Global Research Trends in Tribology: A Scientometric Study

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ABSTRACT: *The present study demonstrates the growth of tribology literature for the period 2000-2019. A total of 1208852publications were extracted from the Web of Science Database for ten years. The Relative Growth Rate (RGR) and Doubling Time (Dt.) of tribology literature have been calculated, supplementing with different growth patterns to check whether tribology literature fits polynomial, linear, or logistic models. The results of the study indicate that the growth of literature in tribology does not follow the linear or logistic growth model. However, it follows closely the polynomial growth model.Identified the global research trends. The study concludes that there has been a consistent trend towards increased growth of literature in the field of tribology.*

Keywords: Growth Models, Modelling, Tribology, 3D Printing, Aerospace

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1. Introduction

Additive manufacturing (AM) technology is developing in many industries, including aviation, automotive and others. 3D printing offers new possibilities in the field of designing and manufacturing of machines and components. AM is currently one of the most developing and promising technologies for the construction of structural components, enabling the growth of practical use of a number of composite materials. 3D printing is expected to be one of the key developmental technologies that will shape the new approach to manufacturing and the products as well as factories of tomorrow.This paper is focused on the avilable datasets of Tribology literature in Web of Science databse for the period 2000-2019.

2. Related Work

In the age of rapid technological advancements in engineering sectors, the production systems are continuously evolving to meet the complex challenges of the present day. Such advancements are raising the robustness, quality and performance barriers of the production systems and the products due to that must operate under extreme conditions. Among the extreme operating conditions, high temperature environments are considered the most critical in industries as metal forming, aerospace, advanced automotive and power generation to name a few (Ur Rahman et al., 2019). Depending upon the applications, the operating temperature of a given manufactured part may range up to 500^{o}C and in some cases up to 1,000æ%C. These elevated temperatures (often coupled with thermal fatigue) can have detrimental effects not only on the mechanical properties of the materials but also their surface morphology. This in turn can affect the friction, wear and lubrication characteristics of materials (Semenov, 1995). The harsh operating conditions and complexity of the mechano-chemical processes involved offer a great challenge from the perspective of material design, manufacturing and surface engineering of the industrial production systems and the products.

Additive manufacturing processes are extensively employed in aerospace, automotive and power generation sectors due to their ability to manufacture geometrically complex parts by substituting several individual machining processes (Sexton, Lavin, Byrne, & Kennedy, 2002). The main advantage of additive manufacture is to fabricate component of advance alloys which are difficult to machine and or would offer serious tooling problems. In these sectors many systems are subjected to high temperature, high stress and vibration effect, leading to erosion and creep (Kaierle et al., 2017; Kathuria, 2000). A few examples of these are engine bearings, cylindrical liners, valves, gas/steam turbine blades, bearing rings, casings, bearing and bushings for space satellites, rocket nozzles, hypersonic aircrafts and missiles, nuclear and chemical vessels. Aggressive operating conditions require novel high-performance wear resistant alloys with self-lubricating characteristics (Zhu et al., 2013). Ti alloys and Ni based super alloys are extensively used under such conditions to ensure the high reliability and surface integrity (Pusavec, Hamdi, Kopac, & Jawahir, 2011; Rynio, Hattendorf, Klöwer, & Eggeler, 2014). As an example, in the gas turbine engine, compressor stages, combustion chamber, and the turbines stages of the gas turbine engine are produced from Ti and Ni alloys (Ulutan & Ozel, 2011).

High temperature tribological processes are extremely complex in nature due to simultaneous interaction of multiple variables involving; thermal softening, surface morphological changes due to oxidation and diffusion, and surface degradation due to thermo-mechanical fatigue and wear (Hardell et al., 2015). Material design and development for high temperature tribological contacts therefore involves the integration of complex chemical compositions with the addition of lubrication media, in order to achieve optimal hardness, toughness, thermal stability, friction and wear (Matthews et al., 2007). However, the current industrial production focus is not only to address the extreme temperature environments, but also to enhance the product service life alongside taking into account the economic and environmental aspects in single-step processes. Thus, using Additive manufacturing new materials with enhanced properties and the utilization of advanced and intelligent production techniques (Singh, Ramakrishna, & Singh, 2017) are developing. In order to enhance the service life during operating conditions of the parts or practical application when operating in the machine's continuous provision of lubrication is required for thermal stability, friction and wear. It is essential to maintain an equal percentage of the lubricants throughout the service life of the composite materials to exhibit a consistent tribological performance.

