Research trends in polymer matrix composites used for personal protective equipment: a bibliometric analysis

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Abstract. Polymer composite materials (PCM) have demonstrated their potential in successfully replacing conventional materials. At the same time, due to their characteristics and mechanical, chemical, and structural properties, they meet the performance requirements in various applications. Using these materials to manufacture different components of personal protective equipment (PPE) offers an excellent strength/weight ratio, comfort, and stability in aggressive environments, but also an essential contribution to the sustainability of the materials. Integrating renewable or post-industrial materials into the PMC represents a significant advantage in developing sustainable materials with a low environmental impact. Therefore, this paper aims to analyze the bibliometric data of scientific works based on the use of these materials to manufacture PPE. This analysis provides new research directions, and the problems encountered in the specialized literature are identified. The extracted bibliometric data were based on polymer matrix composite materials used to manufacture personal protective equipment for different parts of the body: head, body, hands, and feet. Further, processing these results through the VOSviewer and Bibliometrix software thus offers us new research directions in this field.

1 Introduction

Due to the high number of occupational accidents in different industries and the causes that vary depending on the field of activity, occupational safety and health specialists are constantly forced to adapt. The analysis of Eurostat statistics on the type of injuries in non-fatal and fatal accidents shows that most accidents can be prevented or reduced in severity, as can be seen in Figure 1. By wearing appropriate personal protective equipment, the number of main types of injuries could be reduced [1, 2]. The variety of work equipment used, the fulfillment of complex work tasks, and sometimes the extreme environmental conditions,

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translate into risks for workers [3]. In the context of Industry 4.0, the number of accidents decreases using advanced industrial and production technologies. The goal of this increasingly present industry is not and cannot be the complete replacement of human labor. Industry 4.0 will generate a need to change workers' skills and abilities [4].

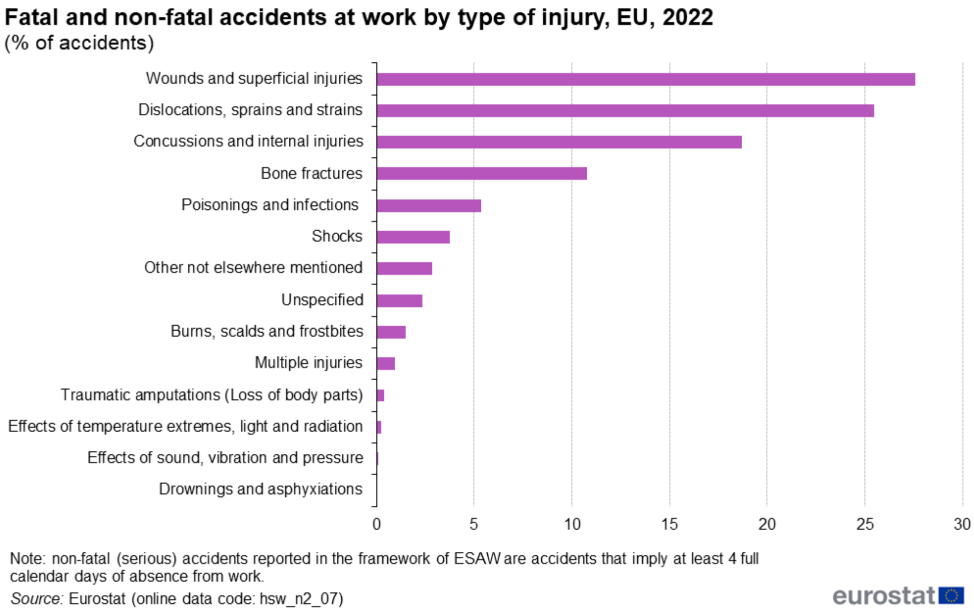

Fig. 1. Accidents at work (fatal and non-fatal) by type of injury in 2022, EU [2].

Isolation of hazards in some cases, including in this context, may be impossible, and workers may be exposed to a wide range of hazards. The latter can generate accidents during the work process. Using personal protective equipment (PPE) can mitigate or even eliminate the consequences of accidents at work. The PPE acts as a barrier against risks, as can be seen in Figure 2. These PPEs must meet strict performance standards and protect against mechanical, biological, chemical, thermal, electrical, radiological, and sometimes even sporting or household hazards [5, 6].

