A Literature Review of Publications Trends to Shape Memory Alloys by Using Bibliometric Analysis

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Abstract: Shape Memory Alloys (SMAs) have been at the lead of research for the past several decades. Shape memory alloys have a variety of applications and are used in many areas. That is why other fields are interested in investigating and researching this area of study. For example, actuators and other responsive devices are products of SME studies applied in medicine, aerospace, fashion, and many other fields. To study the general development of SMA, we reviewed the annual SMA publications, citations, the most active researcher, the core journals publishing SMA investigations, and the most productive countries are all studies in this research using bibliography analyzes. This study will map the progression and highlight the most cited studies, a few of the best review articles, and the most used keyword in the publications are also considered more than fifty years (1971-2021), showing the scientific productivity in the SMA. This will help starter researchers in the SMA area of study by; to begin with, and it's essential to understand how SMA research and conclusions have progressed through time. Furthermore, introduce active researchers/institutes and opens a way for collaborations. This study will also help the decision-makers in the industry to take advantage of the progression in SMA as it is applied in many areas.

Keywords: Bibliometric Analysis, Scientific Productivity, Shape Memory Alloys (SMAs), Cooperative studies, Shape Memory Effect (SME)

1. Introduction

Metals are categorized by physical qualities such as strength, flexibility, ductility, and conductivity. Trainability and shape memory are found in a new family of metal alloys; these new alloys show the shape memory effect (SME) and superelasticity. If you plastically deform these alloys at a temperature, their original shape will be recovered when the temperature increases. Displacement, force, or maybe the combination of both will be experienced as a function of temperature in recovering their shape. Due to these unique and notable properties, a wide variety of problems are solved with the help of SMAs (Schetky, 1979). Martensite and austenite (parent phase) are the main two phases in SMAs. This transformation from solid to solid phase is called non-diffusive (Lobo, Almeida, & Guerreiro, 2015). Temperature reduction or a stress increase can induce change from the parent phase to a softer phase (Martensite), either twinned or detwinned. SMAs behaviour is characterized by superelasticity and by the shape memory effect (Lobo et al., 2015). Four transition temperatures indicate Stress-free SMAs; M_f and M_s, representing the martensite start and finish and A_s and A_f means austenite start and end temperature of the transformation process (Lobo et al., 2015). Shape memory alloys are susceptible to thermomechanical treatments and material composition variations, but still, they are generally categorized into nickel-titanium (NiTi) and Cu-based alloys.

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Specially equiatomic (NiTi) alloys with cold working and treatments are most suitable for different applications in engineering. They have better superelastic properties, high resistance to corrosion and fatigue, and higher temperature variation stability (Auguet et al., 2007; Dolce, Cardone, & Marnetto, 2000; Miyazaki, Imai, Igo, & Otsuka, 1986). SMAs used as actuators in many areas. In a sense, a mechanical signal is converted into a non-mechanical output (e.g., an electrical signal). In contrast, an actuator converts a non-mechanical input (e.g., electrical power) into a mechanical output (P. K. Kumar & Lagoudas, 2008).

The documentation of Shape memory transformation (SMTs) was firstly found in the 1930s were Olander could notice the reversible conversion of cadmium–gold alloy (Cd–Au) based on resistivity changes and metallurgical observations in 1932 (Barbarino, Flores, Ajaj, Dayyani, & Friswell, 2014), just six years later (1938) Alden B. Greninger of Harvard University and V. G. Mooradian of the Massachusetts Institute of Technology showed the formation and vanish of martensite phase with a change in temperature in brass alloys (copper and zinc). At the same time in Russia, the metallurgist G. V. Kurdyumov while working on steel and particularly on the crystallography of steels martensite noted the relation between his work and phase relations in brass. Later at the University of Illinois, Thomas A. Read and his associates investigated the SME in gold-cadmium alloys and noted the importance of phase transitions in future (Schetky, 1979). After Olander's findings and 30 years later, in 1962, William J. Buehler discovered SME in equiatomic Ni-Ti alloys later known as Nitinol which was a remarkable finding in the timeline of SMAs. Nitinol finding was a solution to many discoveries and applications in all areas like medicine, engineering, aerospace, etc. (Baiz, Canbay, & Karaduman, 2018).

