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# Hot Stamping Research Scenarios from the Last Decade †

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**Abstract:** Hot stamping technology has shown a significant scientific yield in the last decade. The research activity in that field has spread across several disciplines such as materials science, mechanics, process engineering, instrumentation, physics, or part-tool design engineering. Some recent publications have gathered this richness in the format of scientific reviews. This work is aimed to draw a picture of this scientific production in bibliometric terms, which are complementary to the existing reviews. The literature is, in this case, approached from different angles: geographical, collaborative, disseminative, and keyword-based. The first one leads to mapping the share of each region worldwide in advance of the hot stamping technology in terms of scientific production volume. The second angle allows identifying the most productive networks that have been established between institutions and the most influential agents in the field. The third one ranks the most influential journals and events based on citation rates, which indicates where to publish in order to achieve the highest impact. Finally, the fourth approach targets to infer research trends from assessing the keywords employed in the published scientific literature. Altogether, the results show a scenario with Asia as the major player both in volume and networking success, CHS2 as the most relevant event, and exploring alternatives to the conventional AlSi coated 22MnB5 hot stamping as a subject rising of interest.

**Keywords:** bibliometric analysis; hot stamping; press hardening; die quenching

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## 1. Introduction

For three decades, lightweighting has been one of the vectors of development and innovation for the major automotive manufacturers. In this context, the Swedish steelmaker SSAB (Svenskt Stål AB) located in Lulea introduced boron steels in automobiles in the 1980s together with the Swedish car manufacturer Saab [1]. The first vehicle in which these materials were introduced was the Saab 9000, see Figure 1, namely the four door reinforcements (side impact beam).

Boron steels have been known for 50 years and used for their suitable wear resistance. The genius of the steelmaker SSAB, together with the car manufacturer Saab in 1986, was to propose its use in the resistant structure of the vehicles. The major difficulty was to introduce it into the competitive automotive production world, extremely demanding because of the high production speeds and reliability required [3].

The presence of boron in these steels ensures high hardenability [4]. This characteristic allowed the development of an industrial process that (a) starting from a hot sheet in an austenitic state is (b) deformed and (c) tempered to obtain a 1500 MPa piece. The high strength thus obtained is unique; in fact, no cold stamped material can be obtained for typical automotive geometries.

**Figure 1.** First use of hot stamping on a production car. Saab 9000. Side impact beam [2].

Thanks to the increased strength of the material, car designers can design parts with lower thickness and therefore lower weight for the same strength. In the Golf 5, Volkswagen introduced 22MnB5 parts for the first time in the B-pillar subassembly, reducing the weight by 1.5 kg compared to the previous model. The car contains three pillars to support the roof and, therefore, the key to safety in a rollover, with the B pillar being the intermediate one between doors. VW introduced the technology on a massive scale in the Passat B6 model.

The weight reduction achieved at VW in the Passat B6 catapulted the development of hot stamping to the rest of the car manufacturers.

The target for 2020 is for all models to have at least 50% of the body in white made up of hot-stamped parts. This situation is reflected in growth forecasts for this technology, including from Dr. Ralf Hund at the German hot stamping die company Braum Cartec [5], and from J. Schimit, T. Lung (2018) [6], T. Taylor (2018) [7], and J. Fekete, R. Hall (2017) [8]. They all indicate that the number of parts obtained by hot stamping will increase from about 100 million in 2020 to more than 600 million pieces in 2022. Volvo's forecasts indicate that up to 50% of the body-in-white mass may consist of parts obtained by hot stamping of boron steels.

Considering the above facts and, taking into account the interest shown by the automotive industry in this area, the host stamping technology has not only a great but brilliant future.

## 2. Research Methodology

### *2.1. General Background*

As part of a doctoral thesis research project, some sets of data about the hot stamping study area have been obtained. The use of scientific indexed databases such as Web of Science (WoS), Scopus, or Dimensions is really useful to carry out an analysis by means of bibliometric indicators. Using these types of indicators, it is possible to analyze the number of papers per year, per author, by source, and so on. The analysis of the results shows concepts such as the relevance of the hot stamping subject over time, the most relevant authors, the most influential journals, the most active countries working in that area, etc. The entire period covers from the hot stamping origins to the present, but this article shows the results of the period 2009–2019 that include two important reviews, [4,9].

