Latest trends in basalt fibre applications and implications of machining processes

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Abstract: Lastly the use of basalt fibre as reinforcement in organic matrix composites has had a particular attention. Applications in products intended for industry or for final consumer have been increased. The good thermal and mechanical proprieties in environmental typical and extremes conditions have facilitated such uses. Moreover, the development of cryogenic machining can contribute, as environmentally friendly process, in these materials because are support extremes temperatures. Thus, a systematic literature review has been carried out through PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. At first approximation, it has allowed to identify the main applications of this material, such as transport sector, in several products types (automobiles, drones, bicycles, among others). Few research groups dedicated to this field have been identified, and they are focused especially on the materials properties. Respect to machining processes, several works have been found and in all of them, the operations were executed in dry and at room temperature. Therefore, a new development is possible through the cryogenic machining in basalt fibre reinforced composites.

Keywords: Basalt fibre, Composite, Green manufacturing, Machining.

1. Introduction

The basalt fibre is a material used typically in construction sector, but its use as reinforcement in organic matrix composites has had a particular attention in the last years. On this manner, applications in products intended for industry or for final consumer have been increased; components in automotive industry as an example of this [1].

The good thermal and mechanical proprieties of these composites in environmental typical and extremes conditions [2] have facilitated such uses.

In general, these new applications require operations on the manufacturing engineering field as the machining processes. Some works have been realized focused on milling processes, in particular in edge trimming, and studying the tool wear [3] or the delamination effect [4]. The development of cryogenic machining can contribute, as environmentally friendly process, in these materials because are support extremes temperatures; in fact, the machining at very low temperatures has shown good results in composites as reinforced polyamide PA66 [5] or reinforced polyether-ether-ketone [6] and even the cryogenic machining on carbon fiber [7].

Consequently, the objectives of the paper are the following: i) identify the main applications of basalt fibre reinforced composites with organic or natural matrix, and the machining operations required, ii)
identify the main research groups involved in this field, and iii) analyze the role of cryogenic machining.

2. Methodology
For this purpose, Web of Science database has been the tool used to identify the research [8]. The search has been realised using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology [9]. Although this methodology emerged in the medicine filed, now it is recognised in other fields as engineering [10]. This method is based on a systematic search previous works that includes the own search in the academic literature, the selection of eligible papers and the removal of data. In fact, the information flow to systematic review follows four phases: identification of records, screening of these records, eligibility of full-text papers and studies included in the meta-analysis.

According to four phases, the methodology applied begins with an identification of records, a collection of papers from Web of Science (WOS) database of Clarivate Analytics™. Other databases were not considered because the main works published in indexed journal, in particular in Journal Citation Reports (JCR), are contained in WOS, although according to PRISMA methodology could be included in the future developments to find emerged studies. Taking into account the characteristics of WOS, period of publication, language and type of paper were selected. The period considered was between 2016 and 2020. These last five years were selected because they are representative to analyse the latest trends, as this paper aims. The language considered was English and the selected works were papers came from all database of WOS (Science Citation Index (SCI), Index Chemicus, Current Chemical Reactions, Conference Proceedings Citation Index: Science, Emerging Sources Citation Index (ESCI)), but excluding meetings, books, abstracts, reviews or editorials.

During the phase of records identification, the subjects initially chosen were “basalt fibre”, “composite”, “green manufacturing” and “machining”, in a simultaneous search for all of them, and a result of zero papers. For this reason, “green manufacturing” was eliminated, and 43 papers were obtained. This phase permits the identification of papers from other sources but a previous exploratory exam observed that the inclusion of word “cryogenic” did not report any additional records, and accordingly, this word was not considered as subject. Later, the screening showed that many papers were found not related to machining because the word “machining” was associated to “machine”; the screening allowed excluding 21 records. Thus, a new filter was selected, using “basalt fibre AND composite AND (drilling OR turning OR milling)”, the three main machining processes, and with a result of 22 papers, the same that would be accepted with the previous screening; these papers were finally analysed, being eligible and being analysed later. As is seen, the subjects chosen are broad in terms of content in order to facilitate the identification of all papers about this study. For this reason, other more specific subjects as “organic matrix”, “natural matrix” or “concrete” of interest were eluded because they are included in “composite”. Note that subjects are selected, not keywords. A process scheme can be seen in table 1.