Bibliometric analyses are among the most susceptible tools that quantitatively measure research outcomes depending on statistical and geometrical data (Dalpé, 2002; Pritchard, 1969). Furthermore, this method can sufficiently investigate metrological features of data generated in a given domain (Ellegaard & Wallin, 2015) over a long period. The bibliography is also could count as a secondary source in research. Static information like scientific publications, citations, and patents holds enormous information in mapping the scientific and technological fields. This analysis gives researchers a structured approach to (i) identify future academic collaborators, (ii) classify the suitable institutes to pursue their academic steps, and (iii) spot emerging research domains, in that way supporting the progress of scientific and technological innovation (Kajikawa & Takeda, 2009; S. Kumar & Jan, 2014). The bibliometric analysis also helps industrial communities analyze and organize vast amounts of experimental data to facilitate decision-making and prediction developing technologies.

2. Material and Methods

An online database was used to take data covered in the present research. Web of Science "v 5.35 Web of Science core collection basic search (WoSCC)" used as a source to get data from which accessed by Firat University, Elazig, Turkey. Furthermore, all data is taken from two main tools: conference Proceedings Citation Index-Science and Science Citation Index Expanded (SCI-EXPANDED). The Web of Science was utilized for covering and reaching data since it is such an excessive foundation data citation and is often used as a course resource in the scientific study of publications (Braun, Schubert, & Kostoff, 2000; Shibata, Kajikawa, & Sakata, 2010). It is also an alive and constantly updated database that can be trusted upon. It provides many services for authors, publications, institutes, sources, and countries in various categories. Besides, another search engine which is Scopus were used to get details about authors even the author's lists were taken from Wen of

Science, but the details like H-index, number of publications in the field, and number of their citations were taken from the Scopus.

In present work, all searches were limited from 1971 till 5/7/2021 in Shape memory alloys because the topic search in web of science means an investigation that includes titles, keywords, abstract of that field. Besides, some keywords were applied, such as Shape memory alloys, Shape-memory alloy, Shape memory effect, NiTi-based, Cu-based, SMA, SME, and martensitic transformations. These major keywords contributed to the most incredible ratio of SMAs publications.

3. Results and Discussion

In this research, we reviewed SMA progression in 50 years (1971 till 1/7/2021); there are 27153 studies in this field, this includes 20626 articles; among these publications, there are 1,391 review articles, some are very extensive and useful, especially for the new researchers in SMA and Smart materials field. The most common keyword used in all the studies is “shape memory effect” repeated (15150). The word martensite is mentioned in different ways like “martensitic transformation” (5567 times), “martensite” (3541 times), and “martensite transformation”, which is (293 times) repeated. The third most common repetitive keyword (4163 times) is “shape memory alloy”, the same keyword is also mentioned like “shape memory alloys”, which is (3832 times), “shape memory” is (1716 times) and “Shape memory alloy (SMA)” (419 times) used as a keyword in studies of SMAs. Less than 3 per cent of whole the investigations are proceeding papers. Twelve books and 257 book chapters are written on shape memory alloys. As it is clear from Figure 1, the rate of publication over the years goes up exponentially in the first 20 years (till 1990) it didn’t reach 100 studies per year, but as the importance of actuators and microdevices increased, the rate of the finding of SMAs increased and in 1999 it could reach above 500 articles in a year. In the last two decades, the growth of shape memory alloys empowered significant developments in energy conversions, biomedical devices, and microelectronics (Braun et al., 2000), and that’s how in 2006, the yearly rate of publication in SMAs got to one thousand, which shows the need of investigating more in this field so that more applicable, easier to produce and chipper SMA to be available to fulfil the needs of world’s progression in all the various areas. In the last three years, we see that the number of publications is peaking compared to the previous years. The highest rate of publication was in 2019, which was 1485, with all the difficulties that we face in 2020 due to COVID-19 and social distancing, but the number of publications was very near to 2019’s rate of publications.

