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Review

Bibliometric analysis of abrasive water jet machining research

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ABSTRACT

Bibliometric research focuses on the statistical analysis of publications. It is a method that is frequently used to classify the information with various variables such as institutions, journals, countries and authors. This paper presents a general overview of research that has been reported on abrasive water jet machining by using the bibliometric indicators. The essential features of bibliometric indicators are that these indicators come out with a general picture of abrasive water jet research. The paper is divided into key analysis sections which focused on relevant journals, research papers, authors, institutions and countries that have contributed to abrasive water jet research. The bibliometric research is conducted through Web of Science database. The goal of this paper is to be informative with this topic, and the indicators summarize the essential research in this field. The analysis shows that the number of publications on abrasive water jet and their citations are consistently increasing over the past years. The data indicates that the Wang J is the most influential and active author in abrasive water jet research and some of the other main leaders in this field are Hloch S, Kovacevic R and Axinte D. The two most influential journals are the International Journal of Advanced Manufacturing Technology and the Journal of Materials Processing Technology and the most influential country is United States of America followed by Czech Republic in abrasive water jet research. Furthermore, the bibliometric analysis reveals the links among the co-authors, co-citation authors and partnering institutions working in AWJ research field.

Contents

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1. Introduction

Manufacturing engineering has grown up in many fields and continues to improve to suit the rapid changes of the new technological era. Manufacturing fields are continually developing upon current designs and approaches to make the life simple and easier. One of the important manufacturing technologies is abrasive water jet (AWJ) machining, which is considered as a non-conventional machining process. Abrasive water jet machining depends on a high-pressure of water provided by a pump on the orifice inside the cutting head where it can be converted into a high velocity jet. At the same time the water creates a vacuum while it passes through the mixing chamber to suck abrasive particles to the focusing tube where the AWJ mixture is created (Anwar et al., 2013). The idea of AWJ started in the 70s when quarry companies were looking for an efficient technique to cut stone over the traditional diamond coated wet saws. It was discovered that directing a very high-velocity narrow stream of water can cut any object (Tiffany, n.d.). The use of abrasive water jet for machining originated almost 30 years ago with the abrasive water jet cutting the metals without heat (Dobbins, n.d.). Since then, the AWJ technology has been rapidly improved to meet the necessity of modern industries. Abrasive water jet has the ability to cut any material ranging from very soft flexible materials to very hard and brittle materials. The main advantages of AWJ over other non-conventional machining processes, e.g. laser and electric discharge machining are the high accuracy of components and features generated, quick setup of the AWJ cutting and no/negligible heat generated during the process (Sreekesh and Govindan, 2014). Furthermore, the AWJ process can generate complex 3D shapes.

In this study, a review of the abrasive water jet machining has been presented by using bibliometric analysis indicators. The main objective of bibliometric analysis indicators is to measure the size and impact of the publications based on a count of scientific papers published and the citations received. Bibliometric indicators are very important to evaluate the authors, journals, universities, institutions and countries to decide their influence in a particular research field. Moreover, bibliometric indicators can also construct a general picture of a research field. Several researchers have presented bibliometric based reviews in various fields to highlight the most vibrant and influential authors, publications, institutions and countries working in the corresponding research areas. Some of these research areas worth to be mentioned include econometrics (Baltagi, 2007), ant colony optimization (Deng and Lin, 2012), innovation (Fagerberg et al., 2012), probability and statistics (Genest and Guay, 2002), environmental and ecological economics (Hoepner et al., 2012), operations management (Holsapple and Lee-Post, 2010), productivity in production (Hsieh, 2010), entrepreneurship (Landström et al., 2012), profiling analysis of pricing research (Leone et al., 2012), data envelopment analysis (Liu et al., 2013), management (Podsakoff et al., 2008), marketing (Seggie and Griffith, 2009), health (Wagstaff and Culyer, 2012), and fuzzy systems (Merigó et al., 2015). However, no bibliometric review has been presented on the research conducted in abrasive water jet machining.

The aim of this study is to come out with a general picture of abrasive water jet research from the beginning of this field using bibliometric techniques. The overview of the most influential and productive research will be presented based on the data collected from the web of science (WOS). The collected data has been arranged by research articles, authors, journals, institutions and countries. The data shows that, Wang J is the most influential author in abrasive water jet research and some of the main leaders in this field are Hloch S, Valicek J and Kovacevic R. The two most influential journals are the International Journal of Advanced Manufacturing Technology and the Journal of Materials Processing Technology. Whereas, USA is the most influential country followed by the Czech Republic in abrasive water jet research. However, the University of Nottingham, UK and Swinburne University of Technology, Australia are the most influential institutions regarding AWJ research. The bibliometric results also shows that in the last few years some of the Asian countries have also conducted significant research in abrasive water jet machining such as Malaysia and India. It should be noted that there will be some limitations in results reported in the current study because all the data is collected from WOS only and the studies not indexed in the WOS are excluded in the current bibliometric review.

2. Methodology

The data for the AWJ research overview is collected from the Web of Science (WOS) which incorporates several databases. WOS covers research from most of the well known scientific resources including more than 15 thousands journals and 55 million articles. For collecting the bibliometric information regarding any research area, other databases such as Google Scholar and Scopus could also be considered. However, in the current study, only WOS is used for collecting the required information. For searching the articles published related to AWJ, the keywords of "abrasive water jet" or "abrasive water-jet" or "abrasive waterjet" are used in the "topic" tab of the WOS website. However, during the data collection process, some papers could be collected that are not related to abrasive water jet research. To avoid this situation, the search results are carefully checked to omit the articles that are not related to abrasive water jet.