### *2.2. Instrument and Procedures*

This research was carried out using Scopus, a scientific database developed by Elsevier. Scopus was inaugurated at the end of 2004, in November, with the content of 12,850 different journals. The language of reference was English, but it covered more than 30 other languages at the beginning. The database was focused on physical sciences, health sciences, life sciences, social sciences, etc. [10].

Nowadays, Scopus includes, apart from articles, more than 3,700 indexed gold open access journals, more than 210,000 books, and more than 8 million conference proceedings, more than 8 million documents in open access; it also includes articles in press of more than 5500 titles and covers 40 languages.

It covers areas of science, technology, medicine, and social sciences (including arts and humanities). It covers more than 35,000 titles from all areas. Apart from magazines, it has monographic series, conference proceedings, books (emptied at the book and chapter level), or patents (more than 39 million, emptied from five official offices: WIPO, EPO, the United States, Japan, and the United Kingdom). Its temporary coverage is from 1996, although sometimes it reaches 1970. It is updated daily [11].

The research strategy began with the selection of the key terms. In that case, "die quenching", "hot stamping", "press hardening", and "press quenching" were selected. The query shows 2316 documents. After that, only documents in English were selected, 1837 documents. Then, only journal type was filtered, 965 documents. The year 2020 was also excluded, and the result showed 854 documents. Finally, the areas of interest were also selected, choosing engineering, material science, physics and astronomy, computer science, chemistry, environmental science, mathematics, chemical engineering, energy, business, management and accounting, decision sciences, and multidisciplinary. That showed 851 documents.

The search equation is shown below. It was used in July 2020 to achieve the used set of data. For this article only, the results between 2009–2019 have been considered.

(TITLE-ABS-KEY ("Die quenching") OR TITLE-ABS-KEY ("Hot stamping") OR TITLE-ABS-KEY ("Press hardening") OR TITLE-ABS-KEY ("Press quenching")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBYEAR, 2020)) AND (LIMIT-TO (SUBJAREA, "MATE") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "PHYS") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "CHEM") OR LIMIT-TO (SUBJAREA, "CENG") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "MATH") OR LIMIT-TO (SUBJAREA, "MULT"))

### *2.3. Data Analysis*

The main bibliometric indicators included in this research show information about the articles, the authors, their affiliation, country, the journal where the papers have been published, citations, etc.

Considering this information, aspects such as scientific production in the hot stamping area have been analyzed, establishing the most relevant authors and journals. Citations have also been taken into account to show the most important investigators.

Finally, a descriptive analysis has been carried out using VosViewer [12], a software tool provided by Leiden University, to show, using a textual map, the relationships between authors.

## 3. Research Results

Figure 2 shows exponential growth in the interest aroused by hot stamping technology during the last decade.

Figure 3 shows the top 10 productive journals regarding hot stamping technology. Analyzing these results with those related to number of citations per author, it can be concluded that the Journal of Materials Processing Technology is, obviously, the reference journal for hot stamping technology with 57 articles in the last decade that have been cited 3095 times. It is also remarkable the contribution of CIRP Annals—Manufacturing Technology with only 13 publications but 1359 citations. This fact also makes this journal a reference in this field.

