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EMPIRICAL STUDY ON MODELING AND OPTIMIZATION OF THE DUPLEX STEEL MILLING PROCESS: A SYSTEMATIC LITERATURE REVIEW

EMPIRICAL STUDY ON MODELING AND OPTIMIZATION OF THE DUPLEXSTEEL MILLING PROCESS: A SYSTEMATIC LITERATURE REVIEW

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Summary: One of the main production processes used in the metalworking industry is end milling. This technique is used in the manufacture of automotive parts, molds and work tools in general. Duplex steel is a metallic alloy basically composed of 20% to 30% chromium and 5 to 10% nickel, with very low carbon content (less than 0.03%) and with additions of nitrogen, molybdenum, tungsten and copper. Response Surface Methodology (RSM) is a statistical technique used for modeling and analyzing problems in which the response variable is influenced by several factors, the objective of which is to optimize this response. The objective is to present a literature review focused on work that was carried out by modeling and optimizing the steel end milling process using RSM, seeking to identify the evolution of the topic over the years and gaps for improvement. To achieve this objective, the Systematic Literature Review was applied, which is a transparent, scientific and replicable method for carrying out the literature review.

Key words: Optimization; Duplex Steel; RSM; Milling.

Abstract: One of the main production processes used in the metalworking industry is end milling. This technique is used in the manufacture of automotive parts, molds and work tools in general. Duplex steel is a metallic alloy basically composed of 20% to 30% chromium and 5 to 10% nickel, with very low carbon content (less than 0.03%) and with additions of nitrogen, molybdenum, tungsten and copper. Response Surface Methodology (RSM) is a statistical technique used for modeling and analyzing problems in which the response variable is influenced by several factors, the objective of which is to optimize this response. The objective is to present a literature review focused on work that was carried out by modeling and optimizing the steel end milling process using RSM, seeking to identify the evolution of the topic over the years and gaps for improvement. To achieve this objective, the Systematic Literature Review was applied, which is a transparent, scientific and replicable method for carrying out the literature review.

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1INTRODUCTION

End milling is a versatile machining method that uses a rotating cutter to remove material in a linear or circular path, resulting in smooth, precise surfaces (SHAW, 2005). As such, it has become important in industries including aerospace, automotive and injection molding, where precision and surface finish are crucial. The end milling capacity of
Producing parts with high precision and surface finish has made it indispensable in the production of high quality mechanical components (SHAW, 2005).

Monitoring allows early detection of variations or deviations in processes. This is critical for quickly identifying problems and taking corrective action before they cause defects or failures.

The experimental approach allows you to identify and optimize the factors that most affect the quality and performance of products and processes. This is fundamental to achieving higher levels of quality and efficiency (MONTGOMERY; 2000). It is also important for saving resources, decision making, innovation and product development, identifying the causes of problems, statistical process control, research and development, risk reduction and continuous improvement.

Response Surface Methodology is a statistical approach that aims to optimize complex processes and systems through structured planned experiments. Myers, Montgomery and Anderson-Cook (2016) define MSR as "a set of statistical techniques for modeling and analyzing complex responses and often non-linear as a function of controllable variables".

Considering the context presented, this systematic literature review aims to identify gaps in knowledge about modeling and optimization of the milling process in duplex steel, in addition to evaluating the state of the art on the subject through a replicable and transparent process.

The next section presents the method used to select works for the literature review. Then, the information collected is analyzed and the results presented and discussed. Finally, conclusions are presented.

twoMETHODOLOGY

Given the investigative nature necessary to fulfill the objective of this work, the research method chosen was the Systematic Literature Review (SLR), since, according to Tranfield et al. (2003), this method is the most suitable for gathering evidence in a transparent, scientific and replicable way, producing robust results and allowing the researcher to map the stage of knowledge in a given area. According to Khan et al. (2003), what differentiates the systematic review from the traditional ones is its explicit and

methodical, and its application can be conducted by identifying relevant works, summarizing, systematizing and interpreting the results.

