THE TECHNOLOGY FORECASTING OF NEW MATERIALS: THE EXAMPLE OF NANOSIZED CERAMIC POWDERS

An-Chin CHENG*
Chia-Yon CHEN**

Abstract

New materials have been recognized as significant drivers for corporate growth and profitability in today’s fast changing environments. The nanosized ceramic powders played important parts in new materials field nowadays. However, little has been done in discussing the technology forecasting for the new materials development. Accordingly, this study applied the growth curve method to investigate the technology performances of nanosized ceramic powders. We adopted the bibliometric analysis through EI database and trademark office (USPTO) database to gain the useful data for this work. The effort resulted in nanosized ceramic powders were all in the initial growth periods of technological life cycles. The technology performances of nanosized ceramic powders through the EI and USPTO databases were similar and verified by each other. And there were parts of substitutions between traditional and nanosized ceramic powders. The bibliometric analysis was proposed as the simple and efficient tools to link the science and technology activities, and to obtain quantitative and historical data for

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helping researchers in technology forecasting, especially in rare historical data available fields, such as the new materials fields.

**Keywords:** new materials, bibliometric analysis, technology forecasting.
**JEL Classification:** C40, E23

1. Introduction

New materials have been recognized as key drivers for corporate growth and profitability in today's fast changing environments. Usually these come about through the replacement of natural materials by synthetic ones that are cheaper or better. The replacement of silk by nylon and the alternative of cotton by a whole host of synthetic fibers are examples [1, 2]. Furthermore, nowadays there is an emerging and important technological change in new materials, which is nanotechnology. According to the estimation by foundation of USA science, the nanotechnology market will experience pretty steep annual growths capable of bringing it to more than US$ 1 billion after the year 2010 [2,3]. Hence, to gain the specific and useful information about technology forecasting in the field of new materials in advance become more and more significant.

In traditional raw materials fields, the ceramic powders were used very popular for their features, such as height melting point, insulation, wear-resisting, etc. But the powders still had several weaknesses, like frailty, tenacity, etc. Recently, going along with the development of nanotechnology, the nanosized ceramic powders had some peculiar characteristics, such as ductile, super plastic, unique functions in height temperature, etc. to improve the functions and expand the applications of traditional ones [3]. Many countries attached great importance to the development for those materials. Accordingly, the main purpose of this study is to adopt the case “nanosized ceramic powders” for instance to investigate the technology forecasting of new materials.

Furthermore, little has been done in discussing the technology forecasting on the topic of new materials. It increases the importance and exigency in this kind of research.

During the past several decades, there has been growth in the number of growth curve methods for examining the development of technology, and the substitution of technology. Growth curve method involves fitting a growth curve to a set of data on technological performance, then extrapolating the growth curve beyond the range of the data to obtain an estimate of future performance [2,4,5,6,7]. However, it is rather difficult to forecast the development of technologies as there are rare historical data available, such as in those new materials fields. The bibliometrics method were proposed recently to solve the problem and it could provide an interesting alternative data source of both quantitative counts of evidence of R&D activity and interesting text materials to be exploited [5,8,9,10]. Consequently, this paper would use the bibliometrics method to gain the useful data for growth curve model to investigate the technology forecasting of nanosized ceramic powders.

2. Overview of ceramic powders market

According to the “Advanced ceramic powders and nano ceramic powders” (Business Communications Company, 2003) to plumb the development of nanosized ceramic
The study investigated the market of ceramic powders, which included the manufacture, techniques, features, price, and application of the ceramic powders. Owing to the U.S.A. is the leader of nanotechnology and major supplement country of nanosized powders, this survey was in the light of this country to plumb the development of nanosized ceramic powders [3].

To compare the outputs and output values of ceramic powders with nanosized ceramic powders in U.S.A. would be shown in Table 1 (included the market performances of forecasting in 2007).

From Table 1, we could find all the tendencies of ceramic powders were increased, especially in nanosized ceramic powders (the growth of annual rate would attend to 9.3%). The outputs of advanced ceramic powders were from 40,594 ton in 2002 to 51,259 ton in 2007 and the outputs of nanosized ceramic powders were from 1,058 ton to 1,641 ton in 2007. When comparing Figure 1 and Table 1, the outputs of oxide ceramic powders downgraded slightly and nanosized ceramic powders upgraded. But the oxide ceramic powders still played an important role and occupied the major part of market. From Table 2, we could find the oxide ceramic powders were applied in many fields; especially the alumina powders took the greater part in those applications.