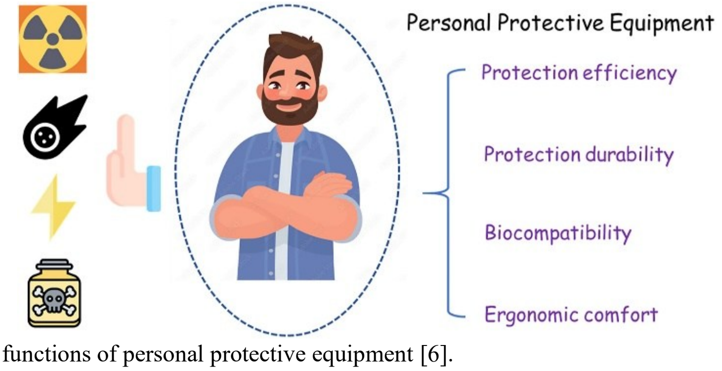

Fig. 2. Main functions of personal protective equipment [6].

A variety of materials are used for the manufacture of components within PPE [7, 8]. Table 1 shows the primary materials used and their main characteristics. The increasing use of natural resources and conventional materials is a level of concern about pollution. Creating products with a short life cycle is also a problem. This problem can be remedied by using circular economy strategies in the design of materials used to manufacture various protective equipment [9].

Table 1. The primary materials and their characteristics used for PPE components [7, 8].

PPE	Material	Examples/Characteristics
Head protection (safety helmet, bump cap)	Polycarbonate (PC); Expanded polystyrene (EPS), Polyethylene (PE), Acrylonitrile butadiene styrene (ABS), High-density polyurethane (HDPE), Fiberglass Composite (GFRP).	Shell, Harness, Foam liner, Stap.
Body protection (coats, coveralls, aprons).	Phase change material (PCM) Laminates, Shape memory alloys (SMA), Microporous membranes, E-textiles.	Smart clothes, Thermal/chemical protection, active cooling/heating.
Hand protection (gloves).	Nomex®; Twaron®; Kevlar®; Dyneema®; Nitrile; Polyvinyl chloride (PVC); Natural rubber latex.	Cut resistance; Thermal/chemical protection, vibration.
Foot protection (safety boots, metatarsal, toe guards).	Sympatex® laminated fabrics; Natural leather; Technical fabrics, expanded polytetrafluoroethylene (EPT) such as Gore-Tex© and eVent©; Polyamide fabrics, Cordura®.	Waterproofing, good ventilation, and high resistance to wear.
Eye and face protection (safety glasses, face shields).	Polycarbonate (PC); Acetate; Photochromic Filter; Mesh, metal grids or frames (Nylon mesh, frames from alloys of Monel, Titan, Epoxy resin).	Protection for mechanical hazards; Splashes with molten metals; Electric shock and/or harmful UV; Dust and gases.
Anti-fall systems.	Nylon, Polyester, Stainless steel.	Harnesses, Carabiners, Ropes, Dampers.

For these reasons, there has been greater interest in the study, development, and use of Polymer Matrix Composites (PMCs) to replace conventional materials. The physical, chemical, and mechanical properties of PCMs, together with their low weight and stability in aggressive environments, make PCMs a good substitute for steel, aluminum, polycarbonate (PC), natural leather, styrene butadiene acrylonitrile (ABS), and other materials [10]. In addition, industrial waste or recycled materials in any shape or size can be integrated into PCMs within the polymer matrix. Particles, fibers of different diameters, lengths, continuous or in the form of plates, a variety of combinations between reinforcement elements and matrices can be obtained, as can be seen in Figure 3 [11, 12].

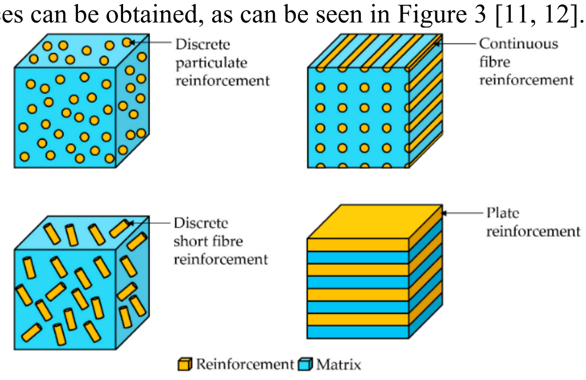

Fig. 3. Types of reinforcement in PCMs [11].