To carry out the searches, different combinations of terms were tested until the most consistent result possible with the topic sought was obtained. Finally, the final search was carried out using the terms*Response surface methodology; Optimization; Steel shaping; End milling;Duplex steel*, filters were applied to select only articles in the areas of Mechanical, Industrial, Manufacturing and Metallurgy Engineering, between the years 2013 and 2023. In the database, the search for terms was carried out in titles, abstracts and keywords as shown in Table 1 .

Table 1 –Basic filters and search strings

Keywords	**Criterion**	**number of publications**
Response surface methodology AND Optimization AND Steel shaping AND End milling AND Duplex steel	Year 2013 - 2023 Free access Areas: Mechanical, Industrial Engineering, Metallurgy and Manufacturing	161

Firstly, a search was carried out in the Web of Science database, which was chosen because it unifies and enables the acquisition of works for analysis, in which 161 articles were collected. This set of works was called initial sample. Next, a screening process was carried out to remove articles from the sample that were not properly aligned with the scope of this research. After reading the titles and abstracts of each of the 161 articles, 76 works were discarded that did not meet at least one of the following criteria: Working material must be Duplex Steel; Process must be end milling; Process modeling must be carried out using the Response Surface Methodology.

Some articles were discarded from the initial sample because they studied other processes, materials, were inconclusive, were available in their entirety for free access, had not been reviewed or were incomplete. Due to these factors, 34 articles were removed at this stage, resulting in 51 remaining articles.

The last phase was the refinement of the sample, in which the articles were read in detail, in order to identify the main aspects of the research, focusing on the

collection of input parameters and respective levels selected by researchers, as well as the response (or output variable), experimental designs and optimization methods. Thus, the number of 46 articles in the final sample was reached, as shown in Table 2.

Table 2 – Exclusion criteria for publication screening

Article selection	Exclusion criteria	Number of articles excluded
Outside the research area, Screening: Titles; abstracts,keywords and citations.	Other processes; inconclusive; paid; incomplete	76 34

All stages of this search, screening and sample refinement process were carried out based on concepts adapted from the PRISMA method (Key Items for Reporting Systematic Reviews and Meta-Analyses). PRISMA is a checklist consisting of 27 items and a flowchart that seeks to guide researchers in conducting and presenting systematic reviews (MOHER et al., 2009). Figure 1 summarizes the four phases of the sample collection and refinement process.

The final sample will be analyzed using qualitative and quantitative approaches. Bibliographic techniques will be applied to statistically describe the sample regarding the evolution of publications over the years and the main journals in the area. These descriptive statistics will be carried out with the support of MS Excel software. Next, an analysis of the content of the articles will be presented, summarizing the main aspects and materials used in these research works. Finally, and most importantly, the main factors, levels and responses identified in the literature will be presented.

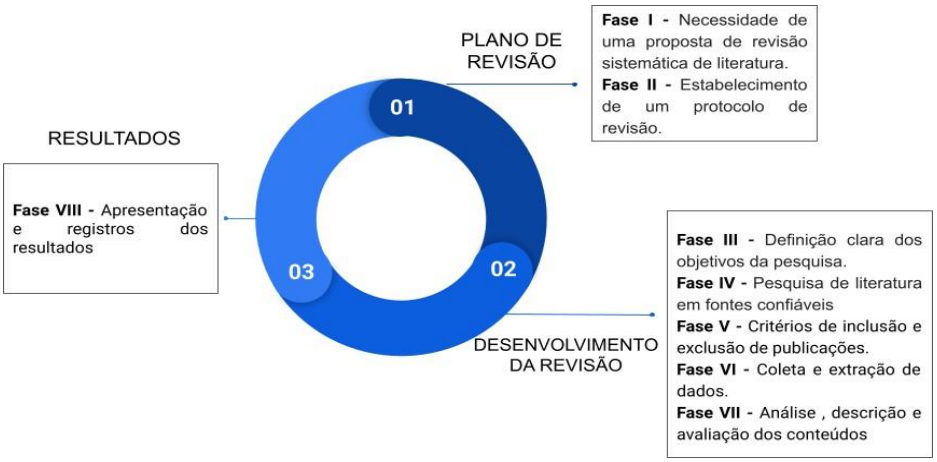

Figure 1 - Systematic literature review protocol adapted from Moher*et al* (2009).