Table 1

<table>
<thead>
<tr>
<th>The output/output value of ceramic powders in USA</th>
<th>2002</th>
<th>2007</th>
<th>AAGR% (2002~2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Output (mil-kg)</td>
<td>Output value (mil-US$)</td>
<td>Output (mil-kg)</td>
</tr>
<tr>
<td>Advanced ceramic powders</td>
<td>405.07</td>
<td>1421.38</td>
<td>511.54</td>
</tr>
<tr>
<td>Oxides</td>
<td>0.57</td>
<td>8.10</td>
<td>0.70</td>
</tr>
<tr>
<td>Carbides</td>
<td>0.25</td>
<td>20.14</td>
<td>0.29</td>
</tr>
<tr>
<td>Nitrides</td>
<td>0.05</td>
<td>2.60</td>
<td>0.06</td>
</tr>
<tr>
<td>Borides</td>
<td>405.94</td>
<td>1,452.22</td>
<td>512.59</td>
</tr>
<tr>
<td>subtotal</td>
<td>10.58</td>
<td>154.46</td>
<td>16.41</td>
</tr>
<tr>
<td>Nano-ceramic powders</td>
<td>416.52</td>
<td>1,606.68</td>
<td>529.00</td>
</tr>
</tbody>
</table>

Note: "mil-kg" means "million kilogram"; "mil-US$" means "million US dollars".

Figure 1

The percentage of output for ceramic powders in USA

<table>
<thead>
<tr>
<th>Year</th>
<th>Oxides</th>
<th>Nanoceramic powder</th>
<th>Carbides</th>
<th>Nitrides</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>97.25%</td>
<td>2.54%</td>
<td>0.14%</td>
<td>0.06%</td>
</tr>
<tr>
<td>2007</td>
<td>96.70%</td>
<td>0.05%</td>
<td>0.01%</td>
<td>0.13%</td>
</tr>
</tbody>
</table>


Table 2

The applications of the oxide ceramic powders in USA

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Output (mil-kg)</td>
<td>Output value (mil-US$)</td>
<td>Output (mil-kg)</td>
</tr>
<tr>
<td>Electronic Applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumina</td>
<td>84.14</td>
<td>354.4</td>
<td>99.38</td>
</tr>
<tr>
<td>Zirconia</td>
<td>2.72</td>
<td>36.0</td>
<td>3.18</td>
</tr>
<tr>
<td>Beryllia</td>
<td>0.02</td>
<td>3.5</td>
<td>0.03</td>
</tr>
<tr>
<td>Titanates</td>
<td>9.98</td>
<td>126.0</td>
<td>12.61</td>
</tr>
<tr>
<td>Ferrites</td>
<td>66.68</td>
<td>238.0</td>
<td>82.56</td>
</tr>
<tr>
<td>Superconductors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>163.54</td>
<td>760.3</td>
<td>197.75</td>
</tr>
<tr>
<td>Structural Applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumina</td>
<td>1.27</td>
<td>31.0</td>
<td>2.00</td>
</tr>
<tr>
<td>Zirconia</td>
<td>0.35</td>
<td>9.6</td>
<td>0.44</td>
</tr>
<tr>
<td>Subtotal</td>
<td>1.62</td>
<td>40.6</td>
<td>2.44</td>
</tr>
<tr>
<td>Thermal Spray Coatings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumina, Alumina/titania</td>
<td>0.95</td>
<td>18.0</td>
<td>1.18</td>
</tr>
<tr>
<td>Zirconia</td>
<td>0.22</td>
<td>10.6</td>
<td>0.25</td>
</tr>
<tr>
<td>Other oxides</td>
<td>0.14</td>
<td>4.5</td>
<td>0.14</td>
</tr>
<tr>
<td>Subtotal</td>
<td>1.31</td>
<td>33.1</td>
<td>1.57</td>
</tr>
<tr>
<td>Chemical Processing and Environmental-Related</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumina</td>
<td>27.22</td>
<td>61.0</td>
<td>31.43</td>
</tr>
<tr>
<td>Silica</td>
<td>13.97</td>
<td>17.0</td>
<td>15.69</td>
</tr>
<tr>
<td>Zirconia</td>
<td>1.15</td>
<td>13.0</td>
<td>1.34</td>
</tr>
<tr>
<td>Titania</td>
<td>1.22</td>
<td>4.4</td>
<td>1.41</td>
</tr>
<tr>
<td>Zeolite</td>
<td>117.03</td>
<td>336.0</td>
<td>145.60</td>
</tr>
<tr>
<td>Cordierite</td>
<td>78.02</td>
<td>156.0</td>
<td>114.30</td>
</tr>
<tr>
<td>Subtotal</td>
<td>238.60</td>
<td>587.4</td>
<td>309.77</td>
</tr>
</tbody>
</table>
### 3. Review of the related applications of growth curve and bibliometrics