2 Methodology

Scientific research trends can be identified by conducting a bibliometric analysis of materials used to manufacture components that protect the wearer or the user. Also, with the help of this method, which uses quantitative data, it is possible to monitor the evolution in this field, but also gaps or problems encountered in scientific research [13]. The main steps in performing bibliometric analysis are shown in Figure 4.

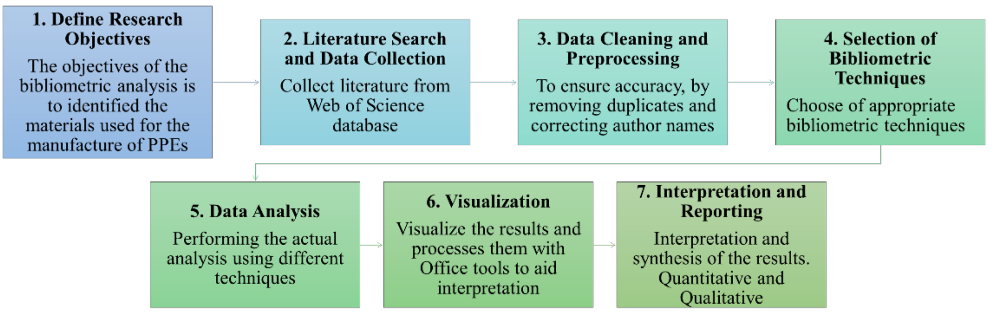

Fig. 4. Main steps of bibliometric analysis.

The data processed in this article were obtained from two large databases, Web of Science (WoS) and Scopus. For their analysis, the Bibliometrix software, RStudio Biblioshiny interface, VOSviewer, and the Office package programs were used for their processing. The Biblioshiny software allows the visualization and mapping of the field of study and the statistical analysis of the performance of academic papers. Therefore, the analysis is both quantitative and qualitative [13, 14].

The query string in the two databases was as follows:

TITLE-ABS-KEY(("polymer composite*" OR "fiber-reinforced polymer*" OR "fiber-reinforced polymer composite*" OR "FRP" OR "thermoplastic composite*" OR "thermoset composite*" OR "polymer matrix composites*" OR "hybrid composite*" OR "composite material*" OR "laminate*")) AND TITLE-ABS-KEY(PPE OR "personal protective equipment" OR "protective gear" OR "protective clothing" OR helmet OR gloves OR workwear OR "hard hats" OR "safety footwear" OR "safety helmet" OR "body armor" OR "ballistic vest" OR "ballistic plate" OR "face shield" OR respirator) AND NOT TITLE-ABS-KEY("metal matrix" OR "ceramic matrix" OR "metallic composite*" OR "metal composite*" OR "ceramic composite*" OR CMC OR MMC OR cermet* OR "metal matrix composite*" OR "ceramic matrix composite*").

This query string was designed so that there were no scientific papers outside this study in the displayed results.

Of the 1258 scientific papers obtained from the Scopus database, only 689 were in the 2015–2025 time frame. The query string in the WoS database had the same conditions as the one used in the Scopus database. The query in WoS showed a total of 479 scientific publications. The next step was to eliminate duplicate publications. Out of the total of 1168 scientific publications, the two databases merged the two files into one with the help of the RStudio software. In order to ensure transparency and reproducibility of the analysis, clear inclusion and exclusion criteria were defined. Duplicates of scientific papers in the two databases were removed if they did not provide full-text articles or did not specifically address the field of PPE, as determined from the title and abstract. Additionally, duplicates were automatically eliminated using RStudio and manually verified to ensure readability. During the manual verification process, any papers that contained terms from the query but did not focus on the field of PPE were also removed. This screening process resulted in a final set of publications relevant and representative of the field of PPE. After this screening, a total of 774 scientific publications from 425 sources, authored by 2,733 individuals, were studied, covering the years from 2015 to 2025.