The aim of research is focused mainly on study of tribology properties and also lubrication. The intensity of wear and particles formation is important factors at practical application of rotating machine components, because of negative effects on operability of the machines. In the extreme case, the negative impact of the wear particles leads to seizure of lubricated points. The rubbing of two surfaces leads to the formation of wear particles, or debris, where some are removed from the contact after their genesis, but some stay in the contact and retransformed by further sliding, modifying contact stresses because they act as load-bearing areas and affecting the formation of protective tribolayers (Blau, 1981) ALES, Z., PEXA, M., (2010).

Wear particles come into oil in lubrication system, where they cause contamination and degradation of lubricating properties and consequently it may result in major failure of machines. Among these contaminants are included mainly water, fuel, water coolant, adhesive, abrasive and fatigue particles wear.

3. Methodolgy

This part of the study elaborates on the data collection methods which include; development of the search query, data collection and processing of data as per the objectives of the study. The data presented in the study was extracted from the web of science by Thomson Routers a bibliographical database. The search strategy was developed by using the topic search on the web of science. The strategy we used to search includes ten phrases related to our study is given i.e.: Tribology as the main topic and the subfields of it i.e. 3D Painting OR Additive manufacturing OR Prototyping OR Art & Jewellery OR Tooling OR Medical &

Dental OR Automotive OR Aerospace OR 3D Printing. Utilized open search strategy which obtained the data where these above phrases appear in title, abstract or keywords were downloaded and imported into the spreadsheet for analysis and interpretation. As of 6 November 2019, the growth of publications in the ten sub-disciplines of Tribology derived from web of science, which all together resulted in 1208852, bibliographic records written in English from 2000 to 2019.

The methodology suggested by Sangam et al (2018) for selecting an appropriate growth model from several competing models on a data relating to publication growth has also been utilized.

4. Results and Discussion

4.1. Growth of Tribology Literature (2000-2019)

4.1.1 . Relative Growth Rate (RGR)

The analysis of growth rate of tribology research input is one of the essential aspects of this discussion. This analysis aims to identify the trends and growth of prospects in the present research. However, explosion of tribology literature has made it extremely difficult for scientists to keep in touch with the recent advances in their fields. Hence the provision of information to information seekers is the prime duty of the library professionals who have to meet the information needs of scientists in various disciplines. In this connection, the published literature is taken as a target to measure the knowledge in a discipline, and the growth rate study of publications would provide some useful results.

The rate of growth of tribology literature is determined by calculating relative growth rates or publications. In the research design, the details of this model have been explained. Table 1 predicts data of relative growth rate for total research input on tribology literature.

RGR is the growth rate relative to the size of population. It is also called as the exponential growth rate or continuous growth rate with reference to scientific literature publication. RGR means the increase in the number of publications per unit of time. Further the mean of RGR of publications over specific period can be calculated by using the formula.

$$R = \frac{W_2 - W_1}{T_2 - T_2}$$

Where:

- R = Relative Growth Rate of Articles over specific period of time
- $W2 = Log\ W_2$ (natural log of final number of publication)
- $W1 = Log\ W_1$ (natural log of initial number of publication)
- T^2 = Final Time in Years
- T^1 = Initial Time in Years

This formula even holds good for the calculation of RGR subject wise.

4.1.2. Doubling Time (Dt)

Doubling Time (Dt) is directly related to RGR and is defined as the time required for the publications to become two-fold of the existing amount. If the number of publications in subject doubles during a given period, then the difference between logarithms of numbers at the beginning and at the end of this period must be the logarithm of the number 2. We used logarithm, and the taken value of $loge^2$ is 0.693. Hence, as per this (0.693) an average growth rate we calculated by what time interval does the logarithm interval does the logarithm of numbers increases by 0.693.