3RESULTS AND DISCUSSIONS

3.1 Bibliometric analysis

To conduct this analysis, a sample study was initially carried out based on bibliometric techniques. The evolution of the number of publications per year shows that, from 2016 onwards, there was an increase in publications on the topic, with emphasis on the years 2020 and 2021, in which important works were published in the area, such as articles by Pimenov (2021) and Glasin (2020), according to data presented in Figure 2.

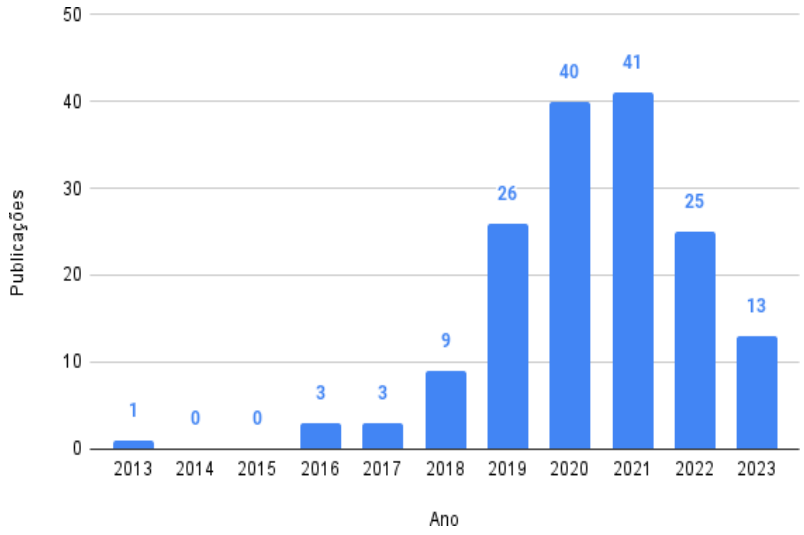

Figure 2 - Evolution of publications 2013/2023.

Approximately 17% of the published articles in the sample related to the study on Modeling and Optimization of the Duplex Steel Milling Process were Indian, followed by England with 17.05%, Russia with 11.20% and China with 8.03%. Brazil appears with three publications in the sample, which means 0.78% of publications, demonstrating that in Brazil there is still a great possibility of the topic being explored, as described in Figure 3.

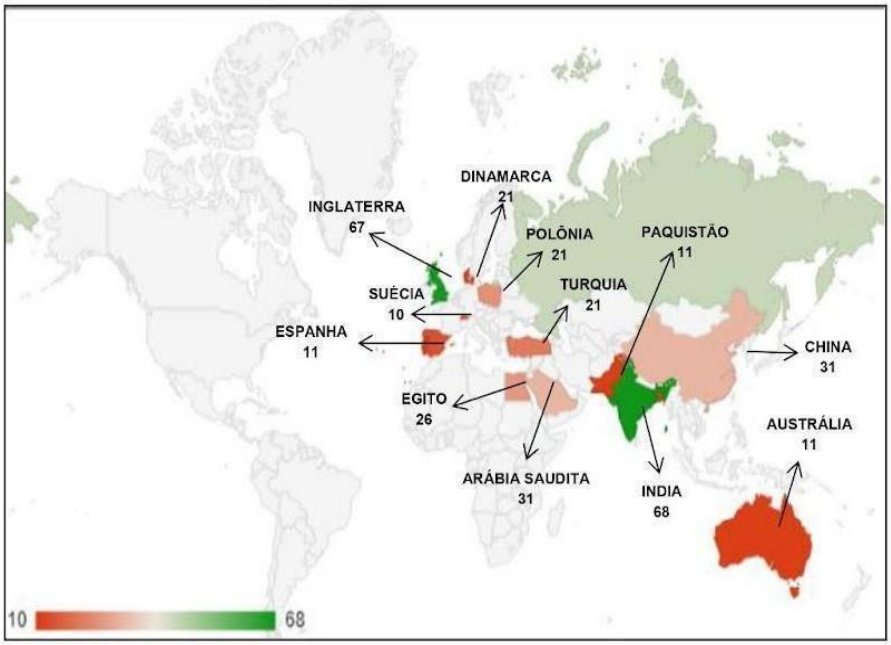

Figure 3 - Distribution by regions of publications.