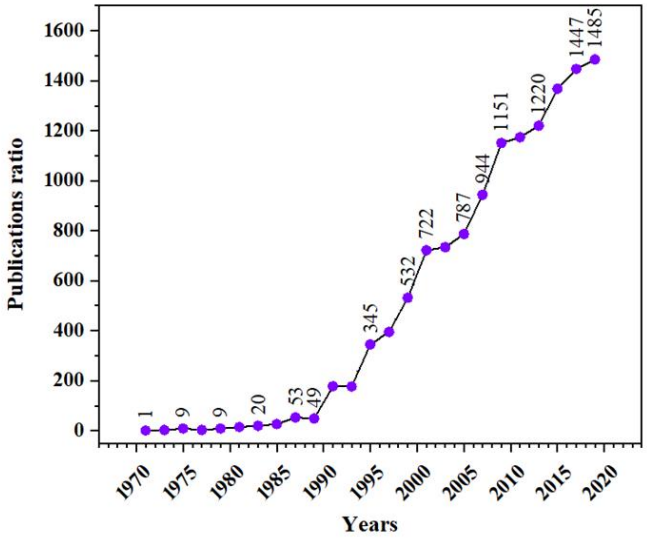

Figure 1: Progression of published studies in the field of SMAs from 1971 to 2021

3.1 Covering Fifteen Most Cited HEA Research

The number of citations cannot indicate the rate of the importance of a study, but it still shows the scientific community's attention to a particular study. Here we offer the fifteen most cited studies in the SMA field, as shown in Table 1. All the published studies in SMA have 272202 citations, with an average of 28.05 citations per published article. Geetha, M.; Singh, A. K.; Asokamani, R.; et al. has a study on “Ti based biomaterials, the ultimate choice for orthopaedic implants - A review” published in 2009 highest citations (2890 citations) among all the studies done on shape memory alloys. This study was on Ti-based alloys, biomechanical compatibility and various surface modification techniques to attain superior biocompatibility, higher wear and corrosion resistance were discussed. The second most cited publication belongs to Otsuka, K; Ren, X with 2561 citations under the title “Physical metallurgy of Ti-Ni-based shape memory alloys”, both published in the journal of “Progress in Materials Science”. The third one is only 1533 times cited which is a review study “A review of shape memory alloy research, applications and opportunities” for Jani, Jaronie Mohd; Leary, Martin; Subic, Aleksandar; et al. published in 2014; the author explains the basics understanding of SMA in this review article, and that helps the new researcher of this field to conclude their knowledge in this field. Still, the essential side of this study is the opportunities mentioned that could be a start of new studies. Five out of fifteen and two in the first three most cited studies are review studies; this shows the importance of summarizing and concluding the articles in both time and simplicity in explaining the information perspective for researchers in review studies.

Table 1: Top fifteen cited studies in SMAs field during the study time

No	Title	Authors	Journal	Year	Times cited
1	Ti based biomaterials, the ultimate choice for orthopaedic implants - A review	Geetha, M.; Singh, A. K.; Asokamani, R.; et al.	Progress in Materials and Science	May 2009	2890
2	Physical metallurgy of Ti-Ni-based shape memory alloys	Otsuka, K; Ren, X	Progress in Materials Science	Jul 2005	2561
3	A review of shape memory alloy research, applications and opportunities	Jani, Jaronie Mohd; Leary, Martin; Subic, Aleksandar; et al.	Materials & Design	Apr 2014	1533
4	Giant magnetic-field-induced strain in NiMnGa seven-layered martensitic phase	Sozinov, A; Likhachev, AA; Lanska, N; et al.	Applied Physics Letters	Mar 2002	1408
5	Magnetic-field-induced shape recovery by reverse phase transformation	Kainuma, R; Imano, Y; Ito, W; et al.	Nature	Feb 2006	1359
6	An overview of nitinol medical applications	Duerig, T; Pelton, A; Stockel, D	Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing	Dec 1999	1147
7	Perspectives on Titanium Science and Technology	Banerjee, Dipankar; Williams, J. C.	Acta Materialia	Feb 2013	1036
8	Giant magnetocaloric effect driven by structural transitions	Liu, Jian; Gottschall, Tino; Skokov, Konstantin P.; et al.	Nature Materials	Jul 2012	945
9	Fabrication methods of porous metals for use in orthopaedic applications	Ryan, G; Pandit, A; Apatsidis, DP	Biomaterials	May 2006	933
10	Self-healing polymeric materials: A review of recent developments	Wu, Dong Yang; Meure, Sam; Solomon, David	Progress in Polymer Science	May 2008	909
11	Metallic implant biomaterials	Chen, Qizhi; Thouas, George A.	Materials Science & Engineering R-Reports	Jan 2015	890

