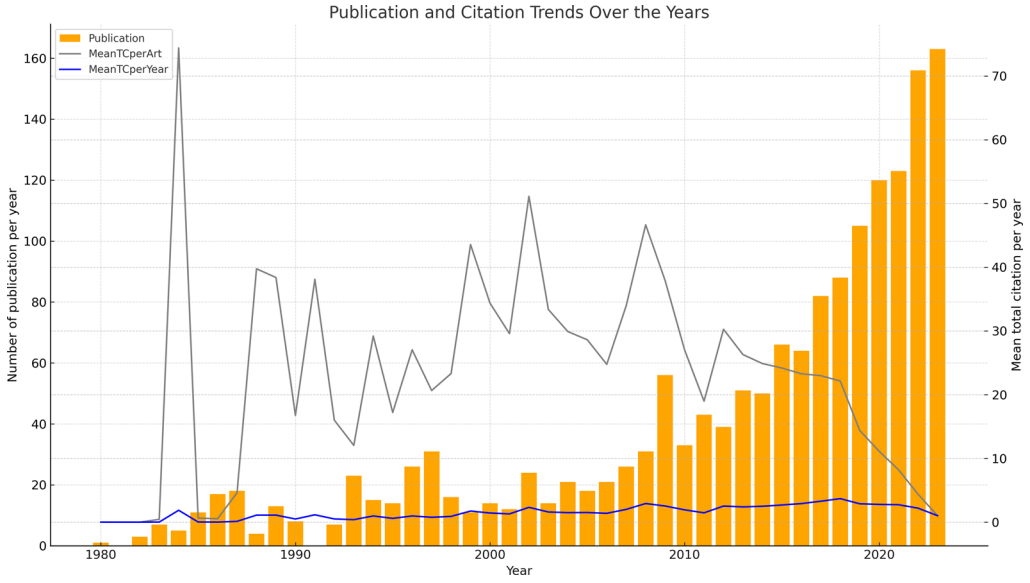

Fig. 4. The average yearly amount of acquired citations.

elements in orange and cluster 8 of 1 element in dusty pink. As defined in the first cluster, "Abrasive waterjet cutting and cutting performance on titanium ", once the most frequent terms refer to kerf characteristics, surface integrity, erosion, fatigue and milling. The second cluster is defined as "Artificial neural network (ANN) and regression analysis in AWJ machining". This cluster encompasses the machining performance within AWJ, including surface roughness, surface morphology, material removal rate, machinability and mechanical properties. The third cluster is defined as "Computer fluid dynamic (CFD) and numerical simulation". Once the main occurrences are related to wear, surface quality, vibration, delamination, and declination angle. The fourth cluster is defined as "Optimisation of AWJ", once the main occurrences are related to the Taguchi method, ANOVA, kerf width, and cutting depth. The fifth cluster is defined as "Abrasive and composite materials", once the main occurrences are related to kerf, taper, surface, and roughness". Cluster six is defined as "Garnet and Abrasives", once the main occurrences are stand of distances (SOD), taper angle and traverse speed". The seven cluster is defined as " CFRP (carbon fiber-reinforced plastic)", once the most frequent term is composite materials. The eight cluster is defined as "SEM (Scanning electron microscope)".

This section also provides a comprehensive analysis and evaluation of index keyword frequency in AWJ of Scopus datasets from 1980 to 2023. The selection of index keywords for AWJ is based on the co-occurrence of specific index keywords. The AWJ dataset consists of 7002 index terms, out of which 136 satisfy the condition of co-occurring at least 20 times. The collection of interconnected things is remarkably vast, consisting of 136 index phrases. These terms are meticulously organized into four clusters, and with a combined link strength of 30183. Figure 9 presents the co-occurrence network diagram of the co-occurrences among index-keywords. The term "Jets" has a total link strength of 5,726 and occurred 910 times. The term "abrasive" has a combined link strength of 3654 and appears 545 times. Lastly, the term "surface roughness" has a combined link strength of 2754 and appears 364 times.

3.7 Word cloud

As a representation of words, a word cloud displays the frequency of occurrence of each word, with its size corresponding to that frequency. Because they are larger and more noticeable, important words are usually positioned in the center of the word cloud, which is often arranged randomly. Figure 10 shows a diagram of the words that appeared the most frequently in AWJ-related articles. The word cloud analysis was conducted over four time periods to examine the evolution of keywords in AWJ research. The magnitude of a word is determined by the number of times it appears in the word cloud. The word placement is random, however the most important keywords are in the center to bring attention to their large size. "Metal cutting" and "jet cutting" are the most researched subject in the first period (1980-1990). "Mathematical model", "erosion", "wear of materials" and "nozzles", "ceramic materials" are the keyword that mainly used in the second period (1991-2001). During the third period (2002-2012), the research topic remained mostly unchanged in comparison to the previous period. This is evidenced by the consistent use of several keywords that were also present in the previous period. "Standoff distance" (SOD), "surface roughness" and "scanning electron microscope" are keywords that appear a lot in the recent decade (2013-2023). The term "nozzle" regularly co-occurs with "erosion" in every time period, and there is a decline in keyword usage of this keyword, as indicated by the reduced word size in the visualisation in the word cloud. Simultaneously, it is evident that no singular primary research tendency prevails in frequency over others. Each

Table 4. The top 20 highly cited journals within the subject of AWJ research.

Source's Title	Citations	Publications	Cite Score	Impact factor	H-index	Quartiles	Production Year Start
The International Journal of Advanced Manufacturing Technology	4038	168	6.2	3.4	145	Q1	1996
Journal of Materials Processing Technology	3215	49	12.2	6.3	215	Q1	1997
International Journal of Machi ne Tools and Manufacture	2871	41	20.9	14	179	Q1	1992
Materials and Manufacturing Processes	1468	44	9	4.8	81	Q1	1995
Wear	1418	29	9.3	5	170	Q1	1993
Journal of Engineering Materials and Technology, Transaction of The ASME	1013	7	2.4	1.2	74	Q3	1984
CIRP Annals – Manufacturing Technology	524	11	9.5	4.1	175	Q1	1996
Journal of Manufacturing Processes	517	27	9.2	6.2	79	Q1	2009
Composite structures	465	10	10.9	6.3	185	Q1	2002
Materials	451	49	5.2	3.4	148	Q2	2013
Journal of Engineering for Industry (continued as Journal Manufacturing Science and Engineering)	413	11	6.6	4	108	Q1	1987
International Journal of Fatigue	408	6	10.2	6	145	Q1	1997
Composite Part A: Applied Science and Manufacturing	407	7	15	8.7	206	Q1	2008
Journal of Manufacturing Science and Engineering, Transactions of The ASME	386	18	6.6	4	108	Q1	1987
Proceedings of The Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture	379	19	5.7	2.6	75	Q2	1993
Machining Science and Technology	366	11	4.8	2.7	58	Q2	2003
International Journal of Rock Mechanics and Mining sciences	363	10	13	7.2	187	Q1	1997
Rock Mechanics and Rock Engineering	289	12	11.4	6.2	122	Q1	2013
Journal of Intelligent Manufacturing	263	8	17.3	8.2	95	Q1	2014
Precision Engineering	253	12	6.7	3.6	97	Q1	2009

Table 5. The author's local Impact in AWJ research.