The doubling time is the given period required for quantity to double in size or value. It is directly related to RGR, where RGR is constant. The quantity undergoes exponential growth and has a constant doubling time or period which can be calculated directly from growth rate. So the Doubling time is calculated by using the formula:

$$Dt(P) = \frac{Loge2}{R(P)} = \frac{0.693}{R(P)}$$

Here, $Dt\ (P)$ = average doubling time of publications

Table 1 shows the tribology contribution i.e. 1208852 publications. The average relative growth rate of publications of worldwide distribution has come down from 0.709970317 to 0.096336556 over a period of twenty years. The mean relative growth for the first ten years block period (2000-2009) exhibits a growth of 0.3020. Similarly for the next block of ten years (2006-2019) the growth is 0.1204.

Years	Publications	Pub. %	Cumulative	Cum. %	LN (p)	-- R (p)	Mean R (p)	Dt (p)	Mean Dt (p)
2000	23931	1.97	23931	1.97	10.08293		0.3020		2.8605
2001	24743	2.04	48674	4.01	10.7929003	0.709970317		0.976097	
2002	26870	2.22	75544	6.23	11.2324705	0.439570261		1.57654	
2003	30601	2.53	106145	8.76	11.5725614	0.340090816		2.037691	
2004	34307	2.83	140452	11.59	11.8526211	0.28005971		2.474472	
2005	37312	3.08	177764	14.67	12.0882121	0.235591034		2.941538	
2006	41278	3.41	219042	18.88	12.2970188	0.208806664		3.31886	
2007	43269	3.57	262311	21.65	12.4772861	0.18026733		3.844291	
2008	47907	3.96	310218	25.61	12.6450306	0.167744453		4.131284	
2009	52354	4.34	362572	29.95	12.8009784	0.155947799		4.443795	
2010	56522	4.68	419094	34.63	12.9458505	0.144872163	0.1204	4.783528	5.8397
2011	62693	5.19	481787	39.82	13.0852574	0.139406869		4.971061	
2012	68167	5.64	549954	45.46	13.2175899	0.132332531		5.236808	
2013	74513	6.17	624467	51.63	13.3446538	0.127063848		5.453951	
2014	79472	6.58	703939	58.21	13.464447	0.119793219		5.784969	
2015	86167	7.13	790106	65.34	13.5799224	0.115475409		6.001278	
2016	94650	7.83	884756	73.17	13.6930672	0.113144787		6.124896	
2017	100993	8.36	985749	81.53	13.801157	0.108089858		6.411332	
2018	112080	9.28	1097829	90.81	13.9088452	0.107688114		6.435251	
2019	111023	9.19	1208852	100	14.0051817	0.096336556		7.193531	
Total	**1208852**	**100**							

Table 1. Relative Growth Rate (RGR) and Doubling Time (Dt) of Publications in Tribology from 2000-2019

At the same time, doubling time of publication of articles increased gradually from 0.976097 % to 7.193531 % over a period of twenty years. Here also the mean Doubling time of the first block period is 2.8605 whereas it has increased to 5.8397 in the second block period.

4.1.3. Doubling time (Dt)

At the same, doubling time of publications of articles increased gradually from 0.90206% to 8.43465% over a period of fifteen years. Here also the mean Doubling time of the first block period is 2.44835, whereas it has increased to 3.84111in the second block period. It is similar to that of world literature.

4.2. Growth Rate of Subfields of Tribology Publications

Table 2 shows the growth of publications in the selected ten sub disciplines of tribology for the period 2000 to 2019. Here it is observed that Tooling contributes maximum number of papers 987986 (81.73%) of the total publications. The second number is of Photo typing the total number of papers being 127587 (10.56%), followed by Automotive having 29861 (2.48%), then Aerospace17950 (1.49%)papers,3D Printing 15680 (1.29%), Additive manufacturing 13620 (1.13%), Medical & Dental 8428 (0.69%) and Tribology 7043 (0.58%), lastly the 3D Painting633 (0.05%) and Art & Jewellery (1.13) with least contribution of publications with 64.

