RESEARCH TREND IN THE FIELD OF ADDITIVE MANUFACTURING WITH BIBLIOMETRICS STUDY

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This paper reviews the current trend in the field of additive manufacturing based on the bibliometrics study. In particular, we assessed the interest of the research community revolving the hybrid material. Scopus database was referred to for the English literature on the hybrid materials in additive manufacturing, published in the time period from 2012 to 2022. As a result, 973 relevant articles were found and studied. Information related to the top journals in which they were published, as well as the topics of the papers were shown. Based solely on the quantitative study, the valuable insights were extracted. Specifically, we report the number of publications over the years, the fields where the publications belong to, the top journals that publish those works, and a network of keywords that are important for such a topic. The paper would serve as a brief and helpful introduction for researchers and practitioners to the current trend of the field.

KEYWORDS

Additive manufacturing, hybrid material, bibliometrics study

1 INTRODUCTION

Recent years have witnessed the rapid growth of the additive manufacturing (AM) technologies both in research and industry. The technology is state-of-the-art because it allows creation of 3d objects additively by adding one layer on top of another. This promises fabrication of more flexible geometry, which traditional manufacturing methods cannot produce. Being able to selectively deposit the materials, AM can help to reduce the waste in production, e.g., no chips as in subtractive manufacturing. Moreover, it has the possibility to combine different materials to make up novel materials with outstanding properties. This potentially opens up a new age for research on new materials and corresponding AM technology to produce them. Because of these advantages, it is expected that AM will play a significant role in the modern, smart factory.

There are two terms that are used for materials with different constituents that AM technology can produce, which are 'composite' and 'hybrid'. Composite is used for mixture of constituents in macroscale, while hybrid is in nanoscale or even molecular scale [Gu 2018]. Owing to the flexibility that AM offers, it is possible to fabricate functional components from both the composite and hybrid materials. The two terms, however, are used interchangeably in a lot of existing literature. Upon discussion about the term 'hybrid', it worths mentioning the definitions of hybrid AM technology and the hybrid material.

The term hybrid AM refers to inclusion various manufacturing tools in one machine to work with multi-functional materials. Specifically, in a integrated hybrid AM system, machining tools, such as pick-and-place (PnP) robotic arm, spray coating, traditional machining, AM technologies, etc. have been incorporated [Wang 2014], [Macdonald 2014], [Macdonald 2016], [Dilberoglu 2021]. The principle of hybridizing the AM process is that we can employ two or more different manufacturing technologies to synergically work to produce the parts that each-standalone technologies cannot. This enables fabrication of multiple and multi-functional materials. First of all, it gives birth to the combination of the terms hybrid additive-subtractive manufacturing (HASM) where 3d printing technology is combined with milling technology [Flynn 2015]. In such a process, parts are first printed and details are refined to the desired tolerances using milling with highly accurate tools. As a step further, in [Ashby 2005], authors even proposed a novel 6-axis (HASM) process with a case study. As for combination of different AM processes, Direct Ink Writing (DIW) was combined with Digital Light Processing (DLP) method in [Vatani 2015] or Material Jetting (MJ) in [Zhang 2019] to produce highly conductive and viscious materials with metal or carbon constituents, enabling the production of flexible and smart electronics, soft robotics.

Due to the increasing demand in the engineering world for their designs, it is necessary to combine two or more different materials to obtain the desired properties which are suitable for the assigned tasks. The combination of different materials gives birth to the so-called hybrid material, which fills the gap of the material property space mentioned in [Ashby 2005]. In the same paper, hybrid materials include but are not limited to foams, composites, sandwiches, segmented structures, and lattice structures. AM, on the other hand, has enabled more freedom in manufacturing complex structures while combining different constituents. This has made AM a desirable candidate for production of hybrid materials. The most popular type is 3D printed carbon fiber composites with reinforcement being the long carbon fiber and matrix being the short carbon fiber mixed with nylon-based thermoplastic [Krzikalla 2022]. Besides, [Chávez 2021] studied the combination of Tin-bismuth (SNBi) powder with three thermoplastics acrylonitrile butadiene styrene (ABS), polylactic acid, and a blend of ABS, styrene ethylene butylene styrene (SEBS) and maleic anhydride graft (SEBS-g-MA). From electron microscopy (SEM), the SnBi particles were drawn to wires and reinforced in-situ, while the melting temperature significantly increased. In [Cakmak 2018], authors experimented fusing a novel metallic hybrid structure with combination of Inconel-718 for matrix and Co-Cr for internal structure. The material was fabricated using Directed Energy Deposition (DED) technology. Inspired by the nature, paper [Pack 2020] investigated the core–shell structure 3d printed with carbon fiber and foam, replicating the plant stems or hedgehog spines.