Furthermore, the areas of engineering and technology with the highest number of publications were found, namely:*Materials Science Multidisciplinary, Metallurgy Metallurgical Engineering, Physical Chemistry, Applied Physics Machines, Condensed Matter Physics, Mechanical Engineering, Mechanics, Engineering Manufacturing, Thermodynamics and Industrial Engineering*according to the classification of publication areas in the Web of Science, as shown in Figure 4.

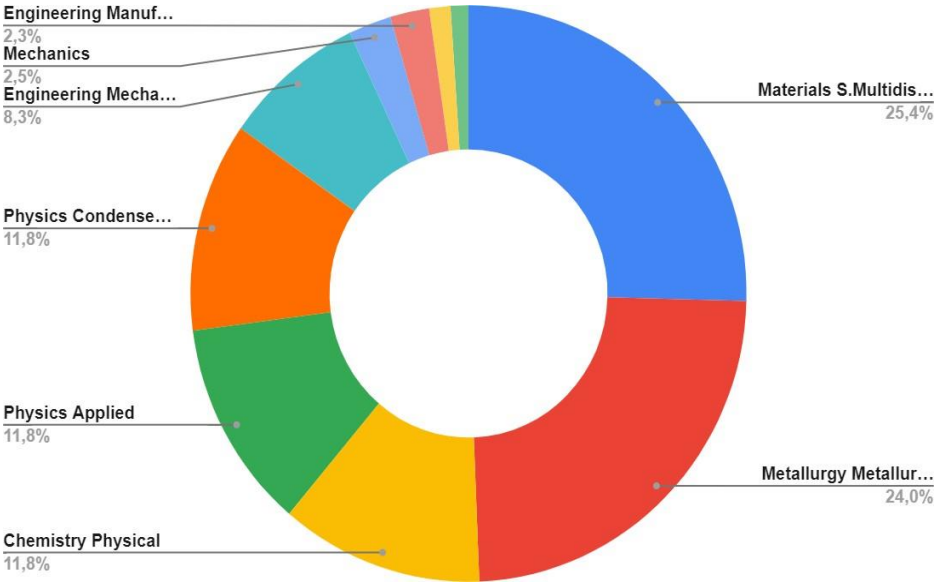

Figure 4- Areas of publications according to Web of Science.

The ranking of the ten most cited articles considering the final sample, as seen in Figure 5, demonstrates that the most cited work was that of Pimenov (2021), in which the author analyzed the behavior of titanium alloys for the turning, milling, drilling and grinding, and the answer to how the type of cooling impacts surface integrity, including surface roughness, tool wear, tool life, temperature, cutting forces, environmental aspects, as well as the disadvantages of different types of cooling. The analysis of these two graphs presented is important to identify the works that have been most cited in recent years.

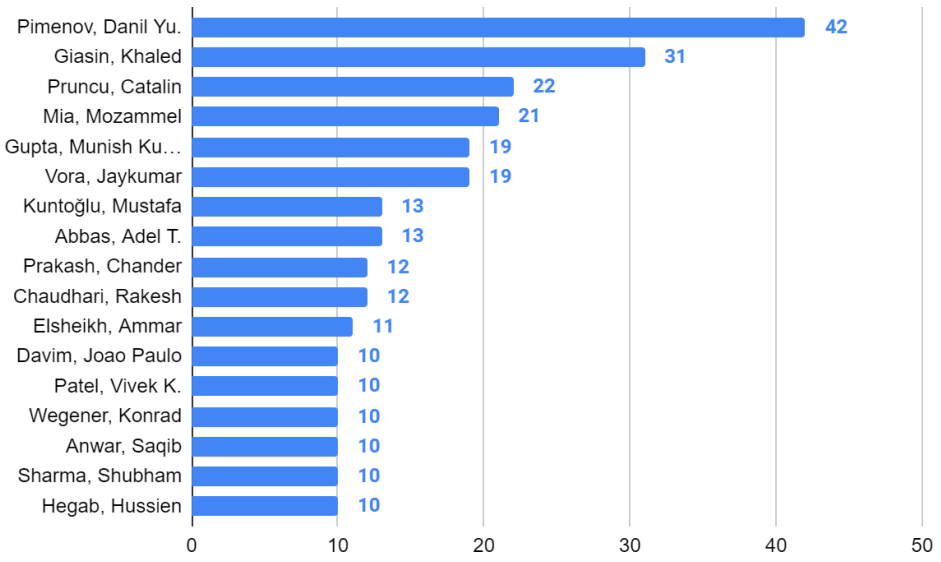

Figure 5 - Most cited authors in the sample.