| Phase                        | Process                                                                 | Papers considered |
|------------------------------|-------------------------------------------------------------------------|-------------------|
| Identification of records    | Records identified through “basalt fibre AND composite AND machining”   | 43                |
| Screening                    | Records through “basalt fibre AND composite AND (drilling OR turning OR milling)” | 22                |
| Eligibility                  | All previous full-text papers                                          | 22                |
| Studies included in the meta-analysis | All previous full-text papers                                          | 22                |

3. Results and Discussion
This Section is devoted to the categorization of the papers and the analysis of items included. The categorization is based on the research areas, the countries of the authors, the year of publication, while the analysis of the items is bases on the keywords of the papers.
3.1. Categorization of the papers

The papers have been categorized according to research areas in the science field due to the nature of this study and to the characteristics of the databases used, also to country of origin of the authors’ institutions and, finally to year of publication within the considered range, period 2016-2020 to identify last trends.

3.1.1. Research areas. According to research areas, the papers found belong to 12 research areas (see figure 1). The most prominent is “Material Science” with 12 papers followed by “Engineering” with 9 papers. Both constitute 96% of the total. The other areas are diverse, and they could show the variety of applications of basalt fiber (e.g. “Construction & Building Technology” or “Energy & Fuels”), its ability to be combined with other types of fibers (e.g. “Polymer Science”) and its own nature (“Geology” or “Mining & Mineral Processing”).

![Figure 1. Research areas.](image1)

![Figure 2. Countries.](image2)
3.1.2. Countries. Regarding the origin of the articles, there are 19 countries involved (see figure 2). The institutions come mainly from India (6 papers), maybe because it is a country with more mining deposits. Other countries with more papers are Italy and Russia with 3 papers each one of them. As is seen in figure 2, the other papers are distributed in many countries, 16 countries.

3.1.3. Year of publication. The results achieved are clustered in four groups respect to year of publication (see figure 3). The year 2017 lacks publications and the last year analysed, 2020, is the year with most papers (55%).

![Figure 3. Year of publication.](image)

3.2. Analysis of items

76 keywords can be found in the 22 identified papers (see table 2), which shows the large scope of this subject under study. In the scope closer to manufacturing processes can be found variables that determine the quality of the process, as delamination, precision or roughness, and the most studied process is drilling. On the other hand, mechanical proprieties were an item more studied than others [11, 14, 21, 26], which can be considered normal given the new combinations of fibres and matrices and the new hybrid composites under study [24,25].

Moreover, in recent papers, aspects related to sustainability have been considered, as recycling [14,15] despite not being recognized as “green manufacturing” by the database.

| Keywords                              | Reference          |
|---------------------------------------|--------------------|
| Basalt                                | [11], [16], [17], [20] |
| Composite materials, Composites       | [11], [15], [17], [19], [20], [22], [28] |
| Roof tiles                            | [11]               |
| Construction materials                | [11]               |
| Mechanical properties                 | [11], [14], [21], [26] |
| Fiber-cement products                 | [11]               |
| Alternative energy sources            | [12]               |
| Energy extraction of energy from its natural resource | [12] |
| Renewable energy                      | [12]               |
| UV exposure degradation               | [13]               |

Table 2. Distribution of keywords.
Table 2 (cont.). Distribution of keywords.