Year	Tribology	3D painting	Additive manufacturing	Prototyping	Art & Jewellery	Tooling	Medical & Dental	Automotive	Aerospace	3D Printing	Total No. of Publications	%
2000	232	11	71	3184	2	18904	189	861	462	15	23931	1.97
2001	271	11	70	3296	1	19610	186	816	464	18	24743	2.04
2002	187	10	81	3570	1	21495	191	852	475	8	26870	2.22
2003	246	13	88	3954	1	24579	225	937	533	25	30601	2.53
2004	290	8	93	4430	2	27740	202	1031	491	20	34307	2.86
2005	294	16	95	4669	3	30413	252	1010	520	40	37312	3.08
2006	298	19	96	5123	6	33587	234	1216	660	39	41278	3.41
2007	306	15	122	4854	-	35774	328	1189	621	60	43269	3.57
2008	321	23	132	5076	3	39924	402	1285	671	70	47907	3.96
2009	373	25	159	5488	4	43843	392	1285	689	96	52354	4.33
2010	337	22	180	5864	6	47454	467	1382	723	87	56522	4.67
2011	328	37	253	6435	-	52748	482	1490	799	121	62693	5.18
2012	344	27	305	6731	6	57710	534	1513	841	156	68167	5.64
2013	416	31	361	7649	3	62647	533	1639	969	265	74513	6.17
2014	365	51	630	8082	5	66277	565	1802	1051	644	79472	6.58
2015	440	45	902	8418	-	71626	552	1905	1165	1114	86167	7.13
2016	447	62	1403	9475	2	77353	628	2162	1346	1772	94650	7.83
2017	461	61	2057	9801	5	81240	667	2348	1618	2735	100993	8.36
2018	528	78	3020	10910	7	88611	689	2620	1823	3794	112080	9.28
2019	559	68	3502	10578	7	86451	710	2518	2029	4601	111023	9.19
Total	**7043**	**633**	**13620**	**127587**	**64**	**987986**	**8428**	**29861**	**17950**	**15680**	**1208852**	**100**
%	**0.58**	**0.05**	**1.13**	**10.56**	**0.00**	**81.73**	**0.69**	**2.48**	**1.49**	**1.29**	**100**	

Table 2. Growth Rate of Subfields of Tribology Publications from 2000-2019

4.3. Application of Growth Models

The present study is conducted with a purpose to apply the various growth models and to assess the growth literature in the ten main sub disciplines of Tribology. Some of the growth models that have been chosen for the study. It has been observed that polynomial growth model fits well for the present study.

Subjects	Best Resulted Obtained in Literature	
	Name of Model	R2
Tribology	Polynomial	0.9176
3D painting	Polynomial	0.9437
Additive manufacturing	Polynomial	0.9146
Prototyping	Polynomial	0.988
Art & Jewellery	Polynomial	0.2531
Tooling	Polynomial	0.9954
Medical & Dental	Polynomial	0.9719
Automotive	Polynomial	0.9827
Aerospace	Polynomial	0.9766
3D Printing	Polynomial	0.9097

Table 3. Fitting of Polynomial Model for Cumulative Growth Publications of Tribology Literature

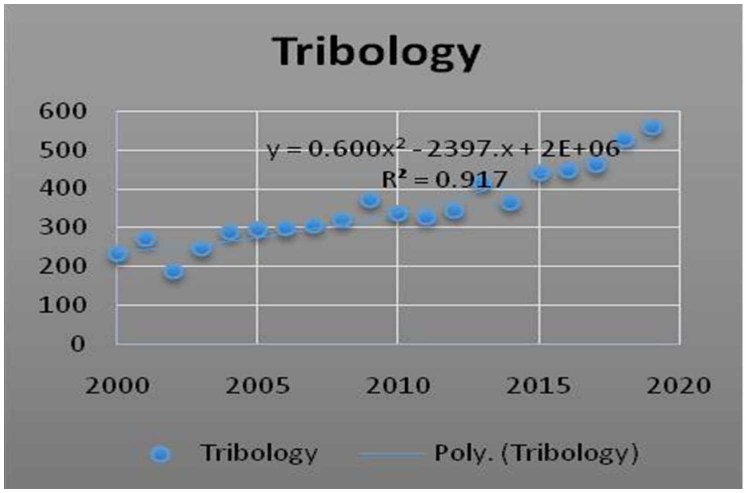
A polynomial is a mathematical expression consisting of a sum of terms, each term including a variable or variables raised to a power and multiplied by a coefficient. Polynomial curve fitting common for data analysis in the field of science, engineering and social science. The standard method to fit a curve to data is to use the least squares method. In this method the coefficients of the estimated polynomial are determined by minimizing the squares of errors between the data points and fitted curve. This method is used to determine relationship between an independent and dependent variable. Historically polynomial models are among the most frequently used empirical models for curve fitting. The advantages of models are; they have a simple from, well known – understood properties, and moderate flexibility of shapes. They are easy to use. Mathematically it is represented as; $Y = ax^2 + bx + c$.