3 Results and analysis

The processed bibliometric data are centralized in Figure 5. The scientific publications processed were from 2015 to 2025 to filter relevant and topical scientific research. It should be considered that the publications of 2025 are incomplete, and the upward or downward trend in the number of publications must take into consideration the years before 2025. This dataset includes a significant number of scientific articles, 499 in number, 90 conference papers, and other times in a smaller number. The papers were obtained from 425 sources, and the annual growth rate of the number of scientific publications of 3.58% indicates that the field of study is of interest. The average age of the documents is 4.14 years, suggesting that this field of polymeric composite materials used in PPE applications is a relatively new but constantly growing field. The average number of citations per document is a significant indicator of the interest given to this field. The average citation of 12.7 per scientific paper highlights the thematic relevance and encourages further study.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2015:2025
Sources (Journals, Books, etc.)	425
Documents	774
Annual Growth Rate %	3,58
Document Average Age	4,14
Average citations per doc	12,7
DOCUMENT CONTENTS	
Keywords Plus (ID)	3059
Author's Keywords (DE)	2450
AUTHORS	
Authors	2733
Authors of single-authored docs	33
AUTHORS COLLABORATION	
Single-authored docs	51
Co-Authors per Doc	4,71
International co-authorships %	13,31
DOCUMENT TYPES	
article	499
conference paper	90
proceedings paper	56
review	50
book chapter	44
others type	35

Fig. 5. Summary of bibliometric data extracted.

The scientific community in this field focuses on publication in specialized journals that emphasize composite materials or advanced functionalized materials. At the same time, as seen in Figure 6, the diversity of the 10 most revealed sources indicates the interdisciplinary interest in which mechanical engineering, materials engineering, and chemical engineering are combined in the PCM study used for PPE. Journals such as *Polymers,* with 25 publications, followed by *Composite Structures,* with 21 publications, are some of the most critical and relevant journals with essential contributions in this field. Journals such as the *Journal of Industrial Textiles* and *Defence Technology* focus on the applicability of these materials in the industrial and military field, with applications in the manufacture of personal protective equipment.

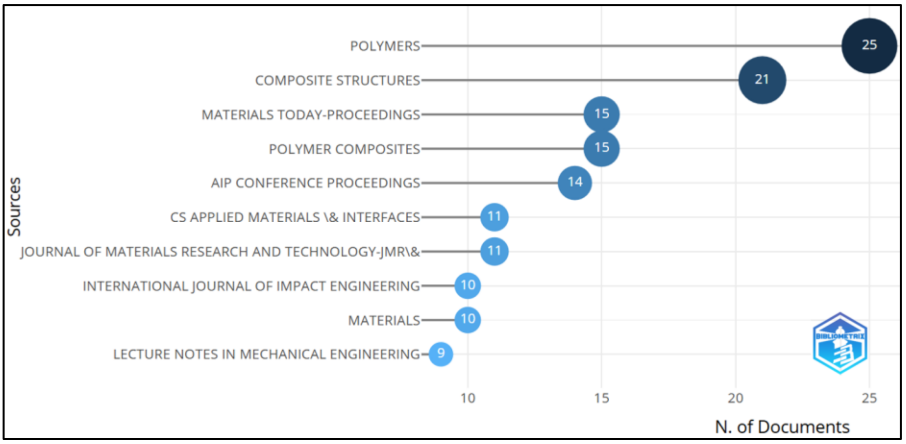

Fig. 6. Most relevant scientific journals.

The scientific influence of publications is also provided by the journals in which they are published. The Composite *Structures journal*, with the highest h_index, dominates the other journals, including the number of citations (TC) with a number of 819. Also at the top of influential journals are *Polymers and ACS Applied Materials & Interfaces, which* are also at the top of influential journals, both with a high h_index and g_index and large publication numbers (NP). On the other hand, other journals emphasize the applicability of the works, such as the *Journal of Defense Technology* or the *International Journal of Impact Engineering*. However, with m_index and h_index smaller, they obtain many citations. By analysing Table 2, we can also compare the impact of items on productivity. Journals with many publications in this field, but with a few citations, indicate that widespread publication can generate little effect, as seen in the Journal of *Polymer Composites or Materials Today: Proceedings*. In contrast, the value of the number of citations for a small number of publications may indicate the quality of those papers, as indicated by the journal *Composites Science and Technology,* with 420 citations for the five articles.