The current search contains the research studies that are presented from 1985 to Dec 2016. More than 700 publications were found by using the selected keywords in the search tab of WOS since 1985. Fifteen different types of publications were found including journal articles, books reviews, proceedings, notes, comments and editorial material. However, the current study is only focused on the journal articles and review papers which reduce the total numbers of publications found from 700 to 537 only from 1985 to 2016. Abrasive water jet research is steadily increasing over the past three decades as evident in Fig. 1 which shows a consistent increase in the number of publications reported on abrasive water jet particularly in the recent few years. Approximately 50% of the articles among the 537 are from the last decade. This shows that the research in the AWJ is gaining more and more importance. According to WOS records the average number of papers published per year in the abrasive water jet field are more than 16 with the

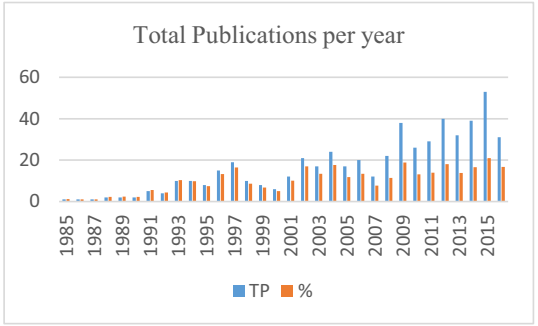

Fig. 1. Number of publications per year in AWJ research (reviews & articles) from 1985 to 2016. The bars with blue colour indicate the total number of AWJ articles published each year in the web of science and the orange one indicate the ratio (N-AWJ-P/TNP) ×1,000,000 where N-AWJ-P is the number of AWJ papers in year X and TNP is the total number of papers published in the WOS in year X.

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Table 1
General citation structure in abrasive water jet research from WOS.

Number of citations	Number of papers	% Papers
≥50 Citations	9	1.68
≥20 Citations	70	13.04
<20 Citations	458	85.29
>Total	537	

highest number of yearly publications recorded in 2012 and 2015 as 40 and 53 articles respectively. Along with the number of yearly publications, the average citation of the published research is also significant. The evaluation of the citation rate of the 537 articles published in the AWJ field is shown in Table 1. The citation rate is classified into various thresholds based on the number of the citation received and the percentage of the articles for each threshold are also presented. Form the Table 1, it is clear that only 2% (9) papers have received more than or equal to 50 citations, 13% (70) papers received more than or equal 20 citations while the remaining papers received less than 20 citations. However, in general the citation in abrasive water jet are not no too high because only 9 papers got more than 50 citations. The H-index, which is also known as H-classics (Martínez et al., 2014) is one of the further interesting action to analyse the abrasive water jet research-index used to measure the significance of articles (Alonso et al., 2009). For example, if some articles has an H-index of 30, thus 30 of the articles included in these papers have received at least 30 or more citation for each. For the 537 collected articles in abrasive water jet, the H-index is 32. This means, 32 articles have been got at least 32 citations. The abbreviations used in this paper has been summarized in Table 2.

The graphical representation of the abrasive water jet research has also been presented in this research by employing the VOS viewer software. The graphical analysis from the VOS viewer elaborates the bibliographic material through co-authorship, co-occurrence, citation, bibliographic coupling and co-citation analysis (Rodríguez et al. 2014).

3. Most influential journals in abrasive water jet

The number of journals reporting the AWJ research have increased from one year to another. The 15 most influential journals covering the abrasive water jet research are shown in Table 3. The two most influential journals from the top 15 influential journals which has been classified by H-index are Journal of Materials Processing Technology and International Journal of Machine Tools Manufacture. Moreover, other journals which are considered as the top influential journals include International Journal of Advanced Manufacturing Technology, Tehnicki Vjesnik Technical Gazette, Wear and Proceedings Of The Institution Of Mechanical Engineers Part B Journal Of Engineering Manufacture. There are also some other productive journals which are interested in this field such as Machining Science and Technology, Journal of Engineering for Industry Transactions of The ASME and Journal of Engineering, Materials and Technology Transactions of the ASME.

The quality of papers can be measured by the impact factor that was presented in Table 4. Moreover, according to the number of publications and citations in all publication areas the Journal of Materials Processing Technology and Wear have been received the highest number of publications and citations. International Journal of Machine Tools and Manufacture journal received the highest impact factor among the top 15 journals presented in Table 3 among all publication fields. Regarding the top 15 most cited papers in AWJ research of all time, Journal of Materials Processing Technology, International Journal of Machine Tools and Manufacture and, Wear, in general, have received the highest H-index among the most influential and productive journals in all field of publications.

The trend analysis of the most influential journals in abrasive water jet were generated to get more useful information. The research has been divided into six intervals. The Fig. 2 shows that the International Journal of Advanced Manufacturing Technology, Tehnicki Vjesnik Technical Gazette, Materials and Manufacturing Processes, and Journal of Engineering for Industry Transactions of

Table 2
Abbreviations used in this research.