Table 3 explains the application of selected growth models to the Cumulative Growth of publications in the selected disciplines of tribology for the period 2000-2019. This indicate that more than one model could explain their growth. The models evaluated in terms of their model parameters fit statistics and the graphical fit to the data. The best fits were shown by polynomial model for the publication in tribology. This is true in the case of growth of Tribology literature (see the figures 1-10).

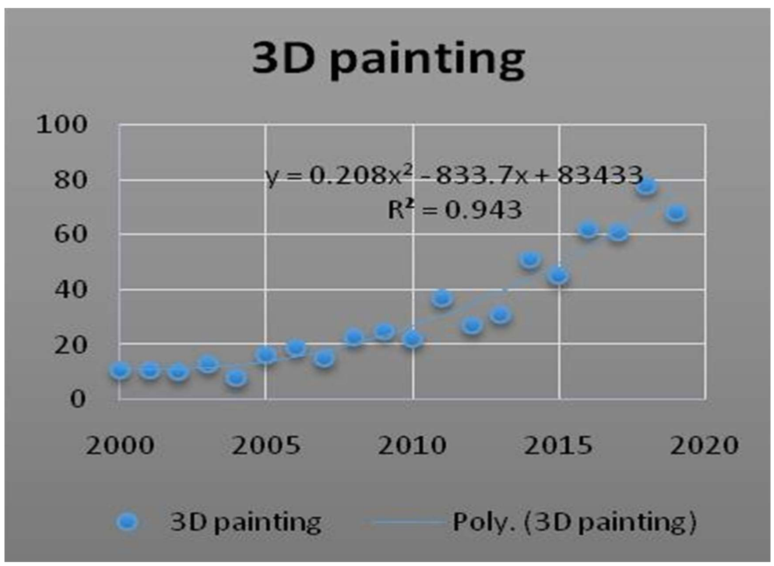
4.4. Country-wise Distribution of Research Output 2000-2019

Bibliometrically, the value of place of publications rests very much with its ability to point to the nationality of the document. It is widely believed that the national production figures indicate the financial and academic status of a country and its position in the world map. A leaf or two can be taken from this about the richness of authors in the country as well. Certain countries give more research input in a particular subject than in others. The information is very much useful not only for the information managers in finalizing the subscription list of periodicals, but also for the research scholars who tend to know the countries that are leaders in their respective fields of research.

To know the position (trends) of tribology publications among the different major contributing countries, the total input in