Table 2. Bibliometric indicators of the main sources.

Source	h_index	g_index	m_index	TC	NP
Composite Structures	15	21	1,5	819	21
Polymers	10	22	1,429	501	25
ACS Applied Materials & Interfaces	8	11	1	545	11
International Journal of Impact Engineering	8	10	0,727	268	10
Journal of Materials Research and Technology-JMR&T	7	11	0,875	226	11
Materials Today-Proceedings	7	10	0,778	122	15
Composites Part B-Engineering	6	7	0,545	187	7
Polymer Composites	6	11	0,75	137	15
Composites Science and Technology	5	5	0,455	420	5
Defence Technology	5	7	0,714	281	7

The authors' affiliation to different universities globally highlights the interest of researchers in this field of study. Figure 7 shows the most relevant affiliations of authors who have studied this topic. Some authors affiliated with various universities on an international scale stood out through their works due to the large number of citations they obtained.

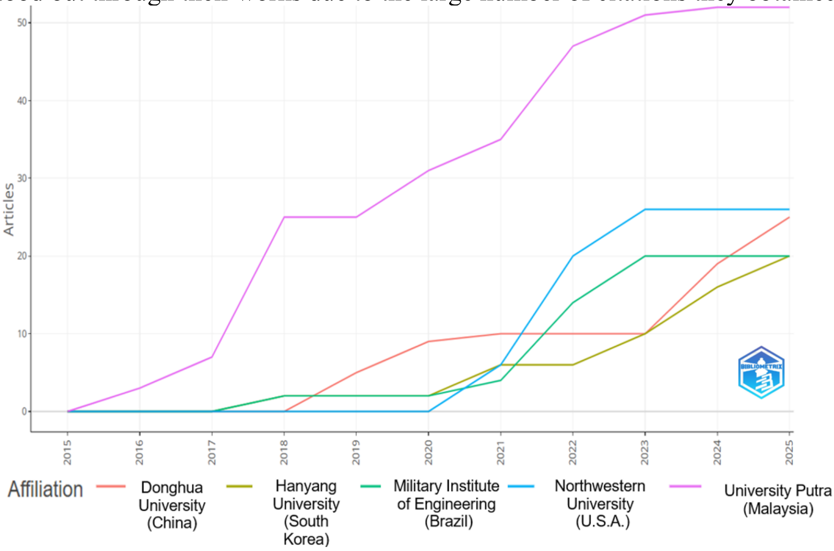

Fig. 7. Most Relevant Affiliations in scientific production over the years.

Table 3 presents a series of scientific articles published in leading materials engineering journals, with many papers on composites, advanced materials, and even defence technologies. These papers, which have an impressive number of citations, suggest the direction of researchers towards the study of polymeric composite materials in practical applications of PPE development. Also, review articles obtain a high number of citations because they summarize the state of research and knowledge in the field of PCM.

Tab. 3. Global most cited documents.

Author, Year, Journal	Article Title	Total Citations
Zheng Y (2017), Composites Science and Technology	Interracially reinforced carbon fiber composites by grafting modified methyl-silicone resin	318
Abtew M (2019), Composite Structures	Ballistic impact mechanisms – A review on textiles and fibre-reinforced composites	263
Nurazzi N (2021), Polymers	A Review on Natural Fiber Reinforced Polymer Composite for Bullet Proof and Ballistic Applications	242
Peterson G (2021), Nature Reviews Materials	Fibre-based composites from the integration of metal–organic frameworks with polymer fibres	199
Crouch I (2019), Defence Technology	Body armour – New materials, new systems	184
Bhattacharjee S (2019), Advanced Materials Interfaces	Graphene Modified Multifunctional Personal Protective Clothing	162
Benzait Z (2018), Journal of Composite Materials	A review of recent research on materials used in polymer–matrix composites for body armor applications	148

Figure 8, a WordCloud, shows the top 50 keywords and how often they appear. The most significant terms are highlighted in the center of the structure by a larger dimension. The graphic representation in this form draws attention to the terms that refer to materials, matrices, or reinforcement elements, their properties, and the applications in which they are used. Also, some of the highlighted keywords refer to the manufacture or the final design of the materials, which suggests that the concrete methods of making these components of the PPE have also been studied. Terms such as "simulation" or "model" indicate that some of the research was of the finite element analysis and numerical modelling type, emphasizing the authors' interest in economic aspects and obtaining predictions about the material's behaviour during tests before the composite material was produced. This type of visualization is effective for observing trends and research directions in the literature on component manufacturing within PPE.