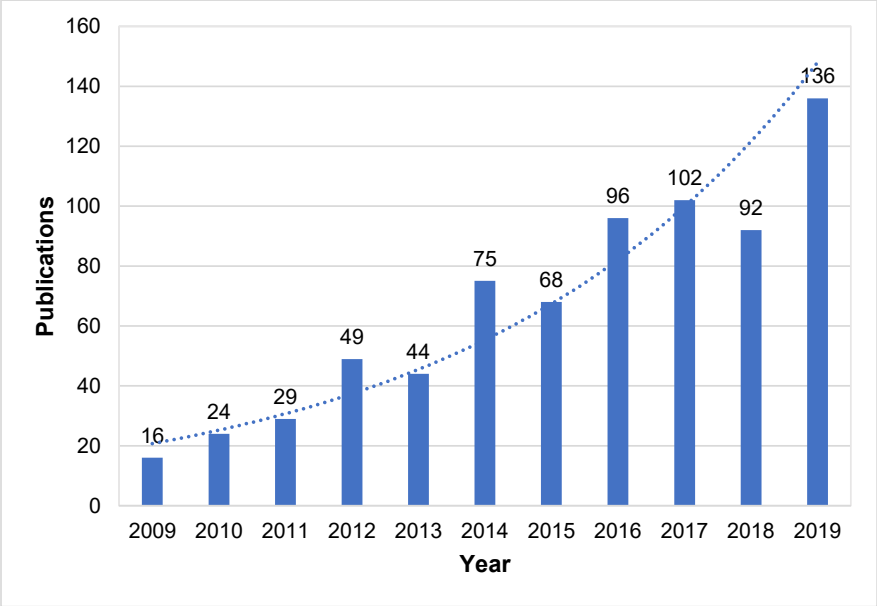


**Figure 2.** Number of publications per year.

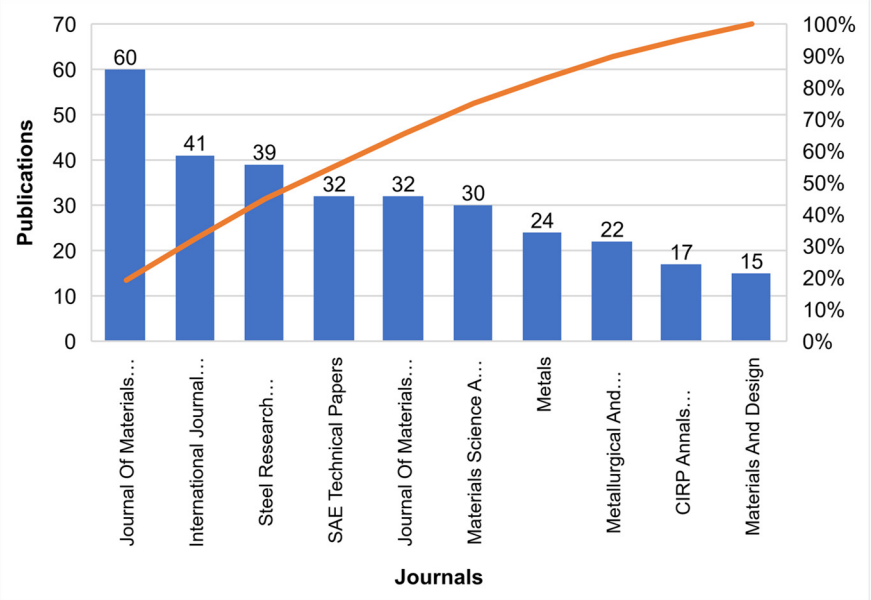


**Figure 3.** Number of publications per journal.

Figure 4 shows the number of publications per year just for the top five journals. It is remarkable the evolution of the International Journal of Advanced Manufacturing Technology, one of the latest to join.

Figure 5 shows the top 10 authors with publications related to the hot stamping area. The most productive researcher is J. Lin, with 31 publications. This data coincides with the Figure 11 statistic, scientific production per country, where China is the most productive country. Top production researchers, such as Merklein, Bruschi, and Ghiotti, are also the authors of the most relevant reviews in the field [2], which indicates that, in hot stamping, most productive authors are also the scientific references.