12	Magnetic and martensitic transformations of NiMnX(X=In, Sn, Sb) ferromagnetic shape memory alloys	Sutou, Y; Imano, Y; Koeda, N; et al.	Applied Physics Letters	Nov 2004	883
13	High manganese austenitic twinning induced plasticity steels: A review of the microstructure properties relationships	Bouaziz, O.; Allain, S.; Scott, C. P.; et al.	Current Opinion in Solid State & Materials Science	Aug 2011	822
14	Development of new metallic alloys for biomedical applications	Niinomi, Mitsuo; Nakai, Masaaki; Hieda, Junko	Acta Biomaterialia	Nov 2012	794
15	Magnetocaloric effect and its relation to shape-memory properties in ferromagnetic Heusler alloys	Planes, Antoni; Manosa, Lluis; Acet, Mehmet	Journal of Physics-Condensed Matter	Jun 2009	753

3.2 Reviewing Top Fifteen Journals

There might be many journals to publish a study in any field but choosing a journal that suits your study is crucial. In this part of our study, we listed the top fifteen journals regarding the number of publications in the SMA area (see

Table 2). More than thirty per cent (8179 publications) of comprehensive studies in SMA are published in the top fifty journals. Journal of "Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing" ranked as the most published journal (1178 publications).

Table 2: The top fifteen Journals that published studies in the SMA field along the study period

No	Title of sources	Publications in that field	Country	Impact factor (2020)
1	Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing	1178	Netherlands	4.652
2	Journal of Alloys and Compounds	890	Netherlands	5.316
3	Acta Materialia	693	United Kingdom	7.656
4	Materials Science Forum	646	Switzerland	0.55
5	Scripta Materialia	626	United Kingdom	5.079

6	Smart Materials and Structures	605	United Kingdom	3.613
7	Proceedings of Spie	532	United States	0.45
8	Journal de Physique IV	491	France	-
9	Proceedings of the Society of Photo-Optical Instrumentation Engineers Spie	483	United States	0.45
10	Journal of Intelligent Material Systems and Structures	480	United Kingdom	2.77
11	Applied Physics Letters	335	United States	4.19
12	Materials Transactions	316	Japan	0.731
13	Proceedings of the ASME Conference on Smart Materials Adaptive Structures and Intelligent Systems	306	United States	-
14	Journal of Materials Engineering and Performance	300	United States	1.819
15	Intermetallics	298	United Kingdom	3.398

It has an impact factor of 4.65, according to the 2020 impact factor list. The first 5 top listed journals all have an impact factor above 4.5. The highest impact factor belongs to the journal of "Acta Materialia", which is ranked third in this list (

Table 2) with 693 publications, and it has an impact factor of 7.65. Most of the journals were placed either in the United Kingdom (5 journals) or the United States (4 journals), and the first two were in the Netherlands. The language used in the studies are (~97%) in English, (~1.25%) in Chines, and the rest are divided by other 16 languages.