Authors	Total Citation	Total Publication	h-index	g-index	m-index	Publication Year Start
Wang J	2731	64	28	51	1.12	1999
Hashish M	1843	51	21	42	0.5	1982
Hloch S	1227	49	23	33	1.353	2007
Ramulu M	1121	24	15	24	0.441	1990
Arola D	1106	15	13	15	0.419	1993
Kovacevic R	1030	39	16	31	0.471	1990
Siores E	697	11	11	11	0.393	1996
Shanmugam DK	645	6	6	6	0.273	2002
Axinte DA	635	12	12	12	0.8	2009
Huang C	634	33	16	24	1	2008
Valíček J	630	29	17	24	0.941	2007
Aydin G	583	15	12	15	0.923	2011
Zhu H	565	26	14	23	0.875	2008
Uthayakumar M	511	18	12	18	1.5	2016
Zitoune R	496	19	8	19	0.727	2013
Karakurt I	494	13	11	13	0.846	2011
Hlavãc LM	490	19	13	19	0.867	2009
Papini M	489	16	12	16	1.091	2013
Shipway PH	460	5	5	5	0.263	2005
Azmir MA	451	3	3	3	0.188	2008

term in the word cloud chart can be interpreted as key themes of development of development and study carried out in the field of AWJ [88].

3.8 Bibliographic coupling of research articles

Bibliographic coupling is a scientometric technique allows researchers to look at a variety of subjects, spot new trends, and think about where to take their research in a given field. Citations to a shared third source in two publications imply that the authors of those publications have similar intellectual underpinnings and build upon them [89]. Bibliographic coupling can identify thematic or social clusters, which allow researchers to monitor the development of a theme. This method aids in understanding how research fields advance, interconnect and shape each other over time. This study used a bibliographic coupling technique to identify current research trends in the scientific literature on abrasive waterjet and to provide a relevant research focus for future work. A citation threshold of 25 per article was set for curationwhich resulted in the selection of 372 research papers that linked together. The final cluster groupings and number of associated documents are shown in Figure 11 and the elements of each cluster are summarised in Table 7. Each node represents a research article, with its size indicating the number of citations received. The connections between nodes reflect shared references, illustrating intellectual relationships and thematic clusters within the research field. Colours denote distinct research communities or topic areas, revealing key contributors and influential works in the domain. The proximity of nodes indicates a stronger thematic connection between studies, helping to identify research trends and the evolution of knowledge within the field.

3.9 Thematic assessment of the clusters

The basic theories of AWJ machining and tool wear are the subject of Cluster 1 (red). This cluster is the largest with 93 articles, demonstrating its fundamental significance in AWJ research. The representative articles most likely examine early and crucial studies that have influenced our knowledge of erosion models [79], material removal procedures [95], and AWJ cutting mechanisms. The erosion mechanics involved in AWJ cutting have been the main focus of studies in this cluster. This field relies heavily on theories like plastic deformation and brittle fracture mechanisms under high-pressure water [82] and abrasive impact.

AWJ can be contrasted with other cutting techniques in studies (e.g. laser or EDM) in terms of precision and durability. Tool wear and the effectiveness of material removal are greatly influenced by the size, shape, and hardness of the abrasive particles. degradation is a major area of research because AWJ depends on high-velocity

Table 6. lists the most-cited articles.

No	Authors	Year	Purpose	Source Title	Total Citation	TC per year	Normalized TC
1.	Hashish M. [68]	1984	To improve the understanding of the use of high-speed abrasive particles in cutting malleable metals	Journal of Engineering Materials and Technology, Transactions of the ASME	324	7.90	4.35
2.	Gutowski T.G.; Branham M.S.; Dahmus J.B.; Jones A.J.; Thiriez A.; Sekulic D.P. [69]	2009	To delineate the energy and material resources employed in manufacturing processes.	Environmental Science and Technology	314	19.63	8.21
3	Arola D.; Williams C.L. [70]	2002	The goal was to investigate how surface roughness affects the fatigue life of low-alloy high-strength steel. The focus was on investigating the fatigue-induced stress concentration.	International Journal of Fatigue	280	12.17	5.43
4.	Herzog D.; Jaeschke P.; Meier O.; Haferkamp H. [71]	2008	This study investigates the effects of laser cutting on the static strength of Carbon Fibre Reinforced Polymer (CFRP) laminate through various experiments. Three high-power laser sources, a pulsed Nd laser, a disk laser and a CO2 laser were used for cutting. The samples were tested under static tensile and bending conditions and the results were compared to those of samples cut via conventional milling and AWJ.	International Journal of Machine Tools and Manufacture	237	13.94	5.04
5	Müller F.; Monaghan J. [72]	2000	This study provides a thorough investigation of the machinability properties of aluminum matrix composites reinforced with SiC particles. This study investigates the effects of laser cutting on the static strength of carbon	International Journal of Machine Tools and Manufacture	237	9.48	6.80

Table 6. (continued).