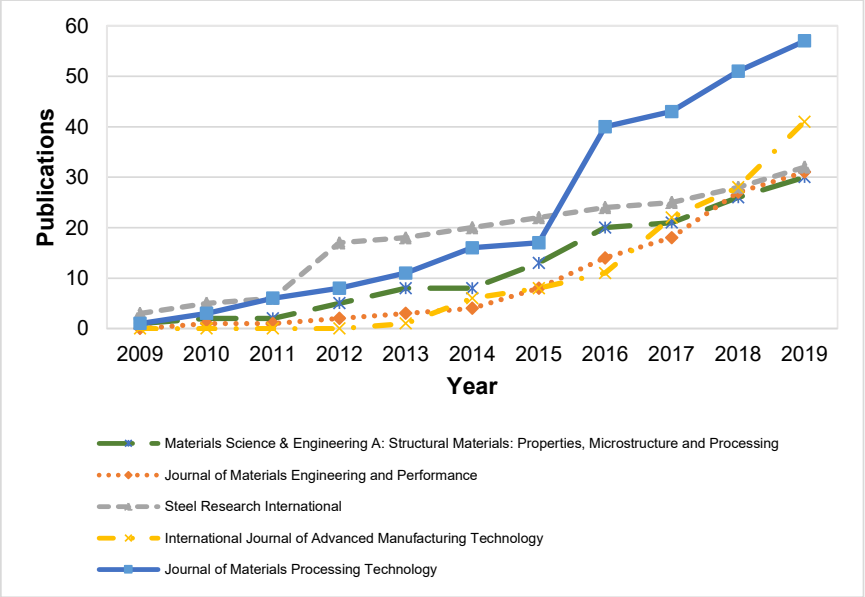


**Figure 4.** Evolution of the number of publications per year and journal.

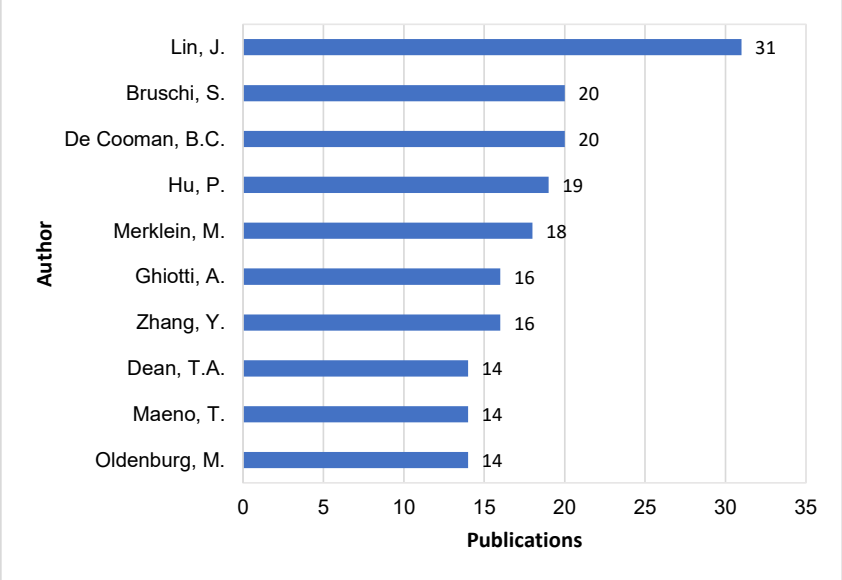


**Figure 5.** Evolution of the number of publications per author.

Figure 6 shows the top 10 institutions with the largest number of published works in the field. The Chinese institutions are, of course, the most productive organizations considering that China is the most productive country as shown below.

Top institutions in hot stamping are mostly universities. It is noticeable that the University of Lulea, the city where hot stamping was born, has kept its bonds to this technology for more than 40 years. Another relevant aspect is the presence of Arcelor Mittal, an industrial agent, in the top publishing entity list. This underlines the applied nature of the research in hot stamping.

Figure 7 shows the citation evolution per year. This graph confirms the results shown in Figure 1 regarding the interest shown in hot stamping technology. Nevertheless, this absolute value does not reflect the actual relevance of citation, such as other factors as the h-index.

