Congresso Brasileiro de Engenharia e Ciência dos Materiais
06 a 10 de Novembro de 2022 | Águas de Lindóia – SP – Brasil

A REVIEW ON WEAR OF HOT STAMPING DIES FOR THE AUTOMOTIVE INDUSTRY

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ABSTRACT

Given the growing concern with energy efficiency and the emission of polluting gasses from cars, there is an increase in the production of parts by hot stamping in the automotive industry, aiming at weight reduction combined with mechanical strength and impact. Currently, 100% of the dies for hot stamping used in Brazil are imported, requiring a complete study of their characteristics for subsequent nationalization. Some important properties for the material of hot stamping dies are high values of thermal conductivity, tensile strength, corrosion resistance and hardness, in addition to a low coefficient of thermal expansion and high wear resistance. Hot stamping dies are made from hot work tool steels, with H13 being the most used. It is known that the die-blank system presents complex friction and wear mechanisms with several phenomena occurring simultaneously and/or in rapid succession within the blank-tool contact system. One of the phenomena reported in the literature is the transfer of material from the blank coating to the die, which can cause ploughing marks and other adhesive and abrasive wear marks, thus, the wear behavior is one of the main determinants for the tool life. Although there are several articles studying the process and determining the best materials to be used, an in-depth study of the wear mechanisms acting on hot stamping dies and the determination of adequate tribological tests to make a pre-assessment of their performance is still necessary. In this work, a broad bibliographic review was performed concerning the occurrence of wear in hot stamping dies for the automotive industry. Given the limited number of articles in the area, the survey was extended to processes with similar requests (for example, hot forging). The literature review contemplated the active wear mechanisms and the friction conditions present in the process. The results of this review will serve as a basis for the failure analysis of an end-of-life hot stamping die used to produce automotive components.

Keywords: *hot stamping, die, wear, automotive.*

INTRODUCTION

The end-of-life of hot stamping dies is mainly caused by the wear mechanisms acting during the process, triggered by the thermal and mechanical cycles to which the tool is subjected. Thus, an understanding of these mechanisms and technological intervention on two fronts of action are essential: 1. the development of approaches that minimize the effect of wear, increasing the life of the dies, such as improving their mechanical properties and using coatings with better wear performance; 2. the application of wear monitoring and identification techniques, making the process control more accurate and the prediction of the die´s end-of-life, enabling its on time replacement in the production line.

In this context, the present work presents a comprehensive literature review on wear in hot stamping tools for the production of automotive parts, in order to identify approaches, techniques and developments in the various fields of action associated with this topic, with the aim to guide a failure analysis of an end-of-life hot stamping die used to produce automotive components that will be performed in the Faculty of Mechanical Engineering at UNICAMP.

MATERIALS AND METHODS

The present bibliographic review is the result of a search in the platform Web of Science, performed on July 15th 2022. In order to range the maximum number of documents published, the search options "all databases" and "all collections" were selected in the platform. Also, the option "topic" was selected, meaning that the terms wanted in the search could be within the title, abstract and keywords of the documents and, also, within the "KeyWords Plus" selection generated by the platform (Web of Science chooses the terms of KeyWords Plus from titles in the reference list of the document). In order to constrain the search to the studied topic, the chosen script was chosen as follows: ("hot" and "stamping" and "die" and ("wear" or "wearing") and "automotive"). In total, 17 works matched the search. A network map with the terms and the correspondent co-occurrence links of the search was plotted via the bibliometric software VOSViewer (version 1.6.18). The parameters selected in the VOSViewer were set as default, except for the counting method (binary), number of occurrences (3), number of terms (100%). Each of the works was categorized according to subject, year of publication, research homeland and journal in which it was published. Finally, the content of the manuscripts was examined and discussed in terms of relevance, novelty and trends related to the studied topic.

RESULTS AND DISCUSSION

Review Metrics

Figure 1 shows the year (a), journal (b) and homeland (c) of publication of the searched documents. The period of the search ranges from 2004 to 2022 (18 years). The number of publications per year varies between 0 and 1 for most of the addressed time range. In 2008 and 2015 a slight increase was observed, with 2 papers published in each year. However, in 2017 a considerable increase is seen, with a peak of 5 documents published. In this particular year, the contribution to the abnormal number was made by the publication of a patent (the only document of this kind found in this research) and of 2 papers from the same research group.