No	Authors	Year	Purpose	Source Title	Total Citation	TC per year	Normalized TC
			fiber reinforced polymer (CFRP) laminates through various experiments.				
6.	Çaydas U.; Hasçalik A. [73]	2008	This research included building a regression and artificial neural network (ANN) models to predict surface roughness in the AWJ process. The predictive models were developed by analyzing various machining factors including travel speed, water jet pressure, distance, abrasive grain size and abrasive flow rate.	Journal of Materials Processing Technology	234	13.76	4.98
7.	Hashish M. [74]	1989	This research involved developing a regression model. A theoretical framework for forecasting the depth of cut attained by abrasive-waterjets on different metallic materials is provided in this paper. The basis of the current model is an enhanced framework for erosion caused by solid particle impact.	Journal of Engineering Materials and Technology, Transactions of the ASME	219	6.08	5.67
8.	Shanmugam D.K.; Nguyen T.; Wang J. [75]	2008	The impact of the shock wave produced by the waterjet during the first cutting stage can be attributed to the start of fracture propagation. Water infiltrating crack ends causes delamination by causing water-wedging and abrasive particle embedding.	Composites Part A: Applied Science and Manufacturing	209	12.29	4.44
9.	Azmir M.A.; Ahsan A.K. [76]	2009	In this work, abrasive waterjet-processed glass/ epoxy composite laminates are examined for surface	Journal of Materials Processing Technology	197	12.31	5.15

Table 6. (continued).

No	Authors	Year	Purpose	Source Title	Total Citation	TC per year	Normalized TC
			roughness and kerf ratio. Analysis of variance and the Taguchi design of experiments were used to assess the effect of process parameters on surface roughness and kerf width.				
10.	Wang J. [77]	1999	This study investigates erosion and cutting performance of polymer matrix composites when subjected to AWJ.	International Journal of Advanced Manufacturing Technology	183	7.04	4.19
11.	Azmir M.A.; Ahsan A.K. [78]	2008	This study investigates the influence of AWJ process parameters on the surface roughness of glass fibre-reinforced epoxy composites.	Journal of Materials Processing Technology	176	10.35	3.74
12.	ElTobgy M.S.; Ng E.; Elbestawi M.A. [79]	2005	A new elastoplastic finite element model intended to precisely model erosion in three dimensions is presented in this work. The impact of recurrent particle collisions, material removal, thermal elastic-plastic behaviour, and numerical and material damping are all included in the FE model. The material that was used to model the workpiece was Ti-6Al-4V.	International Journal of Machine Tools and Manufacture	166	8.30	5.79
13.	Liu H.; Wang J.; Kelson N.; Brown R.J. [80]	2004	CFD models related to AWJ and ultrahigh velocity waterjets are generated using the Fluent6 flow solver. The flow that arises after passing through a very small nozzle is subsequently analysed in a state of equilibrium characterized by turbulent motion and involving the presence of two or three	Journal of Materials Processing Technology	159	7.57	5.27

Table 6. (continued).

No	Authors	Year	Purpose	Source Title	Total Citation	TC per year	Normalized TC
			phases. A thorough understanding of the characteristics of the jet and the process by which kerf is formed in AWJ cutting is attained by observing the velocities of water and particles within a jet across various input and boundary conditions.				
14.	Hascalik A.; Çaydas U.; Gürün H. [81]	2007	Surface profilometry and scanning electron microscopy were used to analyse the profiles, kerf geometries, and microstructural characteristics of the machined surfaces.	Materials and Design	153	8.50	4.46
15.	Hashish M. [82]	1989	This study provides empirical evidence and analytical insights regarding the impact of pressure variations on various operational attributes of nozzles.	Journal of Engineering Materials and Technology, Transactions of the ASME	153	4.25	3.96
16.	Shanmugam D.K.; Masood S.H. [83]	2009	An comprehensive study of kerf taper angle is given in this study, a critical parameter for assessing cutting efficiency, observed when machining two distinct types of composites. Multiple academic fields are interested in the application of glass epoxy with prepreg graphite fabric.	Journal of Materials Processing Technology	147	9.19	3.84
17.	Atas C.; Sevim C. [84]	2010	This study conducted an experiment to examine the effect of effects on laminated composites with PVC foam and balsa wood cores. Several experiments were	Composite Structures	146	9.73	5.36

Table 6. (continued).

No	Authors	Year	Purpose	Source Title	Total Citation	TC per year	Normalized TC
			conducted with varying collision energy. The investigation focuses on the characterisation of damage in sandwich composites by the analysis of load-deflection curves, energy profile graphs, and the visual examination of damaged samples. Fiber fractures on the upper and lower surfaces as well as delaminations between adjacent glass-epoxy layers are the most common forms of damage observed, shear-induced fractures in the core, and separation between the face sheets and the core material.				
18.	Haddad M.; Zitoune R.; Bougherara H.; Eyma F.; Castanié B. [85]	2014	This work aims to investigate the effects of burr tool machining, AWJ, and abrasive diamond cutting (ADS) defects on the mechanical properties CFRP materials. In particular, the study assesses how these defects influence the quasi-static performance of CFRP in conditions of tensile-tensile fatigue, inter-laminar shear, and compression.	Composites Part B: Engineering	142	12.91	5.64
19.	Kovacevic R.; Hashish M.; Mohan R.; Ramulu M.; Kim T.J.; Geskin E.S. [86]	1997	This paper provides a comprehensive summary of the major research and development efforts in abrasive waterjet machining that occurred in the United States throughout the 1990s.	Journal of Manufacturing Science and Engineering, Transactions of the ASME	141	5.04	6.81
20.	Yuvaraj N.; Pradeep Kumar M. [87]	2015		Materials and Manufacturing Processes	135	13.50	5.49

Table 6. (continued).

No	Authors	Year	Purpose	Source Title	Total Citation	TC per year	Normalized TC
			This paper presents a description of the optimisation studies conducted on a cutting process with AWJ. The Technique for Order Preference by Similarity Ideal Solution (TOPSIS) method was combined with the multi-criteria decision-making (MCDM) method to conduct a study that focused on multi-response features of the process.				

abrasive streams. Research investigates the long-term effects of recycling and abrasive fragmentation techniques on jet performance. Research on wear-resistant materialssuch as composite-based nozzles, advanced ceramics, and tungsten carbide has emerged as a critical area in the development of AWJ technology. Enhancing the operational efficiency of AWJ systems necessitates a comprehensive understanding of the interplay between impact angle, material hardness, and jet pressure. Recent advancements in multi-phase flow modeling have contributed significantly to optimising jet velocity and the transfer of impact energy, thereby minimising tool wear and extending the service life of AWJ components.