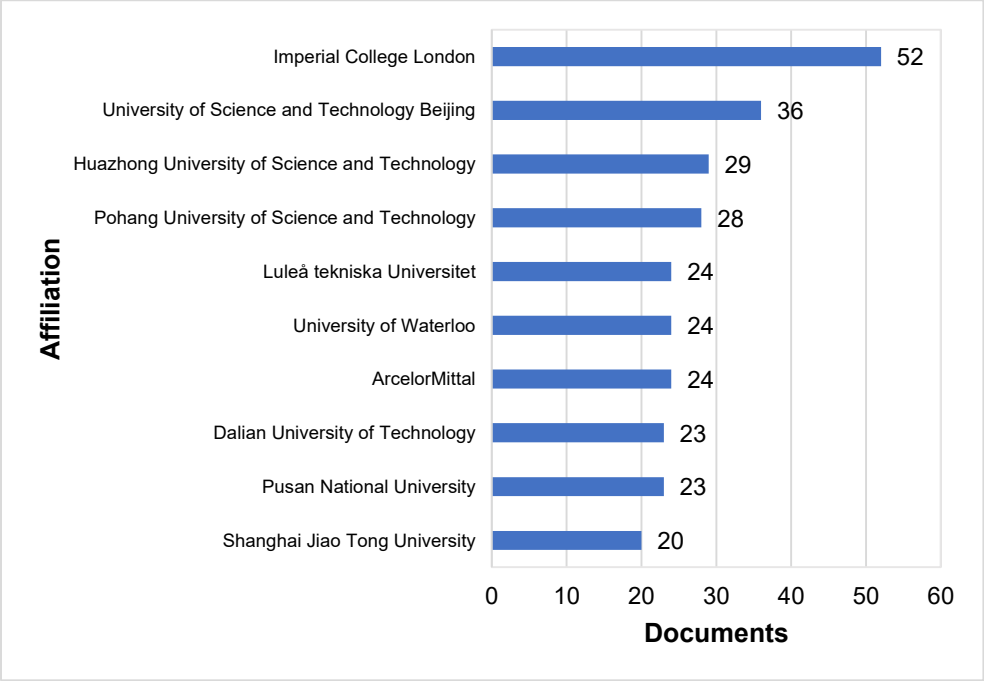


**Figure 6.** Evolution of the number of publications per affiliation.

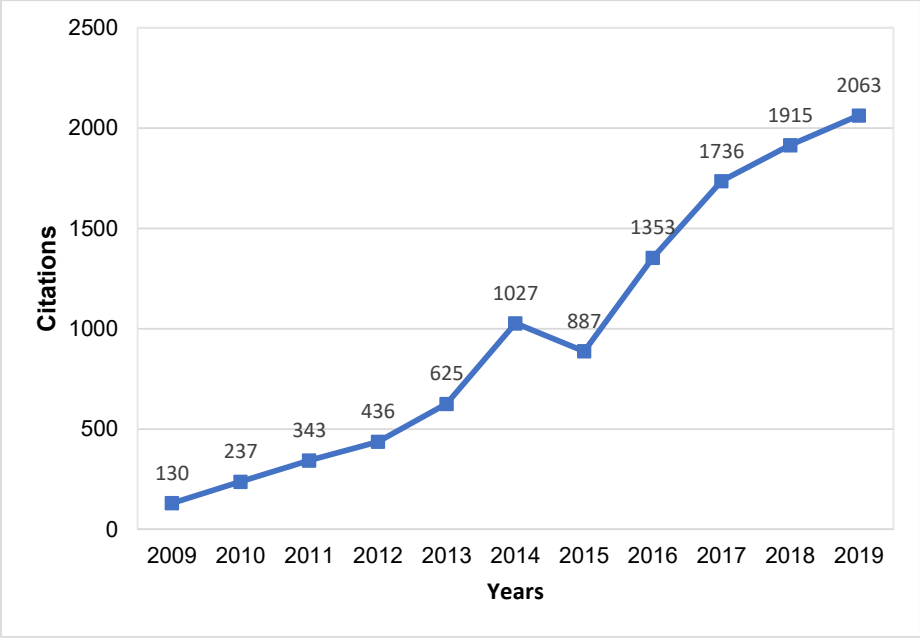


**Figure 7.** Evolution of the number of citations per year.

Figure 8 shows the h-index value established in 53. This means that, between 2009 and 2019, 53 publications have been cited at least 53 times. When compared to a reference technology, such as cold stamping, whose h-index is 30 for the same period, it is evident that hot stamping presents a high interest in the scientific community.

Figure 9 shows the 10 most influential authors who have had the most impact on this topic. H. Karbasian and A.E. Tekkaya [4] are the most cited authors with their review in 2010, followed by M. Merklein and J. Lechler [9] with another review in 2016. Other relevant authors, such as A. Ghiotti and S. Bruschi, were also among the highest production authors.