ABBREV.	JOURNAL'S NAME	ABBREV.	JOURNAL'S NAME
IJAMT	INTERNATIONAL JOURNAL OF ADVANCED MANUFACTURING TECHNOLOGY	*AME*	ADVANCES IN MECHANICAL ENGINEERING
JMPT	JOURNAL OF MATERIALS PROCESSING TECHNOLOGY	*IJEMS*	INDIAN JOURNAL OF ENGINEERING AND MATERIALS SCIENCES
IJMTM	INTERNATIONAL JOURNAL OF MACHINE TOOLS MANUFACTURE	*IJRMMS*	INTERNATIONAL JOURNAL OF ROCK MECHANICS AND MINING SCIENCES
TVTG	TEHNICKI VJESNIK TECHNICAL GAZETTE	*IJSSE*	INTERNATIONAL JOURNAL OF SURFACE SCIENCE AND ENGINEERING
W	WEAR	*JIM*	JOURNAL OF INTELLIGENT MANUFACTURING
PIME-B	PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS PART B JOURNAL OF ENGINEERING MANUFACTURE	*PST*	PETROLEUM SCIENCE AND TECHNOLOGY
JMSET	JOURNAL OF MANUFACTURING SCIENCE AND ENGINEERING TRANSACTIONS OF THE ASME	*PIME-C*	PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS PART C JOURNAL OF MECHANICAL ENGINEERING SCIENCE
MMP	MATERIALS AND MANUFACTURING PROCESSES	*ACME*	ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING
SVJME	STROJNISKI VESTNIK JOURNAL OF MECHANICAL ENGINEERING	*IJF*	INTERNATIONAL JOURNAL OF FATIGUE
CAMT	CIRP ANNALS MANUFACTURING TECHNOLOGY	*IJMS*	INTERNATIONAL JOURNAL OF MECHANICAL SCIENCES
MST	MACHINING SCIENCE AND TECHNOLOGY	*IJIE*	INTERNATIONAL JOURNAL OF IMPACT ENGINEERING
M	METALURGIJA	*CS*	COMPOSITE STRUCTURES
JEIT	JOURNAL OF ENGINEERING FOR INDUSTRY TRANSACTIONS OF THE ASME	*C*	COMPOSITES
EM	EXPERIMENTAL MECHANICS	*MD*	MATERIALS & DESIGN
JEMTT	JOURNAL OF ENGINEERING MATERIALS AND TECHNOLOGY TRANSACTIONS OF THE ASME	*JMS*	JOURNAL OF MANUFACTURING SYSTEMS
JPVTT	JOURNAL OF PRESSURE VESSEL TECHNOLOGY TRANSACTIONS OF THE ASME	*CPASM*	COMPOSITES PART A-APPLIED SCIENCE AND MANUFACTURING
RMRE	ROCK MECHANICS AND ROCK ENGINEERING	*ESA*	EXPERT SYSTEMS WITH APPLICATIONS
H	H-INDEX	*TP*	TOTAL PAPERS
TC	TOTAL CITATIONS	*IF*	IMPACT FACTOR
T50	NUMBER OF PAPERS IN THE TOP 50 LIST	*≥50 & ≥20*	NUMBER OF PAPERS WITH MORE THAN OR EQUAL 50, 20 CITATIONS
TP10	TOTAL PAPERS IN THE LAST 10 YEARS	*TC10*	TOTAL CITATIONS IN THE LAST 10 YEARS
H-AWJ5, TP-AWJ5 AND TC-AWJ5		H-INDEX AND TOTAL PAPERS AND CITATIONS IN 5 SELECTED JOURNALS IN ABRASIVE WATER JET RESEARCH	

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Table 3
Most influential and productive journals in abrasive water jet research.

R	Name	H-AWJ	TC-AWJ	TP-AWJ	%P-AWJ	≥50	≥20	TP	TC	IF	T50	H
1	IJAMT	12	445	58	0.54%	1	3	10,805	81,425	1.568	2	62
2	JMPT	21	898	49	0.36%	2	19	13,613	202,076	2.359	12	103
3	IJMTM	19	861	38	0.97%	2	15	3,904	82,275	3.315	12	90
4	TVTG	8	124	25	2.21%	0	0	1132	1431	0.464	0	11
5	W	12	346	23	0.18%	0	9	12,953	226,497	2.323	4	127
6	PIME-B	7	99	15	0.43%	0	0	3450	18,042	0.978	0	37
7	JMSET	5	122	12	0.49%	0	1	2438	23,331	1.022	1	57
8	MMP	4	68	11	0.38%	0	0	2918	17,146	1.419	0	35
9	SVJME	2	28	10	0.61%	0	0	1641	2611	0.677	0	14
10	CAMT	7	98	9	0.39%	0	0	2297	34,396	2.492	0	69
11	MST	5	101	9	1.66%	0	3	541	4197	1.172	2	30
12	M	4	25	9	0.55%	0	0	1649	3328	0.959	0	18
13	JEIT	7	122	8	0.36%	0	2	2216	18,764	0.909	1	57
14	EM	4	71	5	0.10%	0	1	5035	41,714	1.764	1	75
15	JEMTT	4	222	5	0.18%	2	2	2724	37,364	0.935	3	73

Table 4
The Impact factor in abrasive water jet research.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
TP	20	12	22	38	26	29	40	32	39	53
TC	171	219	313	529	213	210	215	203	152	98
TC2	14	11	24	41	67	106	66	70	97	153
TP2	41	37	32	34	60	64	55	69	72	71
IF	0.341	0.297	0.750	1.206	1.117	1.656	1.200	1.014	1.347	2.155

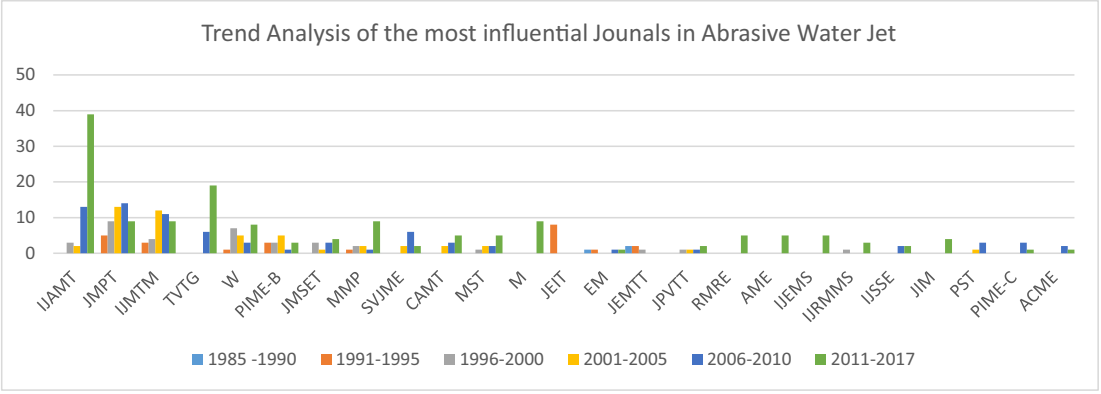

Fig. 2. Trend analysis of the most influential journals in abrasive water jet.