A notable change in AWJ research toward computational modeling and simulation-based methodologies is Cluster 2 (green) addresses. This pattern demonstrates the growing use of machine learning (ML), artificial intelligence (AI), and numerical simulations to improve cutting efficiency, forecast material removal rates, and optimize AWJ parameters. In order to comprehend jet behaviour, pressure distribution, and particle interactions, early research in this cluster concentrated on finite element analysis (FEA), computational fluid dynamics (CFD), and empirical modeling. Improved control over kerf width, surface roughness, and energy efficiency has resulted from researchers' ability to examine intricate interactions between high-speed abrasive particles and target materials thanks to developments in multi-physics simulations. In order to adjust AWJ parameters in real-time, recent studies show increasing integration of deep learning, neural networks, and evolutionary algorithms (such as particle swarm optimisation and genetic algorithms). Furthermore, new technologies that improve accuracy and sustainability include digital twins and real-time process monitoring with IoT and smart sensors.

The growing emphasis on multi-material studies and process development in abrasive waterjet technology Cluster 3 (blue) focuses on. The need to optimise cutting and machining of a variety of materials, such as metals, composites, ceramics, polymers, and hybrid materials, is highlighted by this trend. Understanding how various materials respond to high-pressure water jets has become a crucial area of research as sectors like aerospace, biomedical, and automotive increasingly use waterjet technology for complex material processing. Early research in this cluster mostly concentrated on the cutting performance and material removal mechanisms of specific materials, paying particular attention to variables like thickness, pressure, cutting speed, and distance. Research on multi-material cutting has grown over time. In this process, AWJ interacts with layered, bonded, or other materials, posing issues with kerf taper, uneven erosion, and delamination. In order to improve surface integrity and accuracy, recent advancements emphasize the optimisation of AWJ in composite and functionally graded materials, including hybrid cutting techniques. The capacity of AWJ to create complex materials with little thermal degradation has been further enhanced by developments in simulation tools, real-time monitoring, and artificial intelligence-driven optimisation.

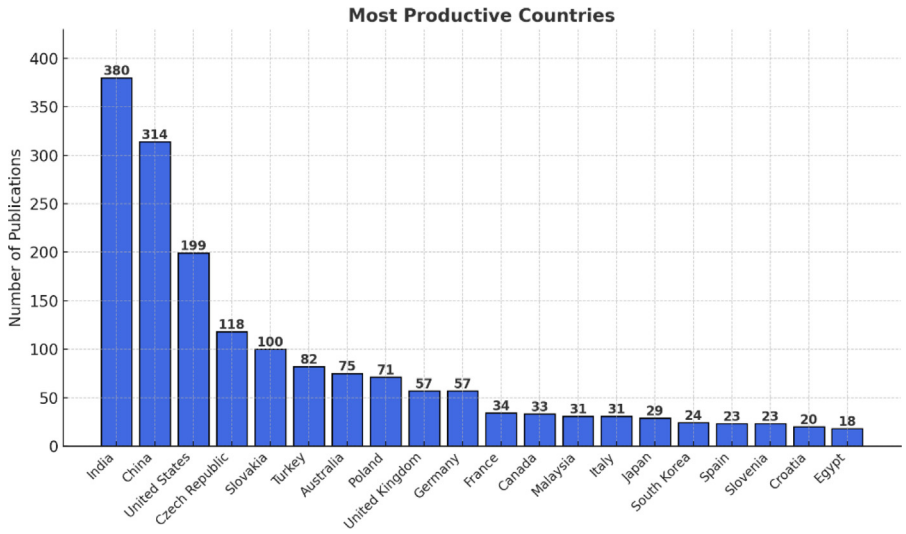

Fig. 5. The 20 most productive countries of AWJ research.

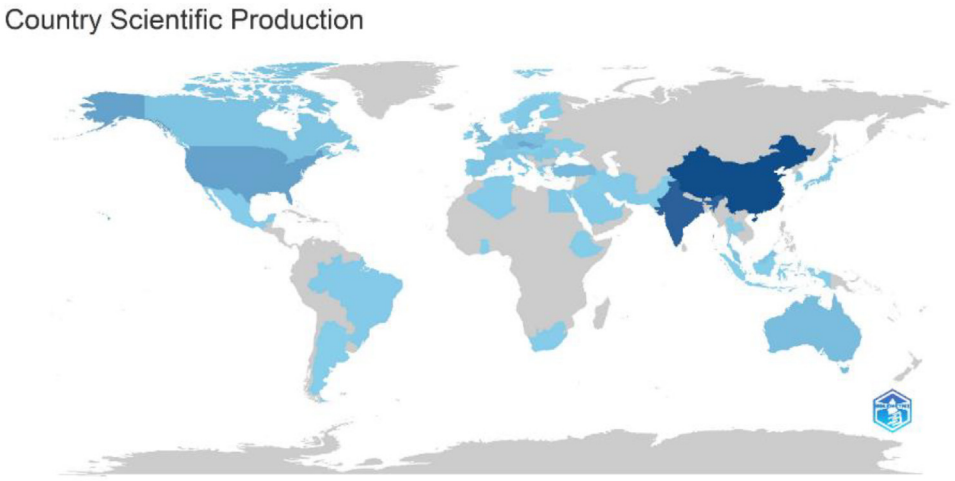

Fig. 6. The Global perspective on the research productivity of nations from 1980 to 2023.

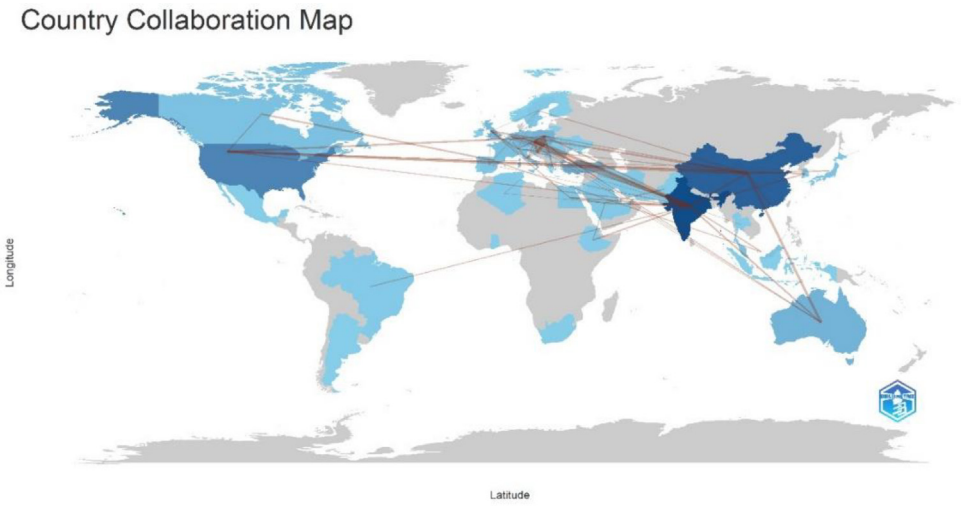

Fig. 7. The international collaboration's map between countries.