#### 3.1 The applications of growth curve method

Frank (2004) used the logistic model to forecast the diffusion of wireless communications in Finland and to plumb the factors which have affected the diffusion process. The logistic model succeeded by means of nonlinear least squares after writing two parameters of the logistic model as functions of certain variables. The results showed that the economic situation has affected the relative growth rate, and that the wireless network coverage has affected the number of potential adopters [4].

Bhargava (1995) proposed a possible generalization of the Fisher-Pry model (one kind of logistic growth curve models) in technology substitution by making the growth parameter time dependent. The computation of time dependence of the growth parameter allows the author to measure departures form Fisher-Pry description. In the study, it adopted three representative data sets: “color TV for black and white in Japan”, “Nylon tire cord for rayon tire cords in USA”, and “synthetic for natural fiber in USA” to verify the reform Fisher-Pry model was better than original one [11].

Ernst (1997) assessed the suitability of patent data for forecasting technological developments, based on the experience in the case of CNC-technology. Following a general description of the technological life cycle concept and the discussion of possible benefits of patent data as a technological forecasting tool, actual patenting activity in CNC-technology was analyzed. It was found that the diffusion of CNC-technology could be appropriately described by means of patent data. Different development stages in the life cycle of CNC-technology would be distinguished, where for each stage strategic R&D investment decisions could be derived [12].

Palmer and Williams (2000) applied the growth curve method to investigate the technology trends within the electronics industry. Through the data from US patents, the model was shown to fit well with an assumed ultimate microprocessor clock speed of 1.2GHz [13].

Bengisu and Nekhili (2006) indicated the steady growth in some of the 20 emerging technologies in Turkey by S-curves method. In the study, which used the most suitable keywords linked to the technologies in question and determined the number of publications and patents in those fields. Through the the bibliometric analysis of publications and patents got the useful data for this survey. The result was also presented a high correlation between the number of scientific publications and patents in most of the technologies investigated [9].

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**Table:**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output value (mil-US$)</td>
<td>1,421.4</td>
<td>2,005.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Output value (mil-US$)</td>
<td>511.55</td>
<td>106.46</td>
<td>7.1</td>
</tr>
</tbody>
</table>

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To summarize the above-mentioned, we could find the growth curve methods were suitable used in examining the development of technology, and the substitution of technology. In addition, there were more and more researches integrating the bibliometric analysis of publications and patent data with growth curve methods for technology forecasting.

3.2. Bibliometrics for data source in technology forecasting

Bibliometrics is defined by Norton [14] as the measurement of literatures and texts. The approach is to capture some of the information inherent in the content and patterning of the literature. Bibliometrics uses counts of publications, patents, or citations to measure and interpret technological advances [5].

Historically bibliometric methods have been used to trace back academic journal citations. However, today bibliometrics can be used to understand the past and even potentially to forecast the future [15,16,17]. Three major forms of bibliometric analysis have emerged. Citation analysis examines referencing patterns among papers and/or patents to detect seminal contributions and interaction patterns, and even to forecast emerging research areas. Patent analysis relates patenting activity to profile company interests and industry trends. Publication analyses take articles and such as telling indicators of R&D activities [18].

Linkage is a particular interest in bibliometrics, leading to development of several analytical approaches based on entities appearing together. Co-word analysis is most common tool to infer the cognitive structure from looking for words appearing together and extracting multiword phrases or keywords frequencies [5]. By the way, it is very prevalent in using the engineering index (EI) database for bibliometric analysis [5,9,10,14,15,19,20]. In this study, we adopt the approach and databases to gain the related information.