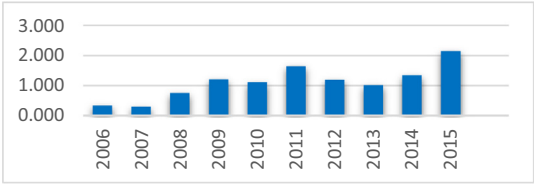

Fig. 3. Impact factor for the last 10 years AWJ (articles + reviews) since 2006.

The ASME are the most interested journals in abrasive water jet in the recent years.

The impact factor is an indicator that shows the publication's value which can be calculated by dividing the citations number received in the last two years (i.e. n – 1 and n – 2) from year n by the total number of papers published in the last two years (n – 1 and n – 2). The impact factors for all papers published yearly on abrasive water jet are shown in Table 4. Table 4 shows that the impact factor has increased from one year to another except some few years which get less than its previous years such as 2006 & 2013 as presented in Fig. 3. Generally, the abrasive water jet research is growing in the last 10 years as reflected by the increase in the impact factor.

4. Most influential articles in abrasive water jet

The most influential articles in Abrasive water jet have been classified according to the highest cited articles. The paper with more citation is more popular and important due to the new and useful ideas contained in it. Table 5 presented the top 15 papers cited at all time in abrasive water jet research. The most cited article has been reported by Gutowski, Timothy G.; Branham, Matthew S.; Dahmus, Jeffrey B.; et al. in 2009. Among many influential authors Wang J and Hashish M dominated the list as each of them has three papers in the list of top 15 most cited paper of all times and the remaining papers/authors have been shown in Table 5.

5. An overview of the most productive and influential authors

Many authors have made contributions in the abrasive water jet research. Table 6 present the top 20 authors with highest number

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Table 5
the most 15 cited papers in AWJ research of all times.

R	J	TC	Reference	C/Y
1	EST	91	Timothy et al. (2009)	13
2	JEMTT	84	Hashish, (2016)	3.111111
3	IJAMT	78	Wang (1999)	4.588235
4	JEMTT	75	Hashish (1989)	2.777778
5	IJMTM	73	Mu and Monaghan (2000)	4.5625
6	IJMTM	63	Dirk Herzog et al. (2008)	7.875
7	JMPT	59	Ulaş et al. (2008)	7.375
8	IJF	52	Arola and Williams (2002)	3.714286
9	JMPT	51	Liu et al. (2004)	4.25
10	IJMTM	47	Eltobgy et al. (2005)	4.272727
11	JMSET	47	Hashish et al. (2014)	2.473684
12	IJMTM	46	Wang and Wong (1999)	2.705882
13	IJMS	45	Wang (2007)	5
14	W	45	Arola and Ramulu (1997)	2.368421
15	IJMTM	43	Chen (1996)	2.15

of publications in abrasive water jet. The number of papers are an indicative only because other factors should be consider such as paper size, co-authorship and journal quality. From Table 6, it is evident that, WANG J is the most influential and productive author in AWJ field with more than 700 citations, followed by Hloch S who is also received more than 300 citations in this AWJ field. Moreover some other authors who are not in the top 5 positions of the most productive and influential authors, but they have received a large volume of citations such as Hashish M at 8th position got more than 350 citations.

The number of publications is different form one author to another, Wang J is the author who has published highest number of papers (48 papers) on abrasive water jet, next is Hloch S (37 papers), Valicek J (34 papers), Kovacevic R (26 papers), Axinte Da (20 papers), Huang Cz (18 papers), and so on for rest of the authors as presented in Table 6. According to the citations, Hashish M comes in the second ranking with more than 350 citations. The data in Table 6 also contains the total citations for all authors for their overall research including other fields of research as well to give a general picture about the most influential and productive authors in the abrasive water jet research. According to the number of publications and citations in general Kovacevic R has received the highest number of publication and citation among all authors. Regarding the top 50 most cited papers (T50) in AWJ research of all time, Wang J has been dominated the list of papers with eight articles. In general, the Kovacevic R has received the highest H-index among the most influential and productive authors in all field of publications.

To come out with full picture of analysing the authors' influence, 5 journals have been selected based on their high H-index in AWJ research from Table 3. The analysis is done regarding the most publishing authors in these 5 selected journals and citations received as presented in Table 7. It can be seen in Table 7 that Wang J has published in four of the selected journals (IJMTM, JMPT, IJAMT, W) which have a very high impact factor. Whereas, some other authors like Hloch S has only published in TVTG (IF = 0.464) and IJAMT (IF = 1.568) which have relatively low impact factors when compared to IJMTM, JMPT and W (see Table 3 for journals' IF). This clearly differentiates which authors are publishing high-quality work.

The trend analysis of the most influential authors in abrasive water jet research is also generated to get some more useful information about which authors are more active recently. The abrasive water jet research has been divided into six intervals. Fig. 4 showed that Wang J, Hloch S, Valicek J, Axinte Da, Zhu Ht, and Zelenak M are the most active authors in abrasive water jet in the recent years. Whereas Kovacevic R was very active up to the year 2000 and then his contribution to the field reduced.