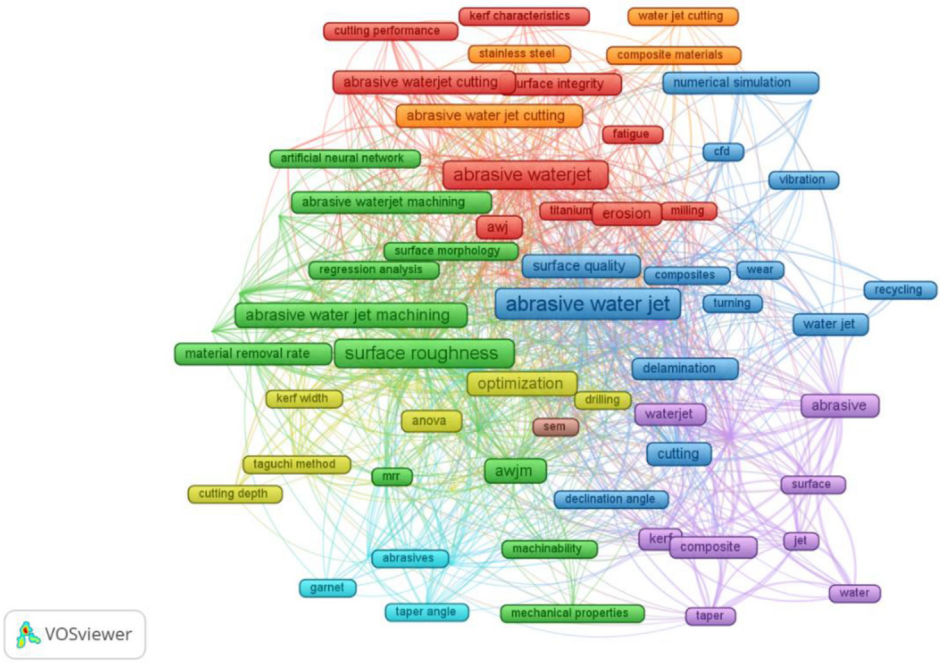

Fig. 8. Network diagram of author keywords (threshold: 10 co-occurrence) and normalisation method (Association strength).

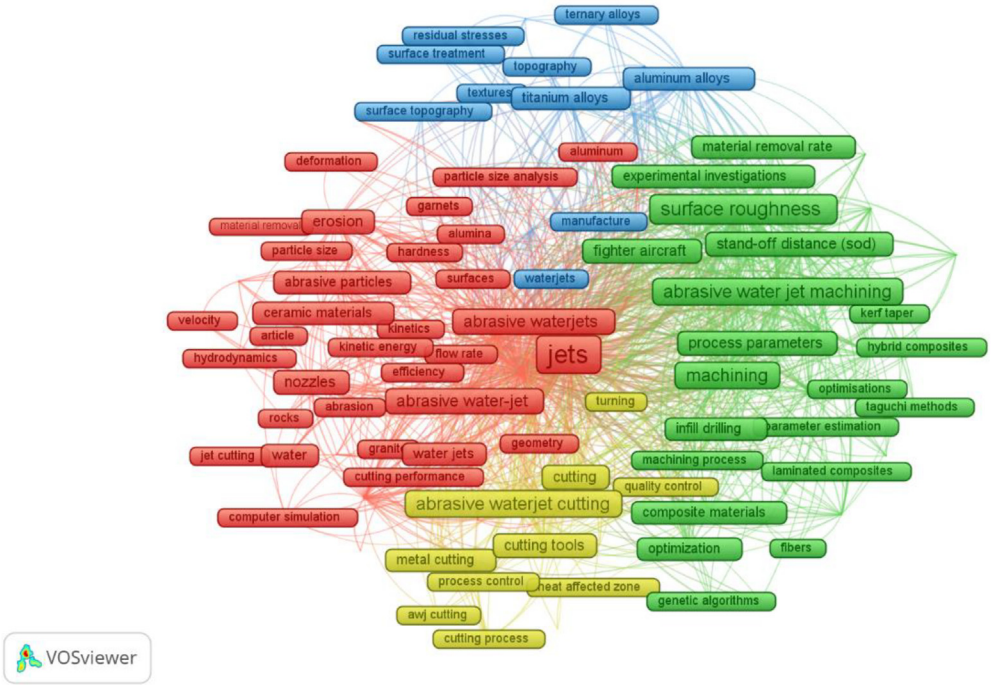

Fig. 9. Network diagram for index keywords (threshold: 20 co-occurrence).

Cluster 4 (yellow) explores recent advancements in optimisation and modeling for AWJ machining, reflecting a significant shift toward data-driven decision-making and predictive analytics in manufacturing. As AWJ technology becomes more integrated into precision manufacturing industries, researchers have emphasized the need for optimized process parameters to achieve higher cutting efficiency, improved surface quality, and reduced material wastage. Initially, AWJ optimisation relied on trial-and-error experiments to determine the best cutting parameters, such as water pressure, traverse speed, abrasive flow rate, and stand-off distance. However, due to the complex, non-linear nature of AWJ processes, traditional methods often led to inefficiencies and high operational costs. To address this, computational optimisation techniques were introduced, leading to multi-objective optimisation