To summarize, Bibliometrics could provide a nicely accessible and cost-effective data or information. It helps to explore, organize and analyze amounts of historical data helping researchers to identify “hidden patterns” that may help researchers in the technology forecasting and decision making process [5,9].

4. The growth curve method

Forecasting by growth curves method is based on the parameter estimation of a technology’s life cycle curve. It is helpful in estimating the level of technology growth or decline at each stage of the life cycle and in predicting when the technology will reach a particular stage [4,5,6,7,11]. Figure 2 illustrates the S-curve concept of a technological life cycle, where four different development stages can be distinguished. The emerging stage is characterized by a relatively low growth of technological performance compared to the amount of R&D efforts. In the growth stage, the marginal technological progress over cumulative R&D expenditures is positive, whereas it is negative in the maturity stage. In the saturation stage small technological performance improvements are only gained through very high R&D efforts [1,12].

Continuously, we would elaborate “logistic growth curve” which was the most popular growth curve model in technology forecasting field.

Owing to the logistic growth curve model involves both particular information about which technology performance level already achieved and distance to the upper limit, the model becomes the most frequently used by technology forecasters [6,7].

The formula for the Logistic curve is:

\[
P(t) = \frac{k}{1 + \exp(-\alpha(t - \beta))}
\]

\(P(t)\): the variable representing performance

Equation (1) produces the familiar S-shaped curve. Note that three parameters are needed to fully specify the curve, \(\alpha, \beta, k\).

The growth rate parameter \(\alpha\) specifies the “width” or “steepness” of the sigmoid curve. It is often helpful to replace \(\alpha\) with a variable that specifies the time required for the trajectory to grow from 10% to 90% of the limit \(k\), a period which called the characteristic duration, or \(\Delta t\) (Meyer, Yung, and Ausubel, 1999). Through simple algebra, the characteristic duration is related to \(\alpha\) by

\[
\Delta t = \frac{\ln(81)}{\alpha}
\]

The parameter \(\Delta t\) is usually more useful than \(\alpha\) for the analysis of historical time-series data, because the units are easier to appreciate. The parameter \(\beta\) specifies the time when the curve reaches \(1/2k\), or the midpoint of the growth trajectory, often re-labeled \(t_m\). The parameter \(k\), as discussed, is the asymptotic
limit that the growth curve approaches, i.e., market niche or carrying capacity. The logistic model is symmetric around the midpoint $t_m$ [21].

The three parameters $k$, $\Delta t$, and $t_m$ define the parameterization of the logistic model used as Equation (2):

$$P(t) = \frac{k}{1 + \exp\left(-\ln(81)\left(t - t_m\right) / \Delta t\right)}$$  \hspace{1cm} (2)

5. Research design

5.1. Survey design

Owing to the research would investigate the technology forecasting of nanosized ceramic powders. This study was conducted to gain the technology performance level already achieved and distance to the upper limit of nano-ceramic powders. The technology performance was developed based on logistic growth curve approach. We adopted bibliometrics analysis, and used the engineering index (EI; included the Compendex and INSPEC) database and trademark office (USPTO) database for the research data. We divided our objects of study into two categories; they were “Traditional ceramic powders” and “Nanosized ceramic powders”. In addition, pondering the performances of output and output value in the traditional ceramic powders field, we picked up the “ceramic powder”, “oxide powder (occupied over 90% in the traditional ceramic powders field; Table 1 and Figure 1)”, and “alumina powder” (occupied over 30% in the oxide ceramic powder field; Table 2) for further objects of study in both categories.

We first cumulated the frequencies of data from bibliometrics. Then the data were input into Loglet Lab software to gain the logistic growth curves. Finally we got the technology growth curves information about saturation, midpoint, and growth time for analyzing the technology developments and tendencies.

5.2. Date collection and analysis

The data collection of this survey, the web of EI database and trademark office (USPTO) database were built up around from 1970 to the present. Our data collections were in this period. We used the Co-word analysis to infer the cognitive structure from looking for words appearing together and extracting multiword phrases or keywords frequencies. And then to cumulate the frequencies of data for fitting logistic growth curves could garner the technology performance of nano-ceramic powders.