| Keywords                                                      | Reference                  |
|--------------------------------------------------------------|----------------------------|
| Accelerated weathering                                       | [13]                       |
| Polymer                                                      | [13]                       |
| Nanocomposites                                              | [13], [31]                 |
| Basalt fiber reinforced polymer composites                   | [13]                       |
| Basalt fibres, Basalt rock fibers                           | [14], [19], [22], [27], [28], [29], [30] |
| Recycling                                                    | [14], [15]                 |
| Heat treatment                                               | [14], [26]                 |
| Fracture mechanics                                           | [14]                       |
| Fracture behaviour                                           | [14]                       |
| Sustainability                                               | [15]                       |
| Wind turbine blade                                           | [15]                       |
| Glass fibre                                                 | [15]                       |
| Fibres                                                      | [16], [21], [26]           |
| Surface treatments                                           | [16]                       |
| Interface/interphase                                        | [16]                       |
| Polymer-matrix composites (PMCs)                            | [16]                       |
| Carbon                                                      | [17]                       |
| Delamination                                                 | [4], [17], [18]            |
| Epoxy                                                       | [17], [20]                 |
| Optimization                                                | [17]                       |
| Drilling / Drilling process                                  | [18], [23]                 |
| Design of Experiment                                        | [18]                       |
| ANOVA                                                       | [18]                       |
| Regression                                                  | [18]                       |
| Grey Relational Analysis                                    | [18]                       |
| Corrosion resistance                                        | [19]                       |
| 7075 aluminum alloy                                         | [19]                       |
| Agglomeration                                               | [20]                       |
| Nanofiller                                                  | [20]                       |
| FRSCC (fiber reinforced self-compacting concrete)            | [21]                       |
| Quaternary composite binders                                | [21]                       |
| First crack                                                 | [21]                       |
| Destruction                                                 | [21]                       |
| Polyurea                                                    | [22]                       |
| Spray coating                                               | [22]                       |
| Thermomechanical properties                                 | [22]                       |
| Magnetic field                                              | [23]                       |
| Thrust force                                                | [23]                       |
| Basalt/epoxy composite                                      | [23]                       |
| Surface roughness, Roughness                                | [23], [27]                 |
| Hybrid composite                                            | [24], [25]                 |
| Heat-affected zone                                          | [24], [25]                 |
| Precise drilling                                            | [24], [25]                 |
| Basalt-glass composite                                      | [24], [25]                 |
| Thermosetting resin                                         | [26]                       |
| Basalt fiber reinforced plastic (BFRP)                      | [4]                        |
| Edge trimming                                               | [4]                        |
| Tool wear                                                   | [4]                        |
Table 2 (cont.). Distribution of keywords.

| Keywords                  | Reference |
|---------------------------|-----------|
| Polysiloxanes             | [27]      |
| Mortar                    | [27]      |
| Surface free energy       | [27]      |
| Thermal Recycling         | [28]      |
| Tensile Failure Stress    | [28]      |
| Agent Size                | [28]      |
| Non fiber inclusion       | [29]      |
| Frequency                 | [29]      |
| Vibrations                | [29]      |
| Sound                     | [29]      |
| Precise separation        | [29]      |
| Mining                    | [29]      |
| Molybdenum disilicide alloy | [30]    |
| Raw material              | [30]      |
| Ceramic bushing nozzles   | [30]      |
| Materials                 | [31]      |
| Ultrasonic methods        | [31]      |

At first approximation, it has allowed to identify the main applications of this material, such as transport sector, in several product types (automobiles, drones, bicycles, among others). Few research groups dedicated to this field have been identified, and they focus their study especially on the field of materials properties, including mechanical [11, 14, 21, 26] and thermomechanical [22] properties.

Respect to machining processes, several works have been found, concentrated on few research. In all of them, the operations were executed in dry and at room temperature. However, a particular attention has been found in the heat-affected zone; controlling the temperature of this area is a permanent topic in machining because, as is known, an increase in heat can cause a reduction in tool life and a worse surface quality. Thus, a machining at very low temperatures that does not require additional cutting fluids, as a cryogenic machining, can be an environmentally friendly option.

4. Conclusions
This work has allowed categorizing the main applications of composites with basalt fibre reinforced, with particular attention to organic and natural matrix; also the relevance of machining process in the operations of manufactured products of this materials has been indicated.

Finally, a new development is possible through the cryogenic machining in basalt fiber reinforced composites.

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