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Editorial

Machining: State-of-the-Art 2022

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1. Introduction and Scope

Although additive manufacturing is gaining prominence in the market, many applications require very high levels of precision, which are currently not attainable by additive manufacturing [1]. Consequently, research in the field of machining continues to be highly vigorous [2,3], as evolution can take place towards the use of hybrid manufacturing processes, which complement additive processes with subtractive processes [4]. Given that machining processes themselves have already been explored in terms of the phenomena to which they are related, as well as machining trajectories, the aspects related to sustainability, the tools used in advanced materials and the study of their wear phenomena have recently been deeply explored [5,6]. In fact, increasing tool life is a matter of economic and environmental sustainability, as it increases the useful machining time of each piece of equipment and reduces the ecological footprint, due to the lower rate of energy consumed and the reduced need to recycle worn-out tools. This Special Issue intends to bring together some of the best works conducted on machining published in 2022 and 2023. Specifically, it aims to provide comprehensive and in-depth reviews that enable new researchers to quickly and efficiently familiarize themselves with specific subjects. By compiling and presenting the results of numerous prior publications in a condensed and well-structured manner, this initiative facilitates access to a substantial amount of information within a short timeframe. However, the investigation of new coatings for tools and even the study of models for the quick budgeting of machining processes have also been taken into account in this Special Issue, which aims to constitute a very interesting piece of work for all those who investigate machining processes.

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2. Contributions

This Special Issue has eleven contributions, five of which are reviews of current issues that deserve particular attention. Two of the articles are essentially focused on models for the management of machining processes, with a view to quickly organizing budgeting processes. The remaining articles are essentially experimental studies, with a view to determining better machining parameters, extending the useful life of tools or studying the wear phenomena that affect tools.

The first review focuses on an extremely important issue: the sustainability of tool-cooling processes during machining [7]. CO_2 is often used for cooling tools during machining processes and is included in cryogenic cooling machining processes. Given that CO_2 does not constitute an added threat to the environment, its use can significantly reduce the wear of tools whose wear mechanisms are particularly associated with the temperature developed during the process. It is clear that cryogenic machining has added advantages over other tool-cooling processes, such as flood cooling, MQL (minimum quantity lubrication) or ADL (aerosol dry lubrication). This review allows readers to gain a quick understanding of the advantages of using CO_2 in the cryogenic machining of different materials, as well as in establishing the best manufacturing parameters when this cooling technique is adopted.

The issue of sustainability associated with the lubrication and cooling of tools and material to be machined is also addressed in the second review presented in this Special Issue [8]. Additionally, the review considers the surface finish quality achieved through the machining process. By examining these aspects, the review contributes to a more comprehensive understanding of sustainable machining practices, emphasizing the need to balance environmental concerns with achieving the desired production quality. Indeed, the drawbacks usually brought about by the use of mineral-based oils are well known, and there are already solutions based on vegetable oils that can be used as an alternative. However, these solutions still present considerable limitations, namely the amount of fluid that is required, the quality of the surface obtained using the process and the tribological aspects related to tool wear. These limitations are conveniently described and analyzed, allowing readers to understand that this solution still does not present a higher performance when compared to mineral-based fluids. However, this review also dissects nanofluids, which have very interesting properties in thermal and physical terms; however, research efforts will be necessary to make this solution more economical.

The need for increasingly demanding properties on the part of the market has led to the development of new solutions in terms of materials, which now have a new range, called fiber metal laminates (FMLs) [9], with concerns in sustainability. The market's growing demand for materials with increasingly stringent properties has driven the development of new solutions. One such solution is the emergence of fiber metal laminates (FMLs) [9], which offer a novel range of properties.

The review work presented in this field is quite comprehensive, reviewing the manufacturing processes of these multi-materials, and subsequently analyzing the challenges presented by the machining processes, when applied to this specific case. Indeed, the combination of different materials leads to the existence of interfaces and the need for tools to be prepared to jointly machine materials with significantly different properties. These factors pose challenges that are difficult to overcome, a fact that has given rise to numerous studies with a view to understanding the scale of these challenges and finding increasingly better solutions to overcome them. In that work, the parameters that best correspond to the requirements imposed by this type of material are also studied, as well as a SWOT analysis that aimed to bring together the trends in terms of the strengths, weaknesses, opportunities and threats found in the different analyzed works.

This Special Issue also includes a review article that compiles previously dictated work on the integration of additive processes with subtractive processes [10]. Effectively, there are still problems in obtaining surface finishes in additive manufacturing that are compatible with the needs of contact and relative movement existing in many applications. Thus, the so-called hybrid manufacturing processes have gained prominence in the market, starting from additive manufacturing, and ending with subtractive manufacturing (machining or other similar techniques), with a view to obtaining the necessary final precision and finish quality. In an attempt to reduce the need to use multiple pieces of equipment and transport parts between these same pieces of equipment (internal logistics), there is a strong tendency for additive and subtractive operations to be performed using the same piece of equipment. The work develops each of the technologies, describing the advantages and limitations of each one and the integration of both processes.

Another review included in this Special Issue is related to the machining of INCONEL [11]. In fact, the problems related to the machining of INCONEL are known, due to its high mechanical resistance and problems of conduction of the heat generated in the contact. This review, based on many consulted articles, covers what has been recently published on this subject, presenting the data in a structured way, as well as some SWOT analyses that allow the readers to quickly and concisely understand the main challenges imposed on the machining processes of nickel alloys. Moreover, this study also extends the analysis to non-conventional machining processes, allowing a wider perspective of the difficulties and current solutions in machining some hard-to-cut metallic alloys.