Because of a huge number of scientific works that are published annually, it is impossible to read all the articles and cluster them manually so that one can understand the overall picture of the research field. Therefore, bibliometrics study is necessary. Bibliometrics stands for statistical and mathematics approaches that are used to evaluate scientific works. It is used to discover the common connections among the scientific literature in terms

of (co)authorship, (co)citation, affiliation, keyword, etc. Being able to analyze and present the data in an understandable manner is undeniably beneficial for researchers.

In view of this, herein, we conduct a bibliometrics study on the hybrid material produced by the AM technology. The aim of the study is to provide a brief guideline for the researchers into this topic. Section 2 describes how we collected the data and methods that were used to process them. Section 3 reports the results and discusses them. Finally, Section 4 sums up the study and describe the future works.

2 MATERIALS AND METHODS

The study was conducted using the English articles published in the year range of 2012-2022. The database that we used for article searching was Scopus. The search term was ALL=((additive manufacturing*) OR (on) AND (hybrid*) AND (material*) with type Article. From the 973 articles that we found, details related to their publication were studied. Mapping study is reported with the help of VoSViewer [Van Eck 2022], [Van Nunen 2018]. VoSViewer is a useful tool for analyzing and visualizing bibliometric networks. Within the framework of this study, VoSViewer is used to list out and construct networks of top journals that publish the relevant articles and the keywords they contain.

3 RESULTS AND DISCUSSION

Fig. 1 shows the number of publications which were found using the searched terms.

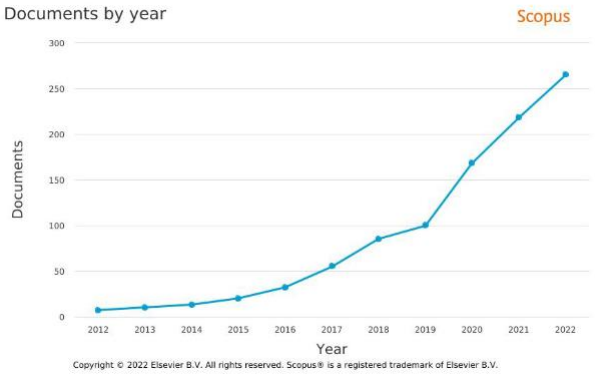

Figure 1. The number of articles in throughout the period of 2012-2022.

It can be observed that the number of publication started to exponentially increase from the year of 2016. Specifically, in just 7 years, from 2016 to 2022, the number of papers has grown approximately 10 times larger.

The subject areas in which the articles were distributed are illustrated in Fig. 2.

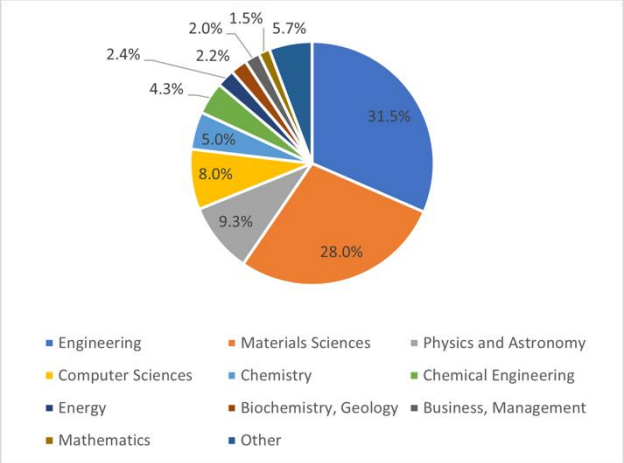

Figure 2. The subject areas in which the articles were published.

Out of the 973 articles, 31.5% and 28.0% of them were published respectively in the area of Engineering and Materials Science. This shows how relevant the two subjects are one to another. Along side inventing a novel material, ones have to think about the manufacturing method to produce them. Besides, other areas make up 40.5% of the distribution, which shows that different fields are starting to consider hybrid materials into their studies as well.

In Tab. 1, the top five journals in which the articles were published are listed.