3.3 Author's Profiling

The number of publications measures the academic productivity of a researcher. Table 3 shows the list of fifteen most active researchers in the past 50 years (1971-2021) listed based on the number of publications in the SMA field of study; H-index, total citation, and citation per study are shown as

well. KAINUMA R acknowledged 280 publications in the SMA field of study; the total citation is 19352. All the top fifteen researchers have 2951 SMA studies, and that is only (~1%) of the whole studies done on SMAs. A comparison between authors in their all publications and their publications in the field of HEA is shown in Figure 2. LIU Y is first in total publication; he has 1596 publications and more than anyone else with 21452 citations. The number of citations evaluates the influence of a research study (Merigó, Pedrycz, Weber, & de la Sotta, 2018). Citation for an investigation is another thing that was considered, listing based on that each of (ISHIDA K, KAINUMA R and MIYAZAKI S) has (45.47, 44.9 and 44.8) citation for each published study that they did respectively. At the same time, ISHIDA K has the highest H-index (71), followed by KAINUMA R who his H index is (69). H-index is H number of studies that each cited by H times or more, where H is the value showed by H-Index; for example, if a researcher's H-index is 8, this means that he/she has at least eight publications that each is cited eight times or more. The mentioned researchers can influence the other researchers in this particular field of study by following their studies.

Table 3: Top fifteen pioneering authors in SMAs along the study period

No	Author	Publication in the field of HEAs	H-index	Total citations	Citations per item
1	KAINUMA R	280	69	19352	44.9
2	CAI W	270	40	7861	19.85
3	MIYAZAKI S	269	62	15186	44.8
4	LAGOUDAS DC	216	54	11284	29.85
5	CESARI E	202	37	6424	23.36
6	KARAMAN I	198	54	10801	28.73
7	LIU Y	186	58	21452	13.44
8	NAM TH	180	30	4070	15.7
9	HOSODA H	179	38	5722	15.96
10	EGGELER G	172	61	15030	37.39
11	ZHAO LC	169	50	10263	19.26
12	CHERNENKO VA	163	41	7179	26.11
13	ISHIDA K	158	71	18688	45.47
14	CHUMLYAKOV YI	157	50	8787	23.31
15	KAKESHITA T	152	39	6496	20.43

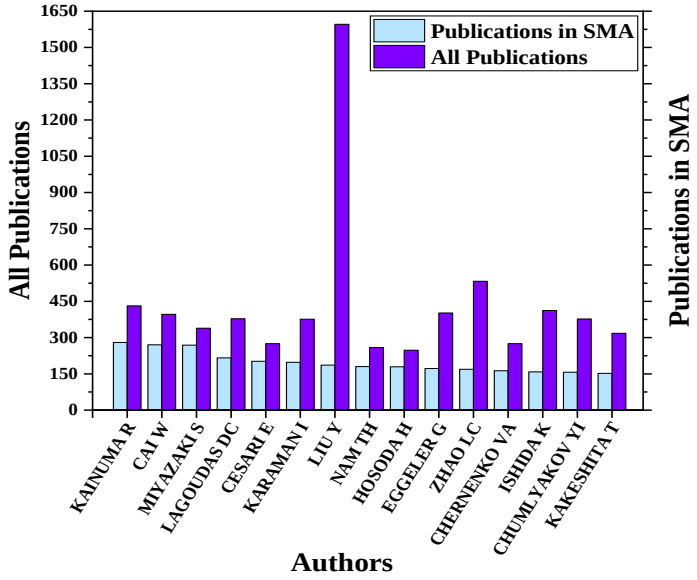

Figure 2: Comparison between authors in their all publications and their publications in the field of SMA

3.4 Countries/Regions with Most HEA Publications

Fifteen countries are listed in Table 4, showing the most productive countries related to SMA studies. The first three countries published (~52%) of the total publication associated with SMAs (1971 and 2021). It can be predicted that China is in the first place of most publishing countries because China's total expense for research and progression has been increasing by 20% per year (Qiu, 2014). SMA field is a very relevant field of study.

Table 4: Most fifteen plentiful countries in SMAs research during the period of research

No	Country	Region	Number of publications	Percentage of total published studies
1	China	East Asia	6062	%22
2	USA	North America	5142	%18.8
3	Japan	East Asia	3266	%11.88
4	Germany	Europe	2240	%8.15
5	Russia	East Europe and North Asia	1492	%5.43
6	France	Europe	1393	%5.07
7	India	South and east Asia	1302	%4.74
8	Spain	Europe	1152	%4.2
9	Italy	Europe	1073	%3.9
10	South Korea	East Asia	992	%3.6
11	Iran	Middle East Asia	801	%2.9
12	Canada	North America	797	%2.89
13	England	Europe	631	%2.29
14	Poland	East Europe	611	%2.22
15	Australia	Australia	531	%1.93