In this study, the logistic growth curve was programmed in Loglet Lab software. It could calculate time-series growth data sets to gain the growth curve information about saturation (it described the saturation level of the logistic curve), midpoint (or turning point; it described the midpoint of the logistic curve, at which point the logistic curve begins to level off), and growth time (it described the time in which the logistic curve goes from 10% to 90% of its expected saturation level or it meant the growth and maturity period of technology life cycle).
6. Results and discussion

6.1. Traditional ceramic powders

We first examined the traditional ceramic powders of technological life cycles. This was done by bibliometric methods and co-word analysis through the EI database.

6.1.1. Ceramic powder

Investigating the development activities of ceramic powder technologies, the numbers of publications of those were obtained through EI database from 1969 to 2005. Using the terms “ceramic” adjacent to “powder” yielded 14812 related cumulative publications in the period. The data of the cumulative ceramic powder publications was modeled by logistic growth curve function, as shown in Figure 3.

The growth curve of ceramic powder by using the logistic model: the number of publications

From Figure 3, we could get significant information about technological life cycle of ceramic powder. The midpoint of the ceramic powder growth curve was in 1998 years and the drop in publication activity in that year also might represent the passage of an inflection point on the technology growth curve. In the years of 1985-1998 and 1998-2011 periods, the curve could be divided into the growth and maturity pattern. The
The saturated number of publications of the cumulative ceramic powder might be attained to 18690.

6.1.2. Oxide powder

In this item, using the terms “oxide” adjacent to “powder” yielded 11109 related cumulative publications through EI database from 1969 year to 2005 year in traditional ceramic powders field. The data of the cumulative oxide powder publications were modeled by logistic growth curve method, as shown in Figure 4.

From Figure 4, we could get important information about technological life cycle of oxide powder. The midpoint of the oxide powder growth curve was in 2001 years and it also might represent the avenue of an inflection point on the technology growth curve. In the years of 1986-2001 and 2001-2016 periods, the curve could be divided into the growth and maturity pattern. The saturated number of publications of the cumulative oxide powder might be attained to 16362.

Figure 4

The growth curve of oxide powder by using the logistic model: the number of publications.

6.1.3. Alumina powder

In this subject, using the terms “alumina” adjacent to “powder” yielded 5092 related cumulative publications through the EI database from 1969 year to 2005 year in traditional ceramic powders field. The data of the cumulative alumina powder publications were modeled by logistic growth curve model, as shown in Figure 5.

Figure 5
The growth curve of alumina powder by using the logistic model: the number of publications

From Figure 5, we would gain significant information about technological life cycle of alumina powder. The midpoint of the alumina powder growth curve was in 2002 years and it also might represent the way of a turning point on the technology growth curve. In the years of 1988-2002 and 2002-2016 periods, the curve could be divided into the growth and maturity pattern. The saturated number of publications of the cumulative alumina powder might be attained to 8124.

6.2. Nanosized ceramic powders

In this section, we would survey the nanosized ceramic powders of technological life cycles continuously. That was done dividedly by bibliometric method through the EI and USPTO databases. We picked up the “nanosized ceramic powder”, “nanosized oxide powder”, and “nanosized alumina powder” for our objects of study connectedly.

6.2.1. Nanosized ceramic powder

To investigate the development activities of nanosized ceramic powder technologies, we gained the data from EI and USPTO databases through the bibliometric analysis separately.

Using the terms “nano or nanosized ceramic” adjacent to “powder” yielded the related cumulative numbers of publications. The cumulative data was modeled by logistic growth curve function, as shown in Figures 6-9. Figures 6 and 8 depicted the cumulative data growth curves in the nanosized ceramic powders field. Figures 7 and 9
stretched the time scale and performance of the technology to deeply comprehend the technology development.

**Figure 6**

The growth curve of nanosized ceramic powder by using the logistic model: the number of publications from EI database
(Time scale: 1980~ 2005)

![Graph](image)

From Figures 6-9, we could gain significant information about technological life cycle of nanosized ceramic powder and verify the performances by each other through the EI and USPTO databases. The midpoint of the nanosized ceramic powder growth curve would approximately be in 2012-2014 years. In the years of 2005-2014 and 2014-2022 periods, the curve could be divided into the growth and maturity pattern. Nowadays, we could boldly conceive the technology of nanosized ceramic powder as an emerging technology or in the initial growth period.