Fig. 8. WordCloud keywords.

From the point of view of the frequency of the appearance of the keywords offered by the authors, it is noted that this collection focuses on polymer composite materials, their performance, and applications in the field of personal protection. The temporal distribution and the trend of studies also bring to the fore the gradual transition towards the functionalization of composite materials. The use of other materials to the detriment of those used conventionally is also highlighted, as seen in Figure 9. Therefore, this field of research is developing and maintaining its upward trend, and in the foreground are the materials' performance and their possible applications.

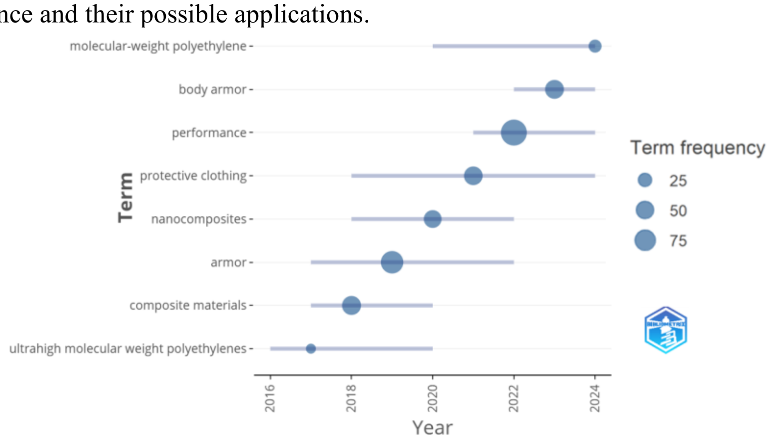

Fig. 9. Median annual frequency of study trends.

The co-occurrence network is divided into 4 clusters of interest. The size of the circles represents the frequency of occurrence of the keyword, and the lines represent the connection between them. The purple cluster emphasizes evaluating materials' performance and mechanical behaviour. The red cluster highlights materials and applications. The blue grouping comprises examples of reinforcing elements and refers to nanotechnology. Last but not least, the area with green nodes contains processing methods. Overall, the network focuses on material optimization, material evaluation, and improvement, as well as applications in the field of protection.

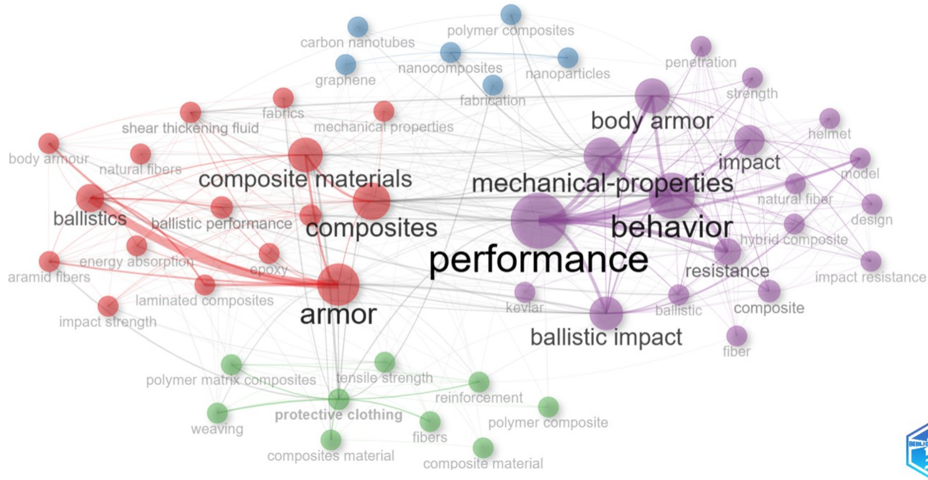

Fig. 10. Co-occurrence network keywords.