Finally, in the last analysis, Figure 6 lists the six main journals with the most publications on the topic.

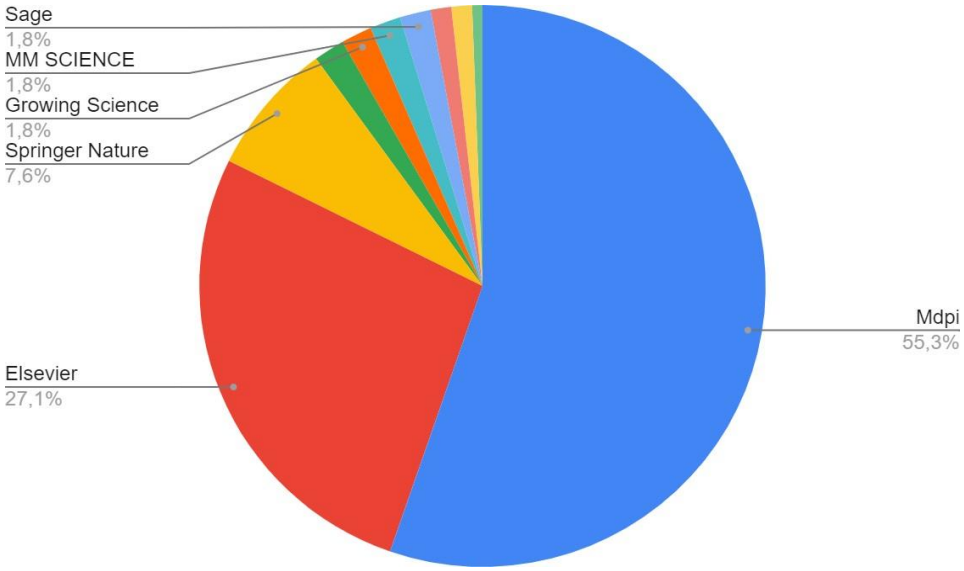

Figure 6 - Databases with the largest volume of publications in the sample.

3.2 Content analysis

The end milling process is widely used in industry for a variety of applications. Each application requires a specific cutting tool, a specific material and a procedure that meets those needs. The works that make up the final sample also feature a variety of tools and materials. Likewise, each work uses some type of experimental design and some optimization method. The objective of this section is to investigate how this variety is distributed, that is, what types of materials, tools, etc. are distributed. There are several types of steel on the market and in the works included in the sample it is possible to identify several different chemical compositions. Table 3 presents the different types of steel used in the sample.

Table 3 –Materials used in the experiments

Classidication	Type	Reference
Mia; Gupta; Lozano; Carou; Pimenov; Krolczy; ; Dhar; (2016)		
Leagues	Ti-6Al-4V; Nitinol;	Gupta; Soood; Sharma,(2016) Chaudhari; Vora; Prabu;Palani; Patel; Parikh; Lacalle. (2021)

High Speed Steels	Molybdenum: T11301,11302,11304,11335,11342,11362 Tungsten: T12015,12001	Kuntoglu; Aslan; Pimenov; Usca; Salur;Gupta; (2020) Mikolajczyk; Giasin; Kaplonek; Sharma. (2021)
Steel	EN 24T	Mia, M; Dhar, N.R. (2016)
Vora; Pandey; Dodiya, Stainless steel	SS-309L; SS316L	Patel; Khanna; Vaghasia; Chaudhari.(2023)
Mixture Macroscopic	Metal Matrix Composites (MMCs)	Salur, E; Aslan, A; Kuntoglu, M; Gunes, A;Sahin, OS (2020) PHILIP; CHANDRAMOHAN; RAJESH, 2015 OLIVEIRA et al., 2020
Stainless steel	Duplex Stainless Steel	

Regarding the experimental designs used by the authors, it is observed that the most used designs are the Response Surface Methodology (MSR), as shown in Figure 7. Planning data collection is an important stage in this type of research. Defines the number of tests to be carried out, as well as each experimental design providing a certain level of precision in modeling.