By far, the most outstanding journal was Wear (Elsevier), in which 5 papers were published, followed by Hot Sheet Metal Forming Of High-Performance Steel - CHS2 (international conference proceedings), The International Journal of Advanced Manufacturing Technology (Springer Science & Business Media) and Journal of Physics: Conference Series (IOP Publishing), each with 2 publications. In addition, the journals Lubricants (MDPI), International Journal of Precision Engineering and Manufacturing (Springer), Key Engineering Materials (Scientific.Net), Applied Sciences (MDPI) and Journal Of Materials Processing Technology (Elsevier) contributed each with 1 publication in the searched field. It should be noted that the work of Tao (2017)[1] is not included in the graph of Fig. 1.b because it is a patent and, thus, it was not published in a Scientific Journal/Proceeding. The journals

who have the majority of the publications (Wear, CHS2 and Int. J. Adv. Manuf. Technol) are dedicated to fields closely related to the topic studied here, so it was expected that they would become preferential choices for authors. The remaining journals present a broader research scope and may have been chosen for particular reasons by each author/research group.

Concerning the homeland of the publications, Italy is the leader, with 5 publications in total, followed by China, with 3. Both Germany and Sweden have 2 publications each, followed by Australia, Colombia, Russia, South Korea and USA, all with 1 publication each. The leadership of Italia in the publication of the studied topic is caused by a single research group from University of Padua, which has authorship of all the italian papers found in this research. China is responsible for the only patent found in the database.

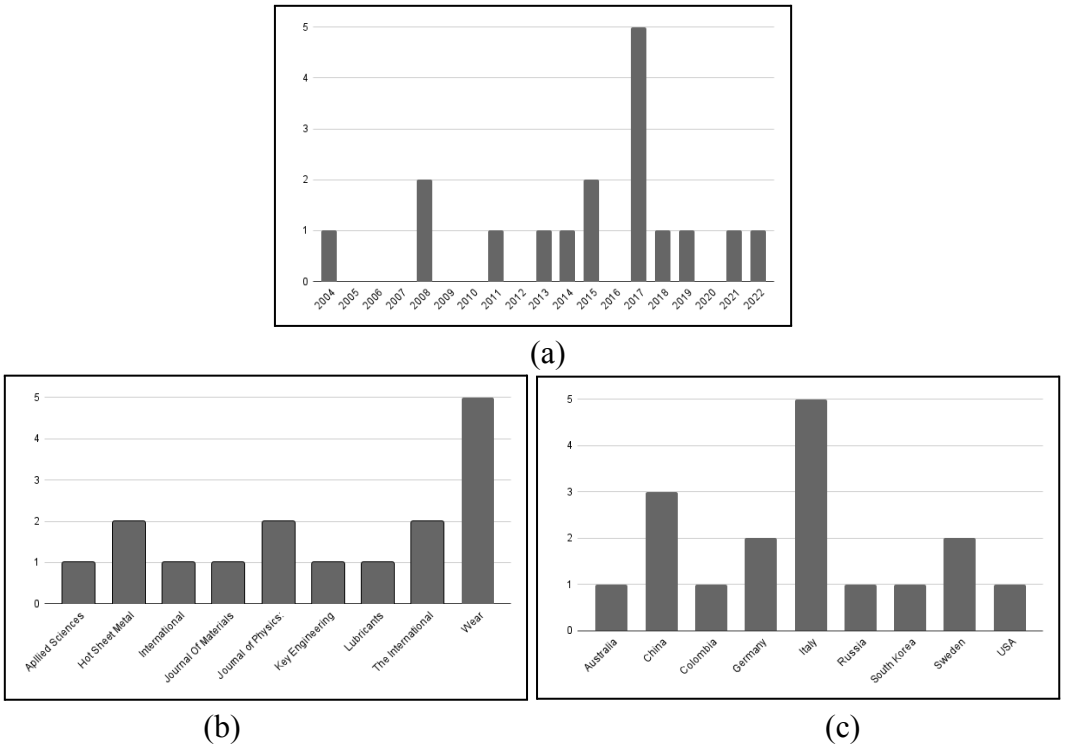

Figure 1. Searched documents classified by year (a), journal (b) and homeland (c) of publication.

Review Content

The first document matching the topic "hot + stamping + die + wear + automotive" available on Web of Science was authored by Wiklund et al. (2004)[2]. It evaluates the surface topography parameters for friction prediction in stamping. After that, other works studied the selection of tool materials and surface treatments for improved galling performance in sheet metal forming[3], galling in forming galvanized advanced high strength steels[1] using the twist compression test (TCT)[4], application of mechanical trimming to hot stamped 22MnB5 parts for energy saving[5] and temperature and contact pressure in hot stamped channels[6].

The University of Padua contributed to the major number of papers in the searched field (total of 5 works). This is the only group research with multiple documents containing the topic of interest "hot + stamping + die + wear + automotive". Their works focus on the influence of die materials on the microstructural evolution of HSS sheets in hot Stamping[7], a novel

approach to wear testing in hot stamping of high strength boron steel sheets[8], comparison of tribological and wear performances of AlSi and Zn coatings in hot stamping of boron steel sheets[9], tribological performances of new steel grades for hot stamping tools[10] and wear onset in hot stamping of aluminum alloys sheets[11].