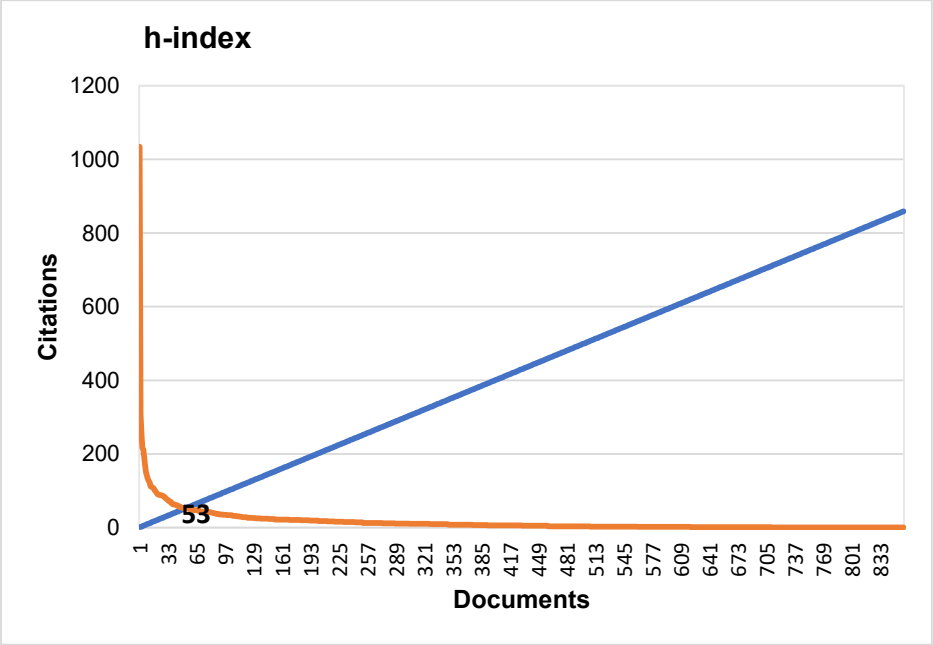


**Figure 8.** H-index.

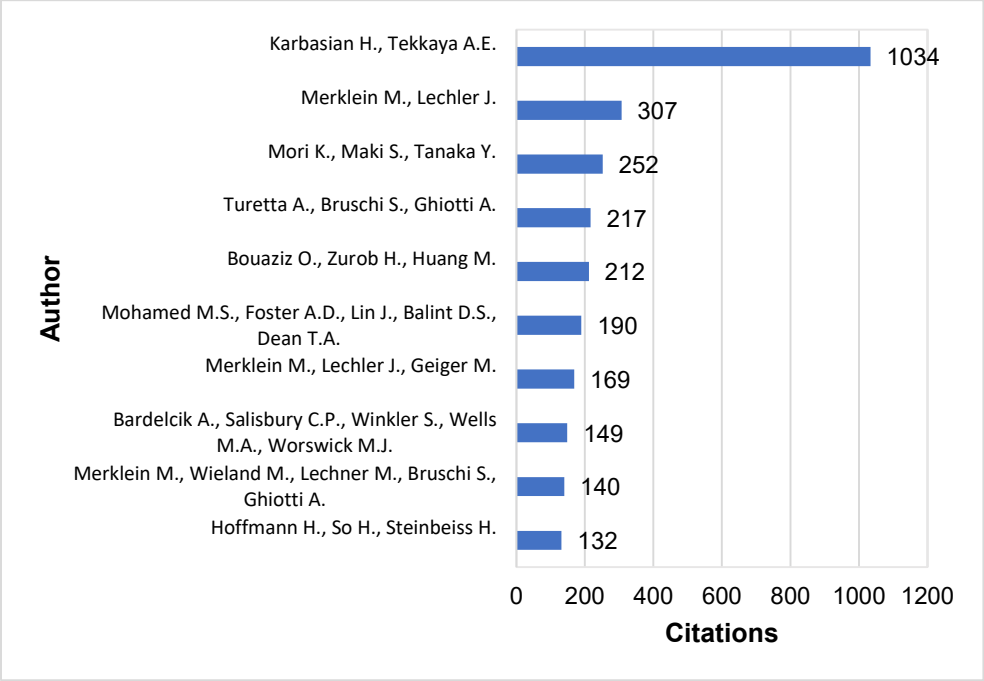


**Figure 9.** Number of citations per author.

Figure 10 shows the number of citations per journal, the Journal of Materials Processing Technology and CIRP Annals—Manufacturing Technology being the most influential in terms of the scientific dissemination of this topic. This observation fits with the list of most prolific journals, meaning that productivity and quality, measured as citations, are related in hot stamping literature.

Figure 11 shows the number of publications per country. The majority of the publications come from China, followed far behind by Germany and South Korea. The USA, together with Canada, constitute a note of research activity too.