The graphical representation of the abrasive water jet research is also generated in the current study as presented in Figs. 5–7. These graphical representations provide a visualization of the common work and occurrence of authors, organizations, and documents. Figs. 5–7 has been generated by using the VOS viewer software that links with the web of science to enable the visual image of the collected bibliographic data regarding the co-authorship, co-occurrence, citation, bibliographic coupling and co-citation analysis.

5.1. Co-authorship – authors

Co-authorship illustrates the volume of publications of authors, organizations, and countries and how these are interconnected. Regarding the co-authorship between authors in abrasive water jet research, it is shown in Fig. 5. The size of the bubble indicates the number of publications from each author and thickness of the linkages between authors show the strength of the co-authorship. Fig. 5 reveals that Hloch S has the greatest co-authorship among all other authors. There exists a 178 times (link strength) for Hloch S with other authors in all his 37 published

Table 6
The most productive and influential authors in abrasive water jet research.

R	Name	Country	TP-AWJ	TC-AWJ	H-AWJ	TP10	TC10	T50	TP	TC	H
1	WANG J	AUSTRALIA	48	709	16	23	226	8	102	1181	21
2	HLOCH S	SLOVAKIA	37	316	12	37	316	0	90	565	14
3	VALICEK J	SLOVAKIA	34	269	12	34	269	0	98	494	14
4	KOVACEVIC R	USA	26	310	10	3	16	4	210	3416	31
5	AXINTE DA	ENGLAND	20	215	11	20	219	1	107	1077	17
6	HUANG CZ	CHINA	18	123	7	11	73	0	148	667	14
7	RAMULU M	USA	17	293	9	1	1	3	187	2301	27
8	HASHISH M	USA	16	396	9	2	2	5	46	785	15
9	AROLA D	USA	15	270	9	3	11	4	150	2514	29
10	HARNICAROVA M	SLOVAKIA	15	59	4	15	59	0	58	149	7
11	ZHU HT	CHINA	14	84	6	11	73	0	74	381	12
12	HLAVACEK P	CZECH REPUBLIC	13	53	4	13	53	0	17	80	5
13	JUNKAR M	SLOVENIA	13	135	7	4	30	0	38	232	9
14	HREHA P	SLOVAKIA	12	86	7	12	86	0	14	90	7
15	KOZAK D	SLOVAKIA	12	105	6	12	105	1	70	243	9
16	ZELENAK M	CZECH REPUBLIC	12	40	4	12	40	0	20	75	5
17	AYDIN G	TURKEY	10	58	4	10	58	0	38	224	7
18	HLAVAC LM	CZECH REPUBLIC.	10	90	6	10	90	0	25	171	9
19	KUSNEROVA M	SLOVAKIA	10	21	2	10	21	0	32	84	5
20	RADVANSKA A	SLOVAKIA	10	70	6	10	70	0	16	80	6

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Table 7
Authors with the highest number of papers in five selected journals.

R	IJMTM		TVTG		JMPT		IJAMT		W	
	Author	TP	Author	TP	Author	TP	Author	TP	Author	TP
1	AXINTE DA	8	HLOCH S	9	WANG J	8	HLOCH S	9	AROLA D	3
2	SIORES E	5	VALICEK J	8	HOOGSTRATE AM	4	VALICEK J	8	RAMULU M	3
3	WANG J	5	HARNICAROVA M	6	KALS HJJ	4	WANG J	7	WANG J	3
4	BILLINGHAM J	4	HREHA P	6	PASHBY IR	4	HLAVAC LM	5	FOWLER G	2
5	KONG MC	4	MONKOVA K	5	PAUL S	4	TOZAN H	4	HUANG CZ	2
6	CHEN FL	3	HLAVACEK P	4	VAN LUTTERVELT CA	4	GEMBALOVA L	3	KIM TJ	2
7	KOVACEVIC R	3	MONKA P	4	PAPINI M	3	HLAVACOVA IM	3	LI WY	2
8	AROLA D	2	RADVANSKA A	4	SHIPWAY PH	3	HUANG CZ	3	PASHBY IR	2
9	BABU NR	2	ZELENAK M	4	SIORES E	3	WANG JM	3	SHIPWAY PH	2
10	CHEN L	2	FOLDYNA J	3	AZMIR MA	2	YAO P	3	ZHU HT	2
11	PATEL K	2	KLICH J	3	BOUD F	2	ZHU HT	3	NGUYEN T	1
12	SHANMUGAM DK	2	KOZAK D	3	CHEN FL	2	JUNKAR M	2	OJMERTZ KMC	1
13	SRINIVASU DS	2	SITEK L	3	CHEN L	2	JURISEVIC B	2	ORBANIC H	1
14	WONG WCK	2	DUSPARA M	2	FOWLER G	2	KOZAK D	2	PAPINI M	1
15	SADASIVAM B	1	KNAPCIKOVA L	2	GUO DM	2	LIU ZW	2	SCHENK A	1
16	SHIPWAY PH	1	PETRU J	2	HLAVAC LM	2	LV Z	2	SCHWETZ KA	1
17	SPELT JK	1	STEPIEN K	2	JAWAID A	2	PAL VK	2	SIGL LS	1
18	STEPANIAN JP	1	STOIC A	2	KOVACEVIC R	2	PERZEL V	2	SPELT JK	1
19	STRNADEL B	1	TOZAN H	2	LEMMA E	2	RIVERO A	2	TORANO J	1
20	TAGGART DG	1	ZLAMAL T	2	MOMBER AW	2	SCUCKA J	2	TORNO S	1
21	TORRUBIA PL	1	VEGNEROVA P	1	SPELT JK	2	SUAREZ A	2	YONG Z	1
22	VALICEK J	1	WEGENER K	1	WEISS DA	1	WANG S	2	YUVARAJ N	1
23	VIKRAM G	1	YAGIMLI M	1	WODOSLAWSKY A	1	WU YQ	2	ZENG JY	1
24	ZHU HT	1	ZAJAC J	1	WONG W	1	ZELENAK M	2	ZHENG JY	1
25	MEIER O	1	ZIDKOVA P	1	WONG WCK	1	ZHANG SJ	2	ZIBBELL R	1