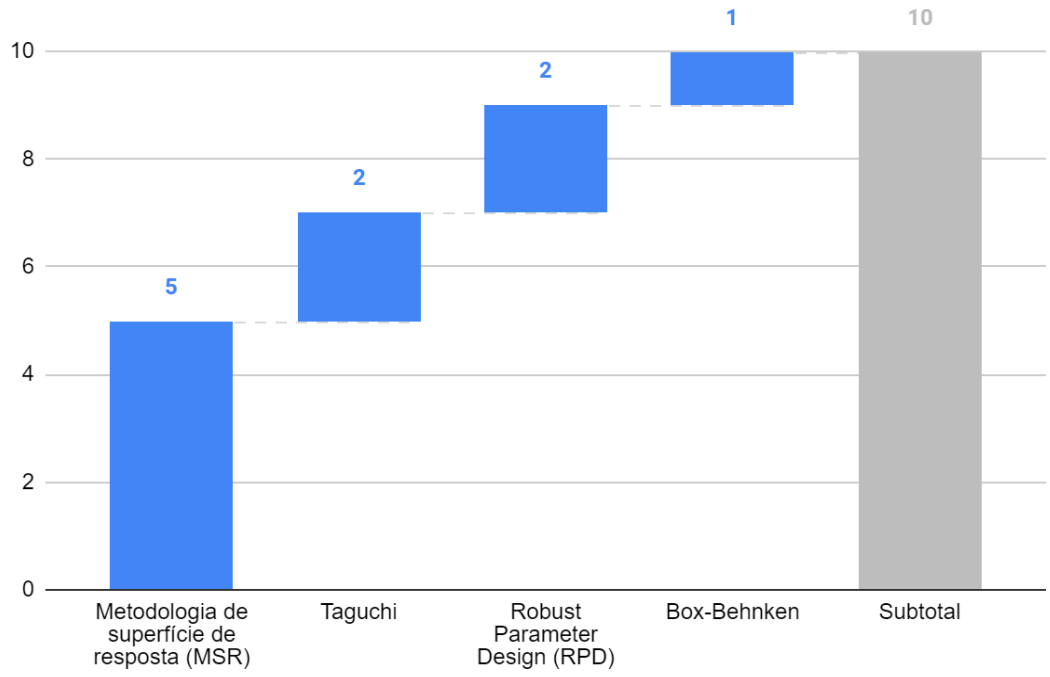

Figure 7 - Experimental designs used in the sample articles.

4CONCLUSIONS

This systematic literature review aimed to identify gaps in knowledge about Modeling and Optimization of the Duplex Steel Milling Process and evaluate the state of the art on the subject through a replicable and transparent process.

The objective was to evaluate the state of the art of Modeling and Optimization of the Duplex Steel Milling Process from descriptive, bibliometric and content perspectives. These analyzes were conducted to highlight trends, methods, impact of publications, growth monitoring on the topic and main authors. It was therefore verified that the studies were applied in different areas of knowledge, but with a predominance of the Industrial, Manufacturing and Mechanical areas.

One can also verify the possibilities for advancement in the topic in Brazil with its low volume of research on Modeling and Optimization of the Duplex Steel Milling Process, as well as the use of the method in growing areas such as “Industry 5.0” which in recent years For years it has been discussed and highlighted as a form of “return to the human” for the means of production.

This literature review has the following limitations: The title and abstracts obtained in Screening 1 were insufficient to reveal all the characteristics of a study, which may have influenced the articles included. Furthermore, the results discussed are generalized, as it is a sample of the existing literature.

Additional studies could explore new production systems, such as additive manufacturing, green and sustainable manufacturing, cleaner production and non-manufacturing applications, such as service and health systems.

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