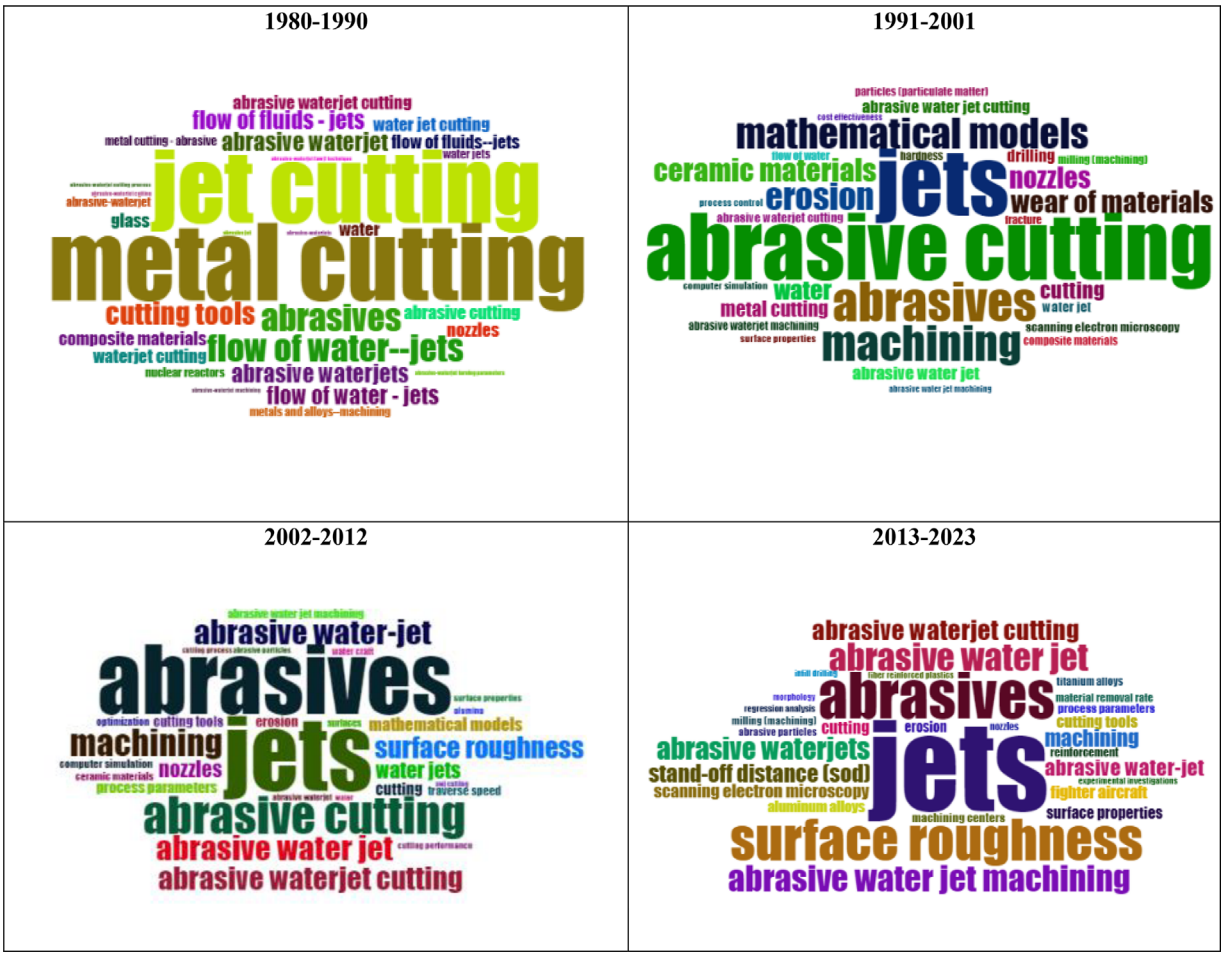

Fig. 10. Word cloud of keyword plus.

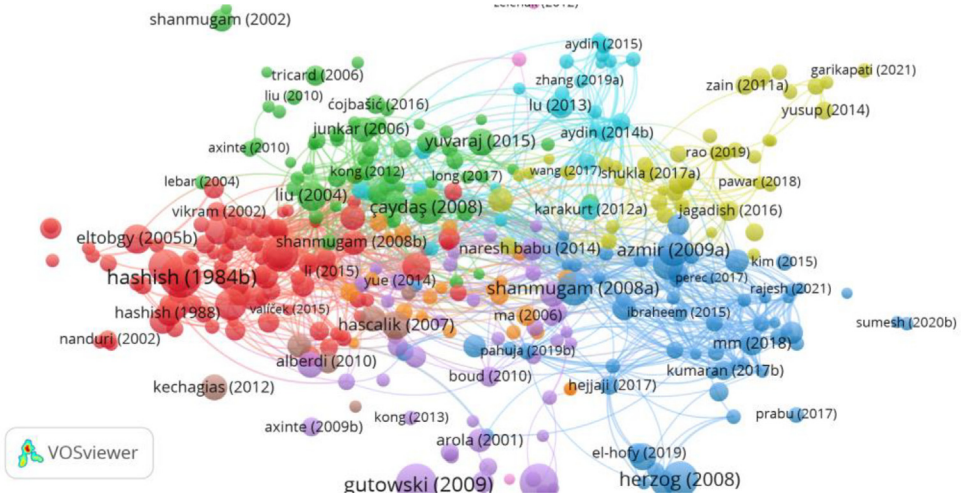

Fig. 11. Bibliographic coupling of articles.

approaches that consider trade-offs between cutting speed, surface roughness, kerf taper, and material removal rate. The introduction of techniques like response surface methodology (RSM), Taguchi methods, and grey relational analysis (GRA) improved AWJ performance by systematically optimising process parameters.

One of the most significant recent trends in this cluster is the integration of artificial intelligence (AI) and machine learning (ML) into AWJ optimisation. AI-driven models provide a more adaptive and predictive approach to optimising AWJ parameters, minimising defects, and improving process stability. Neural networks and deep

Table 7. List of documents Co-citation articles in the clusters (1980-2023).

Cluster no	Items	Node Colour	Node Labels	Representative Articles
Cluster 1	93	Red	Fundamental theories of AWJ and tool wear	[68,82,90–101,82,102,103]
Cluster 2	62	Green	Computational models and simulation-based approaches	[104–117]
Cluster 3	62	Blue	Multi-material studies and process development	[78,108,109,118–134]
Cluster 4	46	Yellow	Recent advancements in optimisation and modelling	[135–155]
Cluster 5	43	Purple	Material interaction and erosion mechanism	[95,156–162]
Cluster 6	27	Pink	Industrial use cases and large-scale manufacturing	[96,163–170]
Cluster 7	23	Orange	Secondary jet erosion and defect mitigation	[171–178]
Cluster 8	9	Teal	Hybrid and advanced AWJ Applications	[179–182]
Cluster 9	6	Light blue	Erosion and corrosion of laser cladding	[183,184,185]
Cluster 10	1	Dark green	Multi-physics and multi-scale studies	[186]

learning algorithms have been developed to predict surface roughness, kerf width, and cutting efficiency based on vast datasets. Genetic algorithms (GA) and particle swarm optimisation (PSO) have been applied to find optimal parameter combinations with limited experimental trials. Fuzzy logic and reinforcement learning are being explored to create adaptive control systems that dynamically adjust parameters during cutting operations. The future of AWJ optimisation will likely be driven by autonomous systems, real-time adaptive controls, and hybrid digital twin approaches, transforming AWJ into a more intelligent and self-optimising machining technology.