No.	Name	Articles	Citations
1	Additive Manufacturing	68	792
2	International Journal of Advanced Manufacturing Technology	49	581
3	Materials	35	295
4	Journal of Manufacturing Processes	22	240
5	Rapid prototyping journal	22	474

Table 1. Top five journals according to the number of published articles.

The names of the journals were sorted in order of the number of the relevant articles that the journal published. The top three journals published the highest number of articles are Additive Manufacturing, International Journal of Advanced Manufacturing Technology, and Materials. Remarkably, on top 5 and 6, eventhough the number of publications are similar, the number of citations are considerably higher. This shows that the number of articles a journal published does not necessarily correspond to the number of citations it would receive. Moreover, it should be mentioned that the average year of publication for all these articles in the top five is 2019. Based on this table, readers and reseachers would know which journals they can refer to for literature review and publication.
Another important factor for bibliometrics study is to assess the keywords. Therefore, Fig. 3 depicts how the keywords are related to each other.

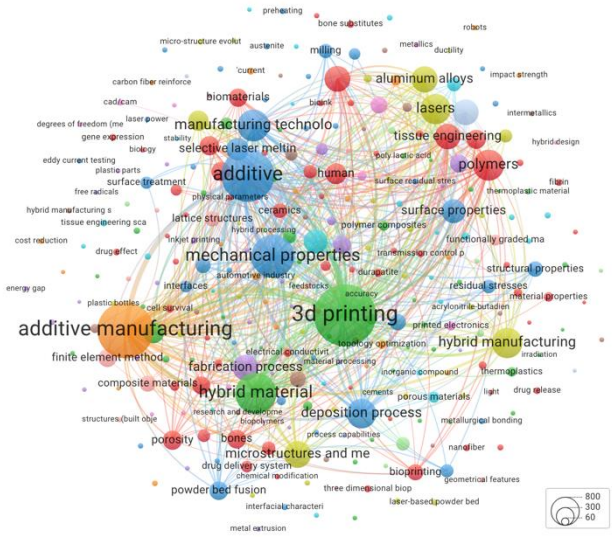

Figure 3. The network of keywords.

A keyword (node) has two factors: the size and the number of links that are connected to it. Each time a keyword appears in an article, the occurrence number counts 1. The occurrence number is the total number of the articles with the given keyword. The higher the occurrence number, the bigger the node. To visualize the map in Fig.3, the occurrence number was set as minimum 4. The top ten keywords are listed in Tab.2.

No.	Keyword	Occurrences	Total link strength
1	3d printing	627	3955
2	additive manufacturing	524	3232
3	additive	429	2869
4	hybrid material	275	1739
5	mechanical properties	259	1901
6	manufacturing technologies	153	1042
7	hybrid manufacturing	152	950
8	polymers	131	985
9	deposition process	128	898
10	lasers	125	944

Table 2. Top ten keywords.

As expected, the keyword (node) with the highest size and total link strength is '3d printing. Other keywords which are similar are 'additive manufacturing', 'additive'. The fourth

Based on Fig.3 and Tab.2, we can see a clear connection between the additive manufacturing technologies and the hybrid material. After successfully fabricating the hybrid material, the next important goal of the researchers is to study the mechanical properties of it. The mechanical properties, however, is of less concern, meaning that the current research only pays attention to new ways to additively create the hybrid material but not to assess their properties for practical purposes. This could be a potential field for future research. Overall, we can see that the field we are investigating has a lot of rooms for innovation.

4 CONCLUSIONS

In conclusion, this paper presents the bibliometrics study considering the hybrid material and additive manufacturing technology. Indeed, the main driving force for the development of multi-functional hybrid materials have been found in various fields, such as, biomedical, electronics, mechanical engineering, etc. Thanks to the growth of AM technologies, the demand for research and practical usage have grown more than ever. However, some of major challenges remain including the bonding of different materials, the printing efficiency, scalability, and practical aspects. This would require a multidisciplinary approach to solve. Future research can include other databases such as Web of Science, Google Scholar for bigger picture into the field. The searching terms as well as the keywords can be polished so that the obtained results are more compact and precise. Another drawback lies in the nature of the VOSViewer. Using the software, we can only visualize the collected data without giving any information about the future trend. To comprehend the insights so that the future research trends can be identified, it is necessary to involve experts in the fields to conduct manual literature reviews. Therefore, future results can be shared with experts in different sub-fields to confirm the relevance of the results so that the outcome of the bibliometrics study can be more comprehensive.

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