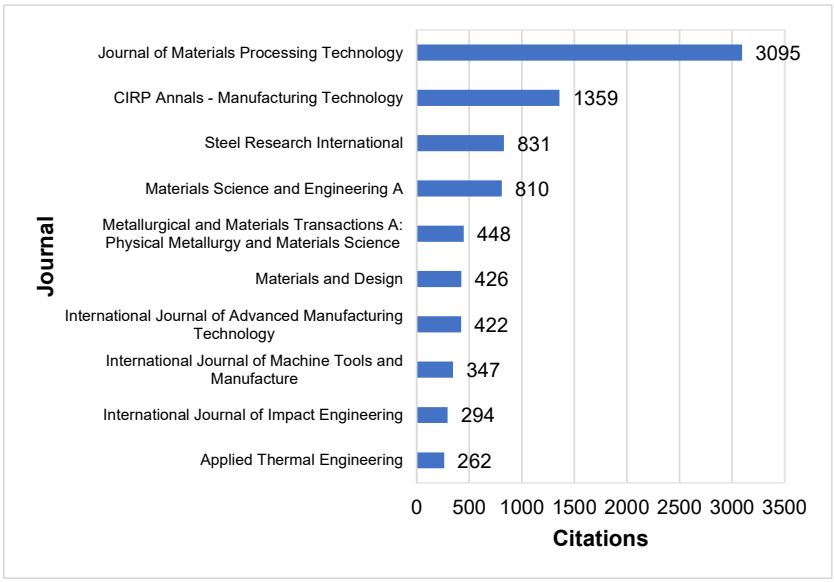


**Figure 10.** Number of citations per journal.

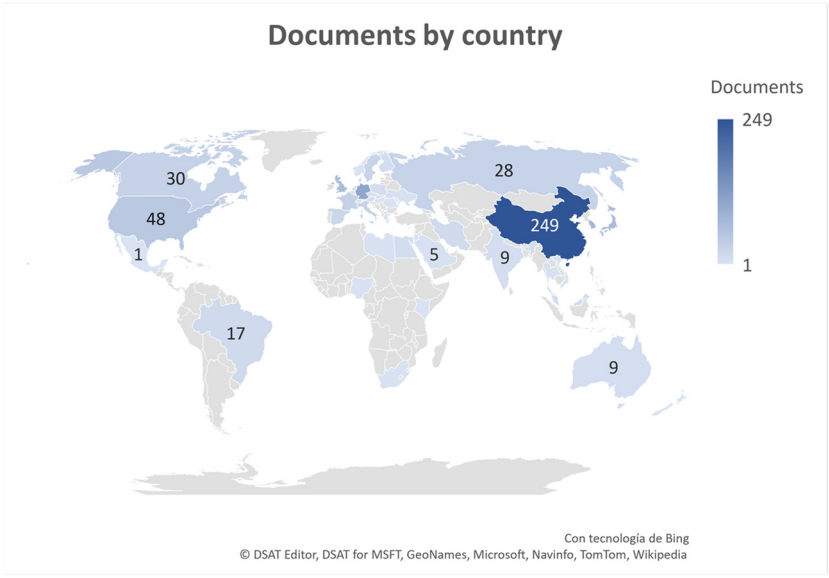


**Figure 11.** Number of publications per country.

Figure 12 shows a network visualization of the author keywords to establish the most relevant of them. There is a total of 207 items grouped in six different clusters. The most relevant keywords can be found in the green cluster with keywords such as hot stamping, stamping, forging machines, etc. It is also relevant to the red cluster with terms such as microstructure, mechanical properties, high strength steel, hardening, etc.

Figure 13 shows a network map visualization of the authors related to the hot stamping technology that have at least two publications. There is a total of 316 authors grouped in 23 clusters. J. Lin, the researcher with most publications in this decade, appears in the pink cluster. S. Brushi, the second relevant researcher, appears in the yellow cluster.