As seen in Fig. 1.a., 2017 was the year with the largest number of publications. In addition to the two contributions of University of Padua seen above, in this particular year the other works published addressed the improvement of the quality of hot stamping parts with innovative press technology and inline process control[12] and the influence of die temperature on the tribological response during interaction with Al-Si coated ultra-high strength steel[13]. Also, in 2017 the only patent available in the performed search was published, entitled "Automobile panel surface hardening processing method"[1] comprising placing automobile cover with warm water, polishing surface, ultrasound, washing with pure water, drying, immersing automobile cover in treating agent, etc.

The most recent publications (last 5 years) focus on an overview of the advance on friction of stamping forming[14], in-line dimensional inspection of warm-die forged revolution workpieces using 3D mesh reconstruction[15], the thermal and tribological performance of localized laser dispersed tool surfaces under hot stamping conditions[16] and the microstructure and wear resistance of hot-work tool steels after electron beam surface alloying with B4C and Al[17].

Overview

Figure 3 presents the network map of relevant terms and their co-occurrence links based on the research "hot + stamping + die + wear + automotive" at the database Web of Science, achieved via the bibliometric software VOSviewer. Terms that appeared before 2015 are presented in purple and terms that appeared after 2018 are shown in yellow. Terms relative to the period in between (2015 to 2018) appear as a transition between the two extreme colors. The time scale was generated automatically by the software, based on the amount per year and relevance of the terms in the search.

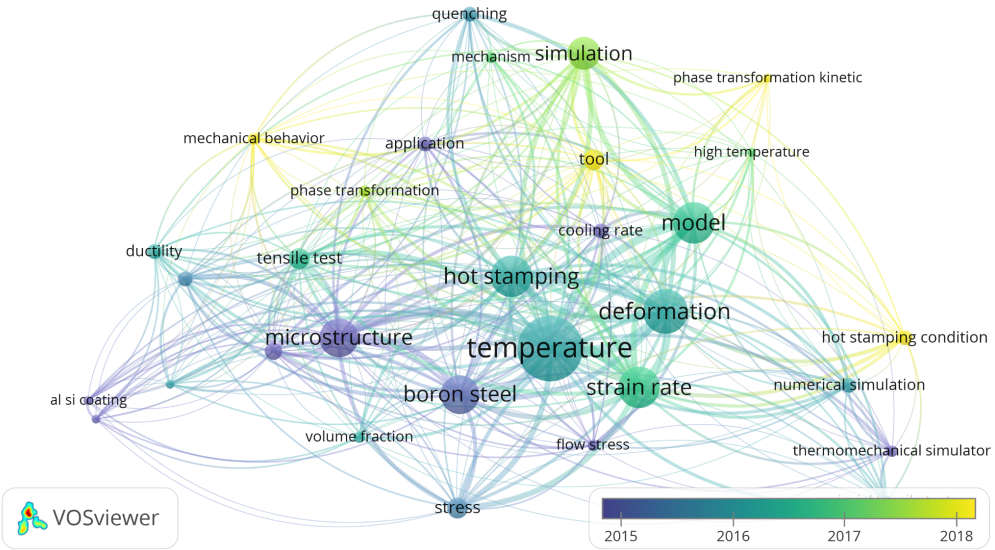

Figure 3. Network map of relevant terms and their co-occurrence links based on the present search achieved via the bibliometric software VOSviewer.

CONCLUSIONS

The subject “hot + stamping + die + wear + automotive” studied in this bibliographic review, even when searched in the most broadly used and highly regarded database that is Web of Science, resulted in a small amount of publications (17 in total) along a broad period of time (18 years). These numbers show the lack of publications concerning a topic of urgent need for research, especially in recent years, when forming processes for automotive parts play a major role in weight reduction and drop in GHG emissions. A single research group, based on University of Padua, is responsible for approx. 30% of the publications on the studied topic, presenting a robust historic on R&D on the field over the years. The journal Wear (Elsevier) represents the preferable choice of authors in the studied field, probably due to the journal´s specificity in this research topic. The repertoire of themes related to the main topic addressed here ranges from the selection and development of tool steels with improved tribological performance, the development of surface treatments, analysis of wear onset, surface topography parameters, temperature and contact pressure associated with friction, the influence of the die tools on the microstructure and surface quality of the stamped sheets, new approaches to wear testing, press technologies and inline process control and dimensional inspection.

ACKNOWLEDGEMENTS

The authors would like to thank the Brazilian research funding agency FUNDEP (Research Development Foundation - Project 27194*27 - Route 2030: Mobility & Logistic for the Future of Brazil, Segment IV: Most Competitive Brazilian Tools) for providing financial support for this study. The authors are also indebted to the Faculty of Mechanical Engineering at the University of Campinas for the practical support very kindly provided.

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