The thematic map, in Figure 11, highlights the concentration of the study in 4 themes divided into the four quadrants. The emerging themes, in decline, demonstrate the diminishing interest in PPE development during the pandemic. The area with basic and motor themes is the most prominent in clusters. They suggest that the PCM study for applications in PPE is a driving force in the field of study. Lastly, niche themes target specific problems identified within the PPE.

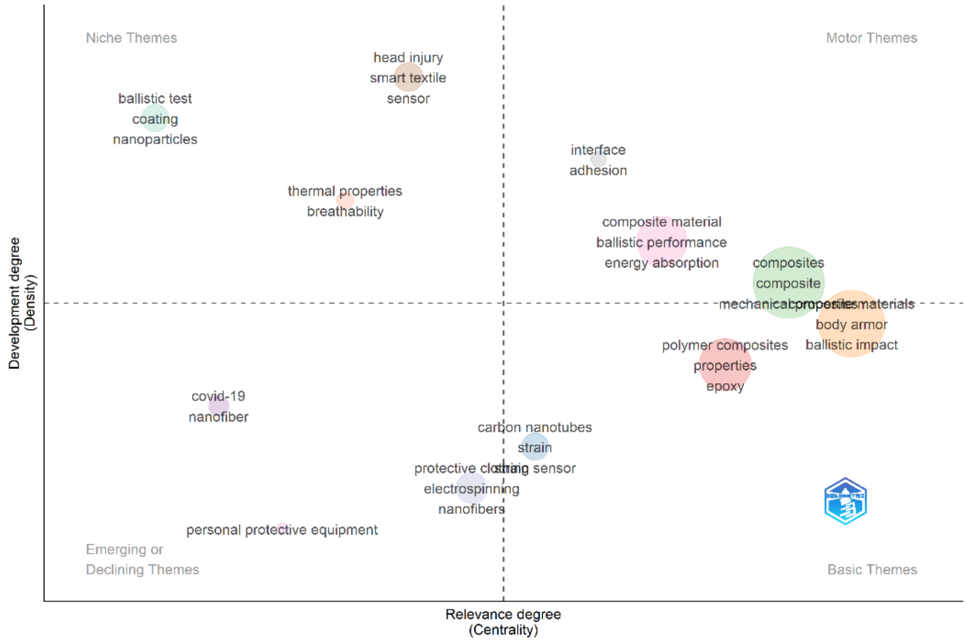

Fig. 11. Thematic map.

The analysis of clusters within the co-occurrence network and the thematic map not only highlights major trends but also reveals some gaps in the literature. While central themes focus on material optimization and the characterization of mechanical properties, there is a notable lack of studies addressing fire and blast resistance, validation under real-world conditions, and the analysis of material degradation in extreme environments (such as high humidity, aggressive chemical agents, and significant temperature variations). These gaps indicate areas for future research that hold significant practical relevance but are still insufficiently explored.

4 Conclusion

The field of materials engineering is vast, and that of polymer composite materials is equally vast. PCMs have demonstrated impressive capabilities and have been involved in many applications, successfully replacing conventional materials. The scientific publications analyzed in this research confirm that the study of PCMs is still interesting. Research on PCM for developing new materials and enhancing their performance is imperative for their final application, specifically in human protection. PPE is vital to reducing the number of accidents in industry. The period during which this research was conducted included current scientific works while maintaining the possibility of identifying trends in this field of study. This study shows that specialized journals centralize and expose quality scientific works with a high impact in the academic world. A series of works with impressive citations was also highlighted, indicating other researchers' reporting on their work and achievements. The variety of applications in which these materials can be used was also observed.

However, the limitations of this type of analysis must be considered, since the query was made only from the two databases, WoS and Scopus. Some publications were not indexed at the time of processing these data. At the same time, some studies could include the selected keywords, thus being detected by the program, but their purpose should not be to study PCM used for manufacturing components within the PPE.

Bibliometric visualizations reveal under-researched areas that could be prioritized for future studies. Based on the results obtained, several key directions for future research can be outlined. First, it is essential to develop materials with enhanced fire and explosion resistance properties, particularly for safety-critical applications. Second, integrating personal protective equipment with IoT technologies and smart sensors would allow for real-time monitoring of usage conditions, thereby improving the level of protection provided. Lastly, long-term experimental studies are necessary to analyze the degradation of these materials in harsh industrial environments, such as mining, to evaluate their reliability under real operating conditions.

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