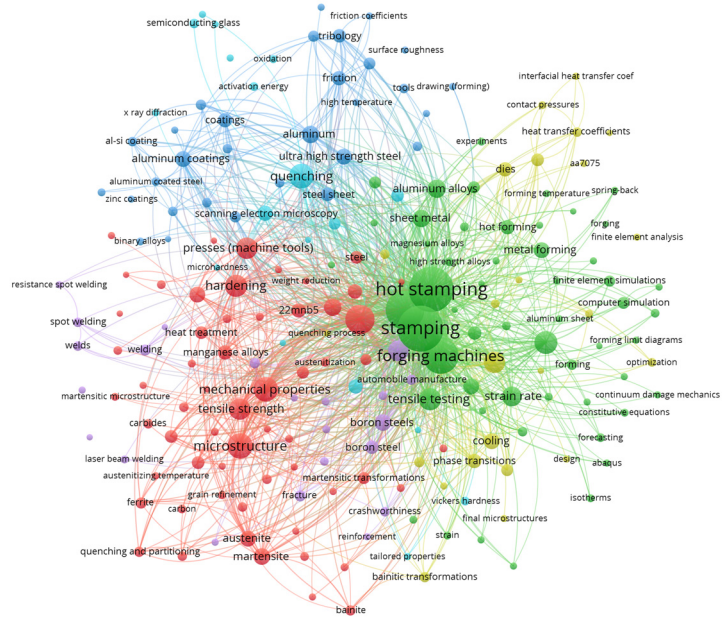


**Figure 12.** Author keywords network.

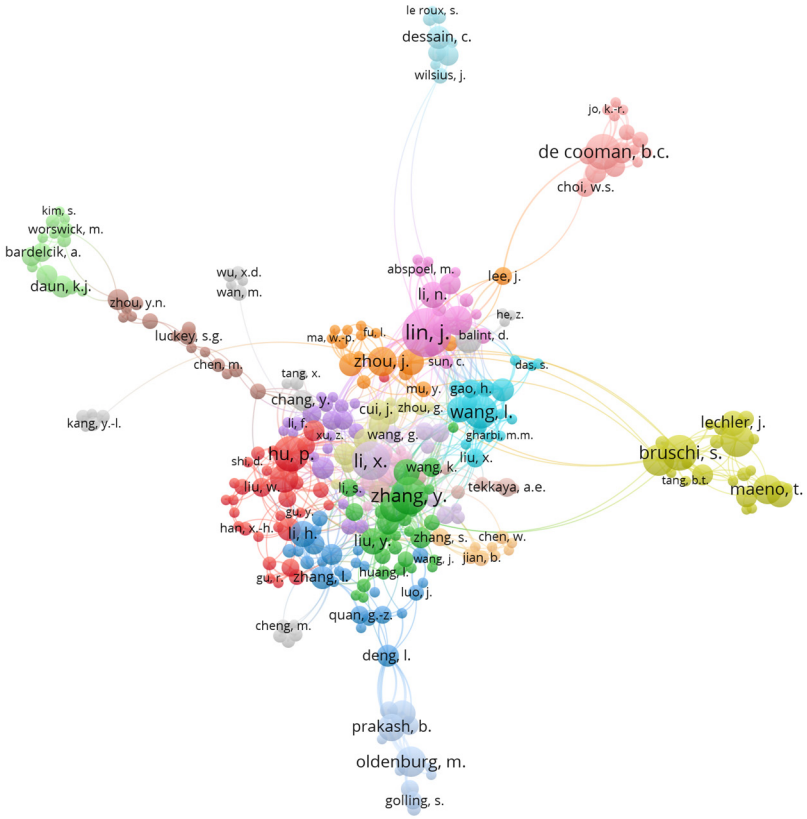


**Figure 13.** Authors related to the hot stamping technology network.

## 4. Conclusions

Taking into account the analyses above, the following conclusions are stated:

- Hot stamping is a strongly evolving technology with an increasing scientific yield and an impact level measured in terms of h-index above its technological competitors, such as cold stamping.

- There is an established set of scientific sources that concentrates most of the production and the citations. The most prolific journals also have the highest number of citations, but regarding the number of citations per number of the total published manuscripts, CIRP Annals—Manufacturing Technology outstands as a high-relevance source.
- The most relevant authors, both measured in terms of their production and their citation volume, are also the references in terms of the key reviews in the field.
- It is noticeable that industrial research in hot stamping appears in the top 10 institutions in terms of scientific production, which points out that it is a relevant industrial driving force for generating new knowledge in the field.
- Geographically, scientific production is concentrated in China, with two further focal points in Europe (led by Germany) and North America (led by the USA).
- Relation graphs show that there are six different thematic clusters in hot stamping research, related to process parameters, material properties, assembling technologies, the quenching process itself, alternatives to steel hot stamping and die cooling.
- In terms of networking, several stable research groups are identified, with a big cluster around the Chinese researchers and several satellites in Sweden, Italy, Germany, the U.K. and Canada.

Thus, hot stamping is a promising and growing technology with a very intense activity powered by industrial interest. It is expected that the already established research teams will keep publishing their results in a reduced number of sources.

**Author Contributions:** For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, L.M.A. and G.A.; methodology, I.P.; software, L.M.A.; validation, L.M.A., G.A. and I.P.; formal analysis, L.M.A. and G.A.; investigation, L.M.A., G.A. and I.P.; resources, L.M.A.; data curation, L.M.A.; writing—original draft preparation, L.M.A., G.A. and I.P.; writing—review and editing, L.M.A., G.A. and I.P.; supervision, G.A. and I.P. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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