Within this Special Issue, two additional research articles focused on the INCONEL alloy are included. These articles delve into the study of tool life, investigating the wear mechanisms involved and identifying parameters that contribute to a prolonged tool lifespan and enhanced efficiency when machining this alloy. One of the papers [12] studies the wear mechanisms of tools coated with TiN/TiAlN via PVD, using the HiPIMS technology, which provides greater adhesion of the coatings to the substrate. It is a double coating, with a first layer of TiN to ensure optimal adhesion to the substrate, and a complementary layer of TiAlN, which has shown remarkable tribological properties in terms of wear resistance in machining operations. The study was conducted based on milling operations. The main objective of the study was to analyze the failure mechanisms of these coatings, concluding that there is abrasion, material adhesion, cratering and adhesive wear. Another work, not using solid coated tools, but polycrystalline cubic boron nitride (PCBN) inserts, studied the influence of two different binder phases (TiN and TiC) on the performance of tools in turning operations of INCONEL 718 alloys [13]. The work revealed that the turning process is sensitive to the cutting speed established for the process, also revealing that the different phases induce different wear mechanisms in the tools. It was also proved that the TiN phase presents a better performance than the TiC phase, also presenting a greater consistency in terms of the final result achieved in the machining process.

Another work presented in this Special Issue [14] focuses on the study of wear phenomena in coated tools, specifically when machining UNS S32101 duplex stainless steel. These alloys, having different machining characteristics from INCONEL alloys, are also classified as difficult to machine, and have a high number of applications where machining is required. Therefore, these alloys, despite having been previously studied, continue to deserve the attention of several research groups. In this study, tools with two or four flutes, as well as TiAlN, TiAlSiN and AlCrN coatings produced via PVD, were tested. The observed wear mechanisms were duly dissected and analyzed for different cutting lengths. It was reported that the TiAlSiN coating presented the best wear behavior, considering the parameters used in the conducted milling operations.

Returning to fiber metal laminates (FMLs), this Special Issue also presents a work on drilling operations, with the focus on studying the delamination occurring between different layers, as well as the fracture mechanisms involved [15]. A modeling study was also carried out, based on experimental results. In fact, FMLs are of particular relevance for the aeronautical industry, due to the fact that they have a lower density, combined with high mechanical resistance, significant impact resistance and high ductility. However, the application of these multi-materials in aircraft presupposes that they are easy to drill, which is not the case, due to problems of decohesion between layers, because of the shear forces developed on the material in general, which is particularly felt in the interfaces. The study revealed that the use of specific step tools with a secondary cutting edge significantly improves the machining performance. The developed model, despite being simplistic, proved to be efficient in predicting the delamination that can be induced in the interfaces of the FMLs used in this work.

Given that machining is widely used in industrial terms, predicting the time of machining operations is extremely useful, and is also the subject of in-depth studies aimed at developing models capable of reliably estimating the time required for certain machining operations, thus minimizing the response time in the budgeting of this type of operation, since outsourcing is a very common practice in this type of industry [16].

Machining plays a crucial role in industrial applications, making the accurate prediction of the machining time highly valuable. Consequently, in-depth studies are dedicated to developing models capable of reliably estimating the time required for specific machining operations. Such models enable the minimization of the response time in budgeting these operations, which is particularly important considering that outsourcing is a prevalent practice in the industry.

The papers included in this Special Issue include two different approaches, with one being a more conventional approach [17], which can be used by any company that regularly uses MS Excel spreadsheets. This model presents different degrees of complexity in machining, distributing these degrees of difficulty by levels in different aspects, and building a model that can be easily adjusted by users, with a view to improving its operational reliability. The model presented in the second work of this nature in this Special Issue uses more advanced techniques, namely artificial neural networks (ANNs) [18]. In this case, a group of drawings of parts was considered, to "teach" the system, followed by a smaller set for testing the accuracy, in terms of the time estimates offered by the model. The maximum precision achieved, in this case, was 2.52%, which is a very acceptable value for this sector. This value is significantly better than the average estimation accuracy found in the traditional model, which was around 14% [17]. However, these models can be fine-tuned by increasing the volume of data considered for learning, improving the accuracy of the estimate offered by the model.

3. Conclusions and Outlook

Machining continues to be a field of strong investment by researchers, looking for new solutions that increase the competitiveness and sustainability of this type of subtractive process. Despite the strong increase in number that additive processes have undergone in the last two decades, the quality of the finish exhibited by machining processes is difficult to match using additive processes. Hence, hybrid processes and equipment are emerging, with a view to responding more effectively to market needs. More recently developed alloys also lead to new research needs, as well as new materials, such as fiber metal laminates.

(The emergence of recently developed alloys and new materials, such as fiber metal laminates (FMLs), creates new research requirements and opportunities.)

Environmental sustainability, in addition to economic sustainability, has also been a factor to be considered in the area of machining. The development of more durable tools, as well as the establishment of cutting conditions that promote a longer tool life, has received increasing attention from researchers. The development of tools capable of assisting professionals in budgeting operations is also another concern of researchers, who have been developing models that aim to increase the accuracy of estimates. It can thus be seen that the machining area remains particularly active in terms of research and development, which is extremely beneficial for all those who are particularly attracted to these technologies. All of this can be found in this Special Issue.

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

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