Tribology

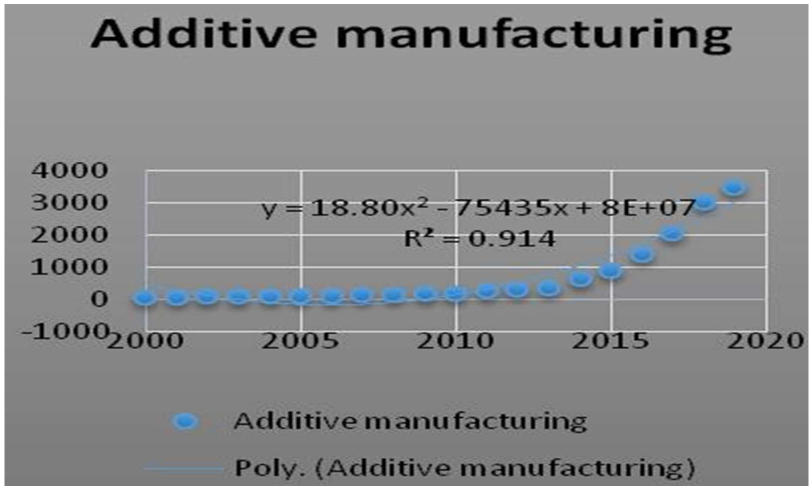


3D painting

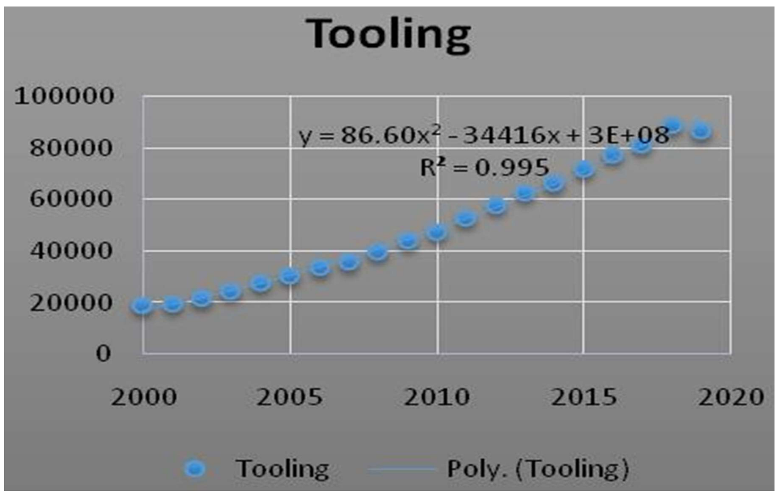
the field of tribology in the field of tribology as a whole for the period 2000-2019 has been taken for 15 major countries as listed in below Table-4.

Table-4 shows the number of publications published in the country wise, USA positioned 1st in the list with 3, 42, 335 (28.32%) contributions to tribology literature, followed by Peoples RChina with 1, 14,270 (9.46%) publications, and the third position go to Germany with 103126 (8.54%) publications, it was quite interesting while we observed that India is in 11th position with 35336 (2.93%) contribution to the field of tribology. The remaining countries made less contribution in the field of tribology.

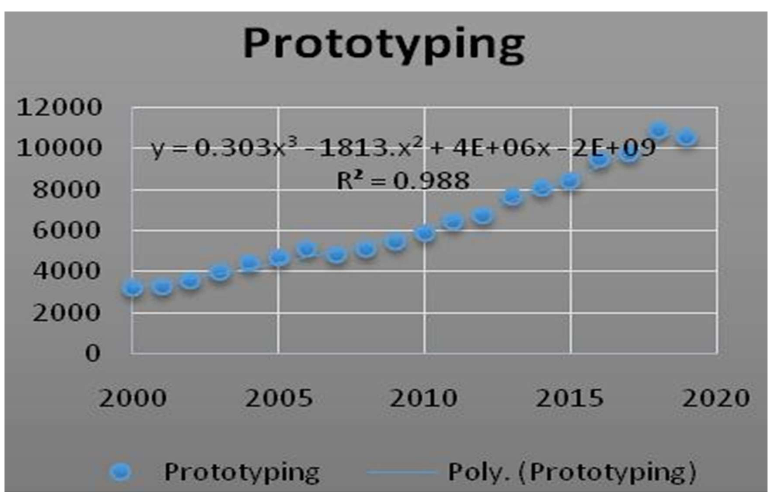
Maximum number of publications published during the fields of Tribology is from Tooling (294,006) followed by Prototyping (33,450); Automotive (6,336); 3D Printing (5,129) Additive manufacturing (4,287) and Aerospace (4,083). During the field periods (2000-2019) Art and Jewellery and 3D Painting has lesser number of publications output.