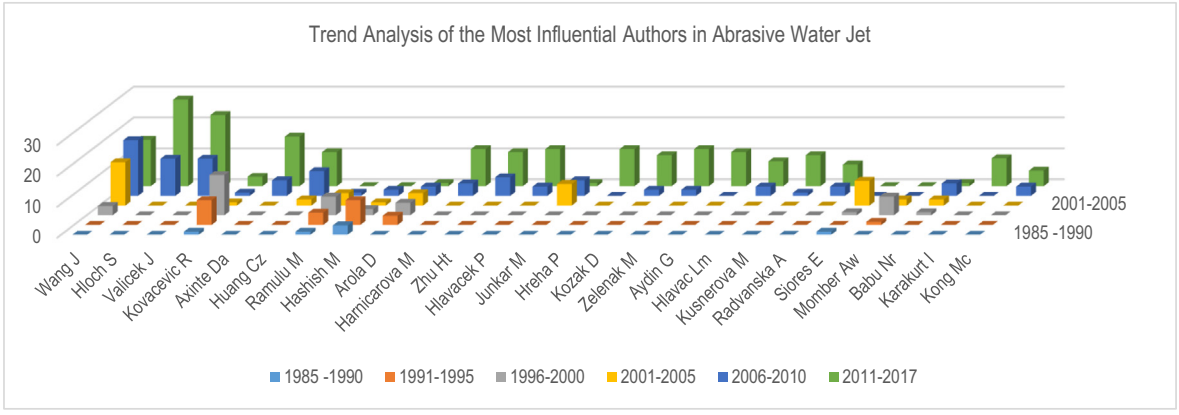

Fig. 4. Trend Analysis of the Most Influential Authors in Abrasive Water Jet.

articles in the field of abrasive water. For example, he published 25 articles with Valicek J. Also Valicek comes in the second position as the one having greatest co-authorship with 125 link strength in his 34 paper, and 13 of them are with Harnicarova M. Furthermore, most of the papers by these two authors are published around 2011 as shown in the color key at the bottom-right of the Fig. 5. It is worth noting that Wang is coming at third rank with 103 link strength of co-authorship. However, he is the most productive and influential author (as shown in Table 6), which also indicate that he is publishing with few number of authors.

5.2. Citation – authors

Citation-authors measures the direct citations between two variables in the set considered (documents, sources, authors, organizations, or countries). For example, with two authors, the connection in Fig. 6 represents the number of times author X has cited author Y plus the number of times that author Y has cited author X inside the set of documents considered. Citation between authors is presented in Fig. 6 which shows that Hloch S has received highest citations and cited others in his 37 articles appeared in this part of the analysis. Hloch interchange most of his citations with Valicek J, who come in the third rank after Wang.

6. Most productive and influential institutions and countries

The top 20 most influential institutions in AWJ research are shown in Table 8 which has been sorted according to the citations received. The institution with the highest citation received is considered to be the most influential. Table 8 outlines that, Queensland Univ Technol from Australia and Univ Nottingham, UK are the most influential institutions. It is worth noting that Queensland Univ Technol receives 414 citations with only 15 total papers and Univ Nottingham receives 335 citations with 27 total papers. However, Tech Univ Ostrava from the Czech Republic receives only 337 citation with 42 publications while these 337 citations also include Citation – Authors as presented in Fig. 6. This clearly differentiates the quality of the work presented by these institutions. In the list of the top 20 institutions, more than 70% are European organizations.

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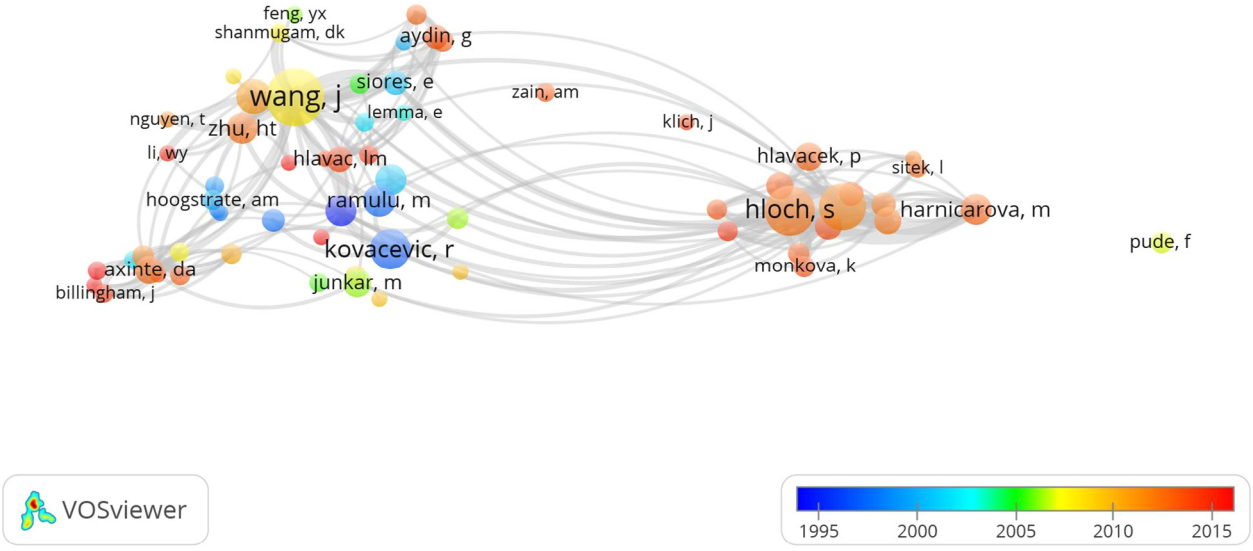

Fig. 5. Co-authorship – authors.

