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Assessing technological developments in amorphous/glassy metallic alloys using patent indicators

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ABSTRACT

Alloys with an amorphous structure represent a class of advanced metallic materials which have great potential for industrial applications and technological innovations as a consequence of their interesting chemical, mechanical and magnetic properties. Considerable effort has been devoted to investigating scientific issues concerning these alloys, but less attention has been paid to assessing the impact of this accumulated knowledge regarding the development of new materials, products and processes. In this study, we evaluated the technological developments in metallic glass using patent indicators. Patent documents are a valuable source of information as they reflect R&D activities and market issues. Data and text mining processing were carried out in order to extract useful indicators from bibliographic records of patent documents indexed in the worldwide Derwent Innovations Index database. The results evaluated the technological advances and showed the life-cycle stage of developments and the interests of companies, research institutions and countries. This study mapped the main alloys and manufacturing processes that have been patented. Amorphous metallic alloys have become ever increasingly important for technological developments regarding metallic alloys in general, and the indicators developed in this study can be used as a source to support decision making in funding new projects and in R&D management.

1. Introduction

Amorphous/glassy alloys have been the subject of research at least since their first synthesis at the beginning of the 1960s [1]. Since then, the number of scientific publications grew continuously until the end of the 2000s, when it reached an average value of 640 articles published per year between 2006 and 2015.[1] Clearly, much intellectual effort has been devoted to developing new alloys and understanding their particular microstructures, optimizing the process parameters, and characterizing their exceptional chemical, magnetic and mechanical properties. A fundamental building block of metallic glass research that exemplifies this effort is the Glass Forming Ability (GFA), which involves a set of criteria to design new bulk metallic glasses. It has been the subject of research since the early 1970s [2] and the current paradigm of GFA relies on characteristic temperatures, structural factors, enthalpy of mixing or phase diagrams. Furthermore, it has been challenging to develop a universal indicator for GFA due to limitations concerning the theoretical frameworks such as measuring thermodynamic and kinetic parameters from liquid state [3–5].

Besides fundamental research, this effort has also sought to achieve potential fields of application, such as structural machinery materials and cutting materials, optical precision materials, corrosion resistant materials, hydrogen storage materials, composite materials, sporting goods materials, soft magnetic materials and high magnetostrictive materials [6]. However, less attention has been paid to evaluating the impact of knowledge accumulation

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[1] This overall trend can be achieved performing a search in the scientific database Web of Science using the following search expression: ("amorphous metallic alloy*" OR "amorphous alloy*" OR "glass* metallic alloy*" OR "glass* alloy*" OR "non-crystal* metallic alloy*" OR "non-crystal* alloy*").

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concerning the technological development of new materials, products and processes. The purpose of our investigation was to assess technological developments regarding amorphous and metallic glass alloys.

Technological advances in amorphous/glassy metallic alloys can be evaluated using patent indicators [7,8] as patent documents are formal registers that contain information concerning the claimed technology, organizations/people involved in the inventing process and other aspects of research and development (R&D) activities or market issues [7–11]. Patent indicators are useful to support decisions in R&D program management, strategic planning, mergers and acquisitions, new product development, and intellectual assets and human resources management [9–11]. They can also be used to diagnose the life-cycle stage of development in technological forecasting evaluations [9].

One of the advantages of using patents as a source of information is the International Patent Classification (IPC), which is a set of general codes that aims to describe the specific content of a document [10]. For instance, all patent documents classified with the IPC code C22C 45/00 will refer to inventions based on metallic alloys with amorphous structures. Moreover, IPC codes are used worldwide and enable statistical assessment of specific issues in technology, such as materials and manufacturing processes [7–10].

Some of the drawbacks of patent analysis are the fact that not every invention is patented and some companies choose to keep their technology confidential. There are differences in national laws, procedures for patenting and the culture of patenting that also affect analyses. Furthermore, emerging subjects (such as nanotechnology and new materials) may experience a rapid increase in the number of patents while mature sectors (such as technologies to produce crystalline low carbon steel) usually level out or experience a decrease in patent activities. All these limitations must be taken into account in the analysis process [7,8,10].