Material interaction and erosion mechanism in AWJ machining is the Cluster 5 (purple) covers, a crucial field that has a direct impact on cutting performance, material integrity, and process efficiency. This cluster investigates the underlying wear mechanisms, how different materials react to fast-moving abrasive particles, and methods for maximising material removal while reducing surface damage. The impact dynamics of abrasive particles largely control material erosion in AWJ cutting. brittle fracture mode: In ceramic, glass, and brittle composites, material removal happens as a result of crack propagation brought on by impacts from high-energy particles. This is one of the main mechanisms examined in this cluster. Chipping and uneven surface morphology are frequently the results of this. Ductile cutting mechanism: Plastic deformation, plowing, and micro-cutting are methods used to remove material from metals and polymers. This produces a smoother finish but may also leave residual stress and heat-affected areas. Mixed-mode erosion: Because composite materials react in both brittle and ductile ways, it can be difficult to achieve consistent surface quality.

Cluster 6 explores AWJ applications in rock and granite machining, particularly for industries such as construction, mining, monument engraving, and decorative stone fabrication. The increasing demand for precision cutting, minimal material wastage, and environmentally friendly machining methods has driven the adoption of AWJ as a superior alternative to traditional diamond saws and mechanical cutting tools. Due to the high hardness and abrasive nature of granite and similar stones, researchers in Cluster 6 are focusing on optimising process parameters to improve cutting efficiency, precision, and tool longevity.

Cluster 7 addresses secondary jet effects and defect control in AWJ. One of the key challenges in AWJ is the uncontrolled secondary jet formation, which can cause surface defects, material delamination, excessive erosion, and geometrical inaccuracies. This cluster explores research efforts aimed at understanding, predicting, and minimising the effects of secondary erosion to enhance the precision and quality of AWJ-processed components. Cluster 7 highlights the challenges associated with secondary jet erosion in AWJ and the research efforts to mitigate its impact. By combining experimental studies, numerical simulations, and hybrid machining approaches, researchers aim to minimize surface defects and enhance machining precision.

Cluster 8 investigates hybrid AWJ techniques, integrating AWJ with complementary technologies to enhance machining performance, expand material compatibility, and improve precision. Traditional AWJ machining is widely recognized for its cold-cutting nature, minimal heat-affected zones, and high versatility. However, limitations such as poor surface finish, excessive taper, and reduced efficiency in hard or composite materials have led to the development of hybrid AWJ techniques.

This cluster explores advanced AWJ modifications and hybridisation strategies, including laser-assisted AWJ (LAWJ), cryogenic AWJ (CAWJ), ultrasonic AWJ (UAWJ), and electrochemical AWJ (ECAWJ). These enhancements enable AWJ to be used in precision manufacturing, high-strength material processing, and micro-machining applications. Cluster 8 highlights the emerging trends in hybrid and advanced AWJ applications, showcasing how technological integrations can expand AWJ capabilities beyond traditional machining. Innovations such as laser, cryogenic, ultrasonic, and electrochemical-assisted AWJ have significantly improved efficiency, surface quality, and material adaptability.

Cluster 9 analyses erosion and corrosion in laser-cladded surfaces, highlighting the interplay between surface modifications, wear resistance, and material longevity in harsh environments. Laser cladding (LC) is widely used to enhance surface properties of metals and alloys, particularly in aerospace, marine, oil & gas, and manufacturing industries. However, despite its benefits, laser-cladded coatings are still susceptible to erosion and

corrosion, especially in high-speed fluid environments, abrasive conditions, and chemically aggressive atmospheres.

Cluster 10 examines multi-physics and multi-scale simulations in AWJ research, aiming to enhance the fundamental understanding of AWJ processes by integrating fluid dynamics, particle mechanics, material deformation, and surface interactions. These studies contribute to improving the precision, efficiency, and adaptability of AWJ cutting, machining, and surface treatment applications.

4 Discussion

4.1 Future research path in AWJ

This review presents a comprehensive overview of AWJ technology, with an emphasis on challenges and recent advances in AWJ research. A thematic classification of article divisions was developed using the results obtained from the citation analyses conducted in Biblioshiny and VOSviewer. This was accomplished although a comprehensive analysis of the publication's content is not within the scope of this review. The outcomes of this analysis are consistent with those of the theme analyses that employ word clouds and keyword analyses. There are still numerous unresolved discussions and unresolved research inquiries that present opportunities for a deeper comprehension of particular ideas or concepts (Table 8). These inquiries may be addressed through future investigations.

4.2 Implications and limitation

Key bibliometric indicators characterising AWJ literature have also been explicitly defined and presented. The obtained bibliometric indicators, both quantitative and qualitative, will support future performance evaluations. These can serve as a means of evaluating advancements in terms of collaboration, citation impact, and research output, and other aspects against the present situation. This evaluation offers an comprehensive set of bibliometric insights that allows researchers to learn about the contributions made by authors, organisations, and nations in the area of expert system research. This tool can be employed to assess progress concerning citations, productivity, collaboration and other relevant factors, in comparison to the current state. Moreover, it is feasible to utilise some indicators to identify potential advancements in research trends and interests in comparison to current trends. The research has a few drawbacks that can guide future studies, considering the study's scope and the review approach employed. Due to the dataset's time range spanning from 1980 to 2023, there is a potential omission of recent or in-press publications. This review presented a number of important details that interested researchers can use to learn more about the contributions by authors, institutions, and countries in expert system research disciplines. Furthermore, some of these indicators can be used to find possible advancements in the interests and trends of research. when contrasted to current patterns. Citation rates represent the biggest restriction. There may be variations in the citation rates acquired from different databases compared to the Scopus database (e.g., WOS, Google Scholar, etc.). Despite this disadvantage, Scopus is commonly used for bibliometric evaluations to perform excellent bibliometric analyses because it has several advantages and is more flexible than other databases. Another disadvantage is that our research only looked at publications and review materials. The absence of other sorts of documents (such as letters, conference papers, editorials, and so on) may result in the loss of vital information and contributions to the area, despite the fact that their inclusion might have enhanced its credibility. studies excluding local-language content will experience adverse consequences. Further investigation ns may aim to broaden the scope of the findings through the inclusion of a more extensive variety of phrases, acknowledging limitations due to keyword-based retrieval.