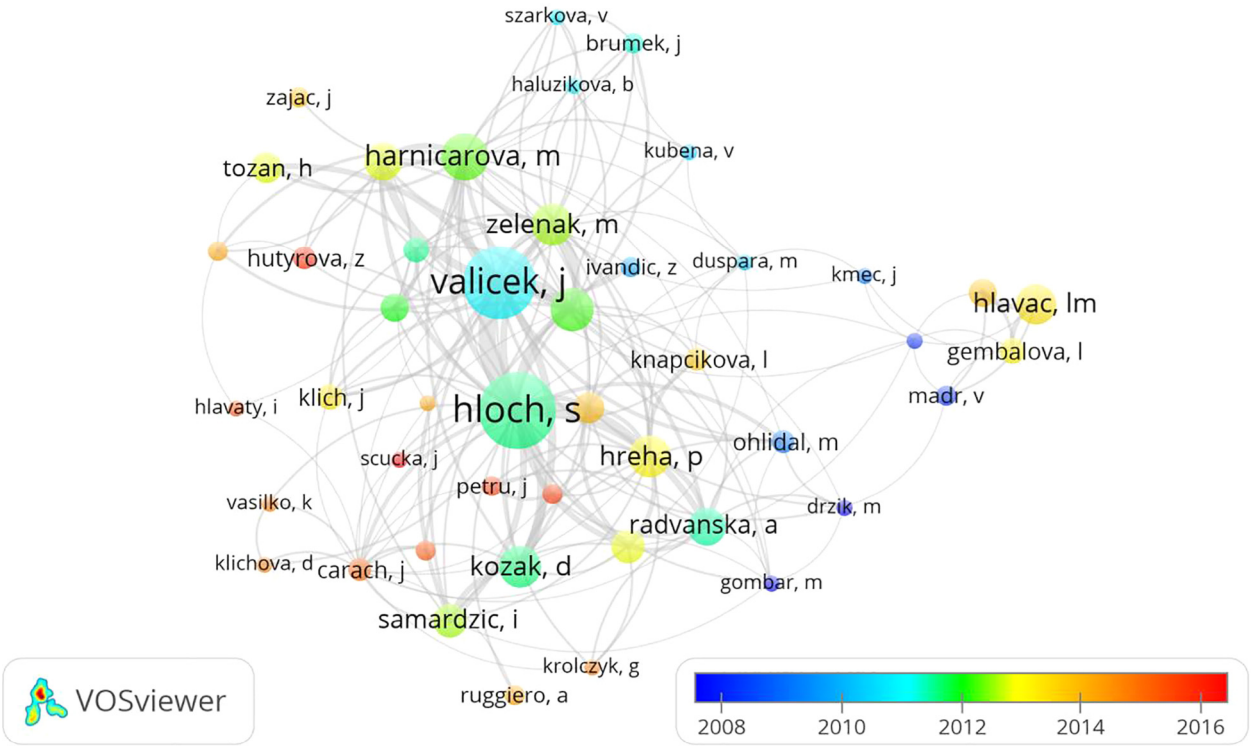

Fig. 6. Citation – authors.

Furthermore, the co-authorship between organizations is shown in Fig. 7. Among all organizations publishing in abrasive water jet research, Technical University Ostrava has the strongest co-authorship with other organizations. It has 82 co-authorships with all other organizations, and the most prominent co-authorship was with Technical University Kosice, which also comes in the second position with 51 total links strength of co-authorship. Note that the total link strength represents the relation of co-authorship of a set with all other, and it does not equal to the number of publications, because the set may have more than one co-authorship in the same paper and then will be counted more than once. Table 9 shows the list of the most influential countries in AWJ research. The country with the highest number of publications is considered as the most influential. The results show that the USA has the highest contribution to the AWJ research with 99 total publications and 1349 total citations. Czech Republic and Slovakia are the most active countries in AWJ research with the highest number of publications in the last ten years (TP10). However, again along with the total number of the papers published, the number of citations received should also be considered. For