Another issue of patent indicators is the huge volume of data currently available. Considering this, patent indicators have been developed using data and text mining techniques, which deal with structured data and unstructured texts, respectively, for a massive number of documents [12,13]. After the mining process, the extracted information is then carefully combined, classified and represented as an indicator. This process may include the uses of algorithms, computing processes and information issues [14,15]. In our study, the analysis verified the evolution of patenting and the state of its life-cycle stage, the main countries engaged in the advances, the role of companies and research institutions, as well as the preferred metallic alloys and manufacturing processes.

2. Material and methods

2.1. Experimental procedure

Patent indicators were developed and analyzed according to the following experimental procedure steps: 1) Information Retrieval; 2) Data Preparation; 3) Data and Text Mining; and 4) Visualization and Analysis. Following the recommendations of the WIPO Guide to Using Patent Information [10], the bibliographic records of patent documents were retrieved (step 1) from the Derwent Innovations Index (DII) database [16] using keywords and IPC codes regarding amorphous and/or glass metallic alloys. We compiled the following search expression: [(IP=(C22C-045*)) OR (TS=("metallic glass*" OR "glass* alloy*" OR "amorphous metallic")].[2] DII was selected due to its worldwide coverage (more than 40 patent offices covered since 1963) and advantages not found in other databases, such as improvements in the patent title and abstract using the texts from other parts of the documents (claims, technical report, etc.), which enables consistent text mining analysis; or the standardization of assignee names that patent regularly. Moreover, the DII groups documents into patent families,[3] which enables worldwide analyses excluding duplicate documents.

There is a challenge working with patent families when developing technological indicators, because each country has a unique legal system [17]. The differences in their laws cause the existence of some patent applications with different years of priority (first application). Hence, before mining data and texts, we prepared the bibliographic records (step 2) using the Earliest Priority Selector software [18], which selects the first date of patent application as it is considered to be the nearest date when the invention was conceived [7,8]. Furthermore, patents first filed in 2014 and 2015 were not considered in the analysis as the number of patents from these years is low due to the period of confidentiality (usually 18 months) and to the delay by the database in indexing them [19], which might create false trends in the indicators. Therefore, the final sample of patents assessed was 3879.

Data and text mining techniques were used to count the patent information and develop indicators (step 3) using the Vantage Point software (5.0 version). Topic 2.2 describes in detail the whole data and text mining processes. Finally, all the indicators were shown (step 4) in graphs using MS Excel (2016 version). Furthermore, the analysis of the indicators considered the opinions of experts in the field of glassy metals research, and research recommendations from the field of quantitative studies in science and technology [7–10,20]. The analyzed indicators included the evolution of patent documents; percentage of representativeness of amorphous/glassy alloys in the overall metallic alloy technological developments[4]; patent activity from main countries and regions; life-cycle stage of development using a patent-based model [9]; evolution of patent documents per type of assignee; evolution of patent documents for the main amorphous/glassy alloys; percentage of patent documents for the main uses/applications of amorphous/glassy alloys analyzed; and evolution of patenting for the main manufacturing process.

2.2. Details of data and text mining

All evolution indicators were depicted in periods of four years starting after 1970 until 2013. In the countries' performance indicator, we considered all countries belonging to the European Union (EU), as of 2016, together. We also analyzed the percentage of patents filed in relevant markets - the triadic countries (i.e. the USA, Japan and EU) - because this statistical analysis assumes that the additional cost of protection in different countries is worthwhile, thus it provides an indicator of valued patent families [8].

Assignee (also called patentees) names were standardized carefully and classified into two groups: companies or research institutions (universities and research institutes). Government and research funding agencies were not considered due to their low number of patents. This classification was necessary to develop the life-cycle indicator and evolution of patenting for each group analysis.

The life-cycle stage of a technology was diagnosed using a

[2] The search was conducted in the Title/Abstract (TS) and international patent classification (IP) fields.

[3] Patent families refer to patents for the same invention that were filed in different countries [17].

[4] The technological developments of overall metallic alloys were retrieved by searching the specific IPC code for alloys: IP=(C22C*). A total of 176,504 bibliographic records of patent documents were retrieved.

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