5 Conclusion

The evolution and advancement of AWJ technology are comprehensively investigated in this study, which presents a bibliometric analysis over a four-decade period from 1980 to 2023. A total of 1666 publications indexed in the Scopus database between 1983 and 2023 were systematically reviewed and analysed using VOSviewer and Biblioshiny (RStudio) to identify key trends and research directions in the AWJ field. Specifically, research in the field of AWJ technology has demonstrated rapid growth, evidenced by a significant publication increase during 1993, showing a 228.57% growth. The strong presence of engineering disciplines is evident, accounting for 43.40% of the total publications, which underscores the sustained and substantial interest of the engineering research community in advancing AWJ processes and applications. This study identifies key milestones and research shifts within AWJ-related research, offering a quantitative performance assessment of influential sources, authors, highly cited articles, and contributing countries. The findings aim to provide a consolidated understanding of the current research landscape and inform future directions in the domain of AWJ technology within manufacturing science. In summary, this review provides valuable insights into AWJ technology by systematically identifying and analyzing key terminology within the existing literature, mapping out thematic knowledge clusters and semantically aligned research communities. It further synthesizes previous studies and proposes future research pathways to guide future investigations in the field. This comprehensive review highlights several significant developments in AWJ technology:

- Studies were categorised using bibliographic coupling and categorized into the ten previously identified research themes: *fundamental theories of AWJ and tool wear, computational models and simulation-based approaches, multi-material studies and process development, recent advancements in optimisation and modelling, material*

Table 8. Proposed areas for future investigation cited in publications with significant influence.

Research topic	Potential Research
Dynamic simulation of multiphase flow	● Investigate how the impacting mechanism, abrasive particles, and waterjet flow interact dynamically. ● Investigate the characteristics of multiphase flow inside nozzle head. ● Develop multi-model simulation approaches to discover the material physics of the topography formation. ● Applied mathematical modeling, statistical model and topology model.
Machining performance of AWJ	● Develop efficient handling of the high precision of the work materials. ● Determine the operational parameters and processing steps, including material and machine preparation, experimental setup, and process monitoring. ● Conduct innovative research using intelligent algorithm to predict and control the process.
Techniques for AWJ optimisation	● Develop a integrated optimisation approach by integrating traditional optimisation methods with modern techniques using machine learning. ● Developing optimisation techniques to minimize noise and vibration during AWJ operations, improving the working environment and equipment longevity. ● Creating adaptive control systems that learn and adjust to varying conditions in real-time to maintain optimal performance
Nozzle wear issue	● Exploring methods for recycling and refurbishing worn nozzles to reduce waste and lower operational costs. ● Exploring different nozzle designs and geometries to reduce wear and improve the efficiency and lifespan of nozzles. ● Developing real-time monitoring systems and predictive models to track nozzle wear and anticipate maintenance needs, reducing downtime and operational costs. ● Investigating the specific mechanisms and modes of nozzle wear, including erosion, abrasion, and cavitation, to inform the development of more wear-resistant nozzles. ● Analyse the flow behaviour of the water-abrasive mixture within the nozzle to understand wear patterns.
Abrasive particles	● Exploring methods for recycling and reusing abrasive particles to reduce waste and lower operational costs in AWJ processes. ● Discover more economical and sustainable abrasive materials ● Analyzing the flow dynamics of abrasive particles within the water jet stream to optimize cutting performance and minimize wear on nozzles. ● Studying the breakage and breakdown mechanisms of abrasive particles during AWJ machining to improve their longevity and performance. ● Researching techniques to achieve uniform dispersion of abrasive particles within the water jet to enhance cutting precision and consistency.
Application of AWJ in industry	● Investigate the capability of AWJ to machine the intricate shapes and complex geometries that are frequently present in aerospace components. ● Explore the ability of AWJ to deliver high-precision machining with tight tolerances required for industrial components. ● Investigate the efficiency of AWJ in cutting composite materials and other advanced materials used in aviation, such as titanium alloys and carbon fiber-reinforced polymers (CFRP). ● Explore the possibilities for integrating additive manufacturing with AWJ to create hybrid manufacturing systems for industrial applications.

interaction and erosion mechanism, industrial use cases and large-scale manufacturing, secondary jet erosion and defect mitigation, hybrid and advanced AWJ applications, erosion and corrosion of laser cladding, and multi-physics and multi-scale modelling.

- Analysis of co-occurring keywords indicates that surface integrity, erosion, and fatigue are among the most frequently addressed topics in current AWJ research. Additionally, the increasing use of artificial intelligence techniques such as artificial neural networks (ANN), regression analysis, and other machine learning methods reflects a growing interest in predictive modeling of AWJ performance characteristics. The future of AWJ optimisation is expected to evolve through the integration of AI, autonomous systems, real-time adaptive control, and hybrid digital twin technologies, enabling smarter and more self-optimising machining processes.
- Researchers will have numerous opportunities in the future to explore cost-effective and sustainable abrasives, reconditioning nozzles to minimise waste, and combining additive manufacturing and AWJ to develop hybrid manufacturing frameworks for industrial use.

The AWJ serves as a principal hub for frontier research in the fields of manufacturing, specializing in advanced machining processes that enable high precision, minimal thermal distortion, and the ability to cut complex materials. It functions as a nurturing environment for noteworthy the newest topics in AWJ research as well as developing trends. In summary, this bibliometric assessment is dynamic and subject to future refinement. Therefore, it is essential to conduct these analyses regularly to capture achievement and shortcomings in relation to the various bibliometric performance metrics of a particular journal.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

This article has no associated data generated.

Author contribution statement

Nuraini Lusi: conceptualisation, literature review, methodology, resources, writing—original draft preparation, analysis, visualisation and validation. IGNB Catrawedarma: resources, analysis, visualisation and validation. Mebrahitom Gebremariam: review the data, analysis. Kushendarsyah Saptaji: review citation, analysis. Azmir Azhari: conceptualisation, review, writing—original draft preparation, validation, funding acquisition, resources, supervision.

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