It has applications in most areas, and that's why industrial, technological, productive countries invest in such studies to reach the aimed scopes yearly. The first four countries (China, USA, Japan, and Germany) are the most manufacturing countries with (2010, 1867, 1063, and 700) billion dollars for each, respectively. East Asia region includes (China, Japan, South Korea, a part of India, and some of Iran) published (40.46%) of the publications in the top fifteen countries in 50 years. They were followed by Europe (25.83%) and North America (21.61%) regions, as shown in Figure 3. This country and region productivity opens a door for the new researchers to work in these places to be a part of the progressions and new findings in the SMA research study.

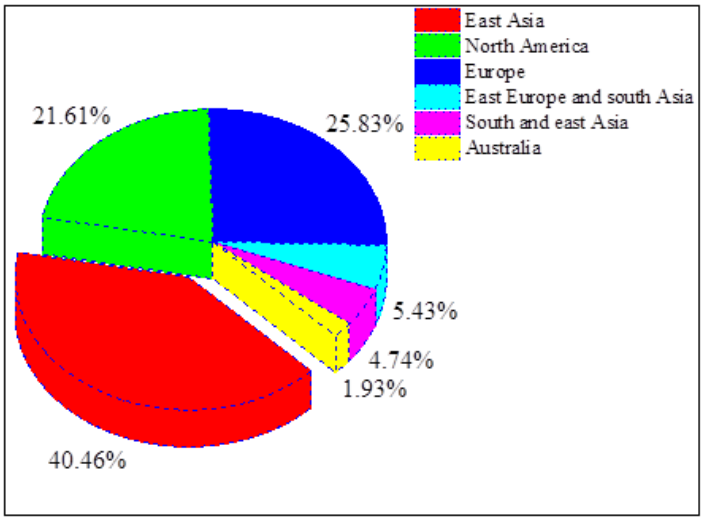

Figure 3: Regions' involvement in the top 15 active SMA nations from 1971 through 5/7/2021

4. Conclusions

The fast progression and recent new findings in the SMA area of study make it crucial for the researchers to follow studies in this field to be continually updated with the current investigations. That's why this bibliographic analysis helps in understanding and familiarizing the new progressions and direct the researchers to the gaps by reviewing the status of SMAs publications internationally over numerous SMAs research domains from 1971-2021. It has been understood that the number of publications increased exponentially, especially in the past two decades; the rise is significant due to the evolutionary development in technology (sensors and actuators). This rising was up except for a slight decrease in 2020, obviously because of the (COVID-19) pandemic and social distancing that the world faced. That's how the highest rate of publication was in 2019. The total investigations done on SMAs between 1971 to 2021 are 27153 studies. The "shape memory effect" is the most common keyword. In this study, the main used language is indicated; English is the dominant language used for the studies scenes 1971 till now with ~97%. The number of citations is also shown; the average of 28.05 citations for a publication shows the attention of researchers for this area of study. The study of "Ti based biomaterials, the ultimate choice for orthopaedic implants - A review" published in 2009 by Geetha, M.; Singh, A. K.; Asokamani, R.; et al. has the highest citations. The core journal that published the highest number of SMA studies is the Journal of "Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing". Among all the researchers in this period studying SMAs, KAINUMA R is the one who acknowledged 280 publications in the SMA field of study.

We have confidence that this study will assist early-stage researchers by helping them first realize the panorama of current worldwide SMA studies and findings. Secondly, classify the potential researchers/institutes to take advantage of the mutual synergistic collaborations. Another portion of this study is categorizing the most productive counties and regions; the first three countries (China, the United States, and Japan) published (~52%) of the total publication associated with SMAs (1971 and 2021). (China, USA, Japan, and Germany) are the first four countries listed amongst the most productive countries investigating in SMAs. In the main while, these countries are the most manufacturing countries. Since the industry is also highly dependent upon recent research endeavours,

this study should take the attention of policymakers in industries to expect future SMAs industrial progress.

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