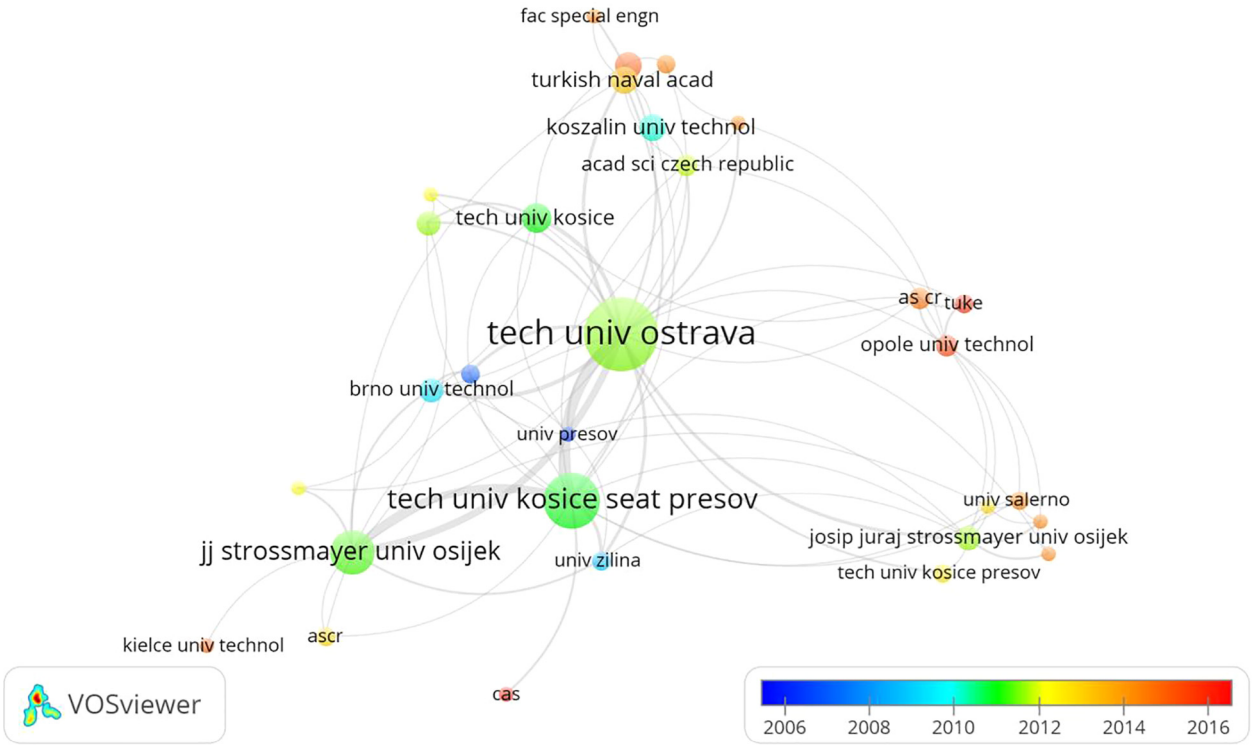

Fig. 7. Co-authorship – organizations.

Table 8
The most influential institutions in AWJ research.

R	NAME	COUNTRY	TP-AWJ	TC-AWJ	H-AWJ
1	QUEENSLAND UNIV TECHNOL	AUSTRALIA	15	414	13
2	UNIV NOTTINGHAM	UK	27	335	13
3	TECH UNIV OSTRAVA	CZECH REPUBLIC	42	329	12
4	UNIV WASHINGTON	USA	19	313	9
5	INDIAN INST TECHNOL	INDIA	21	290	10
6	UNIV KENTUCKY	USA	18	280	8
7	SWINBURNE UNIV TECHNOL	AUSTRALIA	14	280	11
8	UNIV NEW S WALES	AUSTRALIA	27	269	9
9	TECH UNIV KOSICE SEAT PRESOV	SLOVAKIA	24	200	10
10	UNIV MARYLAND BALTIMORE CTY	USA.	11	180	7
11	UNIV LJUBLJANA	SLOVENIA	15	143	7
12	QUEST INTEGRATED INC	USA	6	143	5
13	SHANDONG UNIV	CHINA	21	113	6
14	DELFT UNIV TECHNOL	NETHERLANDS	9	113	6
15	SO METHODIST UNIV	USA	8	103	5
16	UNIV RHODE ISL	USA	4	99	4
17	JJ STROSSMAYER UNIV OSIJEK	SLOVAKIA	15	95	6
18	WOMA APPARATEBAU GMBH	GERMANY	6	92	5
19	RYERSON UNIV	CANADA.	9	76	4
20	INT ISLAMIC UNIV MALAYSIA	MALAYSIA	4	74	4

Table 9
The most influential countries in abrasive water jet research.

Rank	Name	TP-AWJ	TC-AWJ	>50	>20	TP10	TC10	H
1	USA	99	1349	4	18	24	183	21
2	CZECH REPUBLIC	66	434	0	4	66	434	13
3	AUSTRALIA	57	943	2	18	21	241	20
4	PEOPLES R CHINA	57	199	0	1	42	161	7
5	SLOVAKIA	56	394	0	3	56	394	12
6	INDIA	43	358	0	6	28	167	12
7	TURKEY	42	323	1	4	39	255	10
8	ENGLAND	36	465	0	8	26	271	14
9	GERMANY	31	274	1	3	11	86	9
10	CROATIA	22	169	0	1	22	169	8
11	POLAND	19	76	0	0	17	64	6
12	SLOVENIA	15	143	0	1	5	31	7
13	CANADA	14	141	1	1	11	83	6
14	JAPAN	13	86	0	1	6	52	5
15	FRANCE	11	79	0	0	6	41	5

instance, it can be noted that Australia with 57 papers has received more than double the citations when compared with the Czech Republic with 66 papers.

7. Conclusions

The study shows that the abrasive water jet has become one of the widely researched topics due to its many useful applications in manufacturing field. The current paper discussed a bibliometric overview of abrasive water jet machining research. The main objective of this study is to be informative about the abrasive water jet research and to summarize the useful bibliometric information from the studies reported in this field. From the bibliometric analysis, following main conclusions could be inferred.

- The USA is the most influential and active country in the abrasive water jet machining research.
- Wang J has pushed the institutions that he worked with to be the most influential institutions in this field as he is the most influential and productive author in abrasive water jet research. Moreover, Wang J is found to be the most active author among all in abrasive water jet research with the highest number of published articles and citations received.

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- Queensland Univ Technol from Australia and Univ Nottingham from UK are the most influential institutions in abrasive water jet regarding total citations received for their published research. It should be noted that some institutions like Tech Univ Ostrava (Czech Republic) and similarly some authors (e.g. Hloch S) have a high number of publications but receive fewer citations. This is due to the reasons that publications are mostly presented in low impact factor journals such as Tehnicki Vjesnik Technical Gazette, co-authoring with the same authors and same citation authors.
- In general, the results showed that the European countries are focussing more on abrasive water jet research, whereas Asian countries have shown less interest in this field. Furthermore, all the mainstream manufacturing journals have captured the research on AWJ and the number of papers published per year and their citations and impact factor are consistently increasing over the years.

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