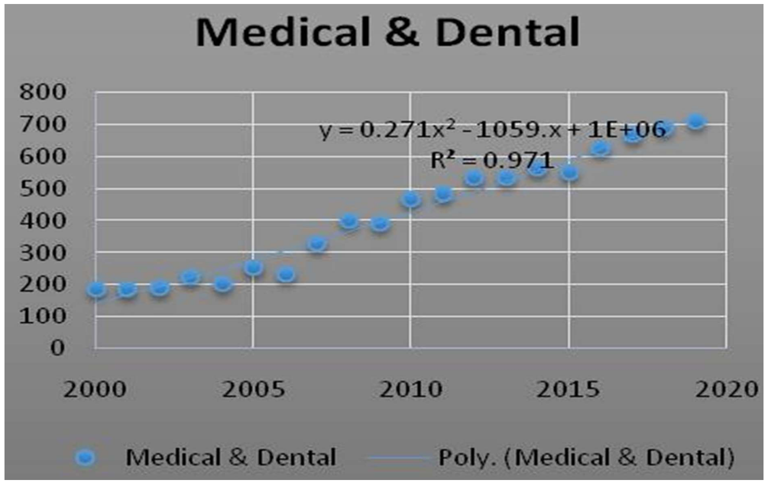
Additive manufacturing



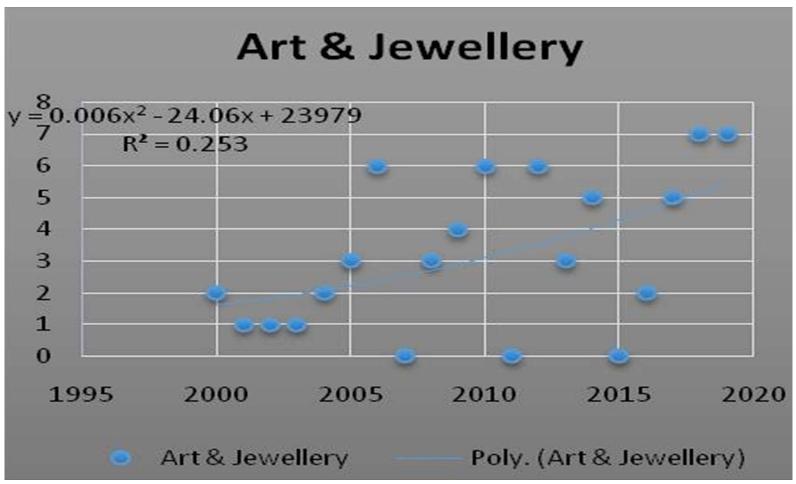
Tooling



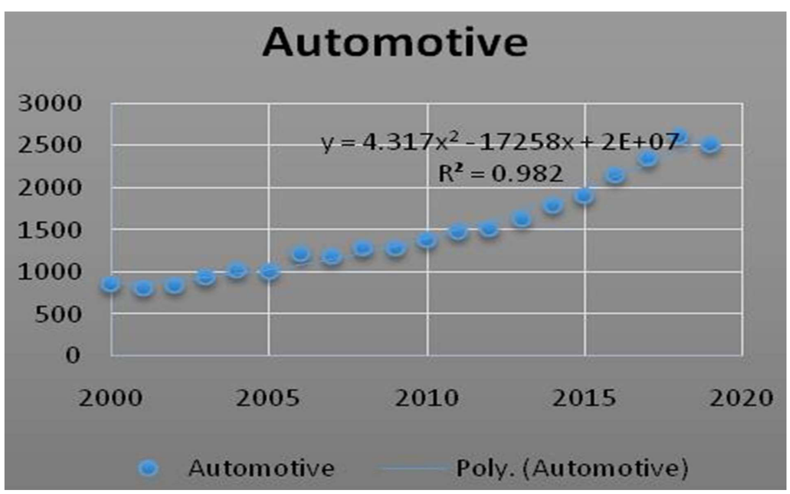
Prototyping



Medical & Dental

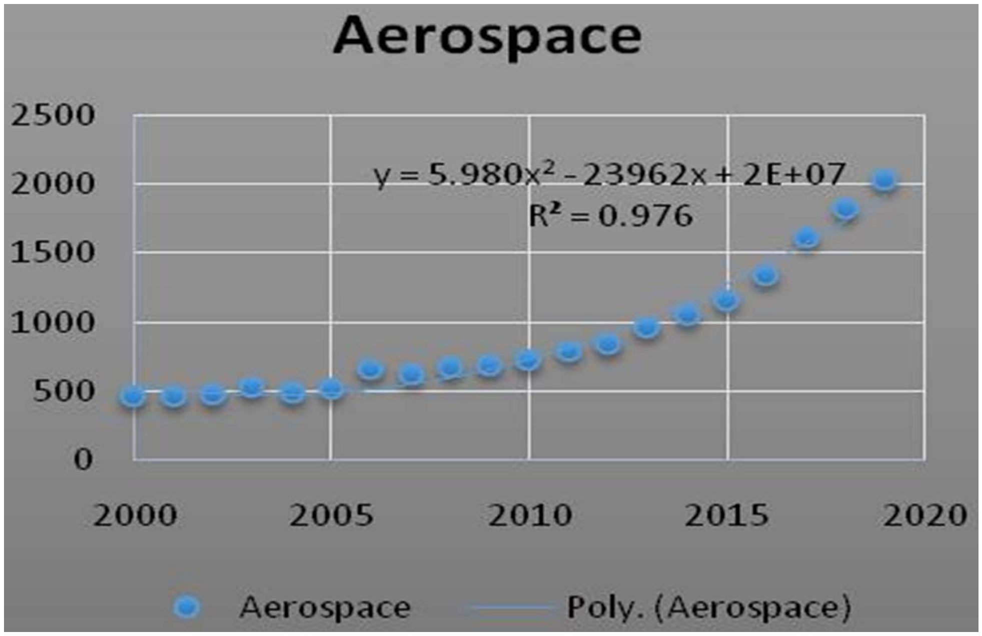


Art & Jewellery

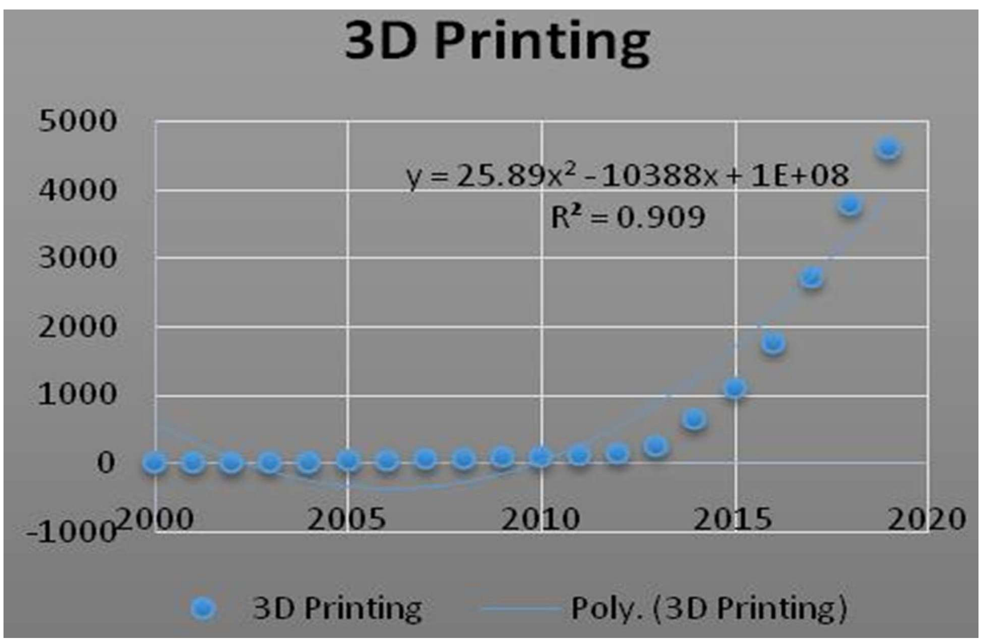


Automotive

Figure 8. Aerospace



Aerospace



3D Printing

5. Conclusion

The study concludes that there has been a consistent trend towards increased growth of literature in the field of tribology.These figures help publishers in tuning their coverage policies; librarians in caring the acquisition policy and researchers in their research design. For pragmatic research, availability of citations with the place of publication as one of the parameters is of great value.

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Table 4. Country-wise Distribution

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