**Figure 7**

The growth curve of nanosized ceramic powder by using the logistic model from EI database (Time scale: 1980~ 2030)
Figure 8
The growth curve of nanosized ceramic powder by using the logistic model: the number of patents from USPTO database
(Time scale: 1980~2005)

Figure 9
The growth curve of nanosized ceramic powder by using the logistic model from USPTO database (Time scale: 1980~2030)
6.2.2. Nanosized oxide powder

In this subject, using the terms “nano or nanosized oxide” adjacent to “powder” yielded the related cumulative numbers of publications in ceramic powders field through the EI and USPTO databases. The cumulative data was modeled by logistic growth curve method respectively, as shown in Figures 10-13. Figures 10 and 12 depicted the cumulative data growth curve in the nanosized oxide powders field. Figures 11 and 13 expanded the time scale and performance of the technology to perceive the technology development.

From Figures 10-13, we could get important information about technological life cycle of nanosized oxide powder and verify the performances by each other through the EI and USPTO databases. The midpoint of the nanosized oxide powder growth curve would probably be in 2013. In the 2006-2013 and 2013-2020 periods, the curve could be divided into the growth and maturity pattern. The growth limits of publications and patents about the cumulative oxide powder might be attained to 7790 and 3378. Up to now, we could conjecture the technology of nanosized oxide powder as an emerging technology or in the initial growth period.
Figure 10
The growth curve of nanosized oxide powder by using the logistic model: the number of publications from EI database (Time scale: 1987~2005)

Figure 11
The growth curve of nanosized oxide powder by using the logistic model from EI database (Time scale: 1987~2030)
6.2.3. Nanosized alumina powder
In this item, using the terms “nano or nanosized alumina” adjacent to “powder” yielded the related cumulative numbers of publications in ceramic powders field through the EI and USPTO databases. The cumulative data was modeled by logistic growth curve method, as shown in Figures 14-17. Figures 14 and 16 depicted the cumulative data growth curve in the nanosized alumina powders field. Figures 15 and 17 stretched the time scale and performance of the technology for comprehending the technology development.

From Figures 14-17, we could gain significant information about technological life cycle of nanosized alumina powder and validate the performances by each other through the EI and USPTO databases. The midpoint of the nanosized alumina powder growth curve would approximately be in 2010-2012 years. In the years of 2002-2012 and 2012-2022 periods, the curve could be divided into the growth and maturity pattern. The growth limits of publications and patents about the cumulative alumina powder might be attained to 1351 and 700.

Finally, to sum up all of the comparative results of this survey would be presented in Table 3.

Figure 14

The growth curve of nanosized alumina powder by using the logistic model: the number of publications from EI database
(Time scale: 1985~ 2005)
The growth curve of nanosized alumina powder by using the logistic model from EI database (Time scale: 1985~2030)

![Graph](image1.png)

Figure 15

The growth curve of nanosized alumina powder by using the logistic model: the number of patents from USPTO database (Time scale: 1980~2005)

![Graph](image2.png)

Figure 16
Figure 17

The growth curve of nanosized alumina powder by using the logistic model from USPTO database (Time scale: 1980~ 2030)

Table 3
Comparison of the technology performances of nanosized ceramic powders

<table>
<thead>
<tr>
<th></th>
<th>Midpoint [years]</th>
<th>Growth period [years]</th>
<th>Maturity period [years]</th>
<th>Saturation [numbers]</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Oxide powder</td>
<td>2013</td>
<td>2006-2013</td>
<td>2013-2020</td>
<td>7790</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3378</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nanosized alumina powder</td>
<td>2010-2012</td>
<td>2002-2012</td>
<td>2012-2022</td>
<td>1351</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>700</td>
</tr>
</tbody>
</table>

Note: [ ] the number of patents from UEPTO database.

6.3. Sensitivity analysis on the estimated parameters

In the growth curve model, it is very important to know “how accurate are the estimated parameters for the data”? Owing to we programmed the growth curve models in this study by Loglet Lab software which applied the “bootstrap method” to solve it. The bootstrap method [22] provides a means for re-creating and re-sampling data using
Monte Carlo methods. The bootstrap method used the residuals form the least squares fit to the synthesize data sets. Then by the Central Limit Theorem, it assumed the bootstrapped parameter estimates were normally distributed around a sample mean. From these sets it could proceed to compute confidence intervals for the parameters. And from the confidence intervals of a parameter, it would form a confidence region which contains the set of all curves corresponding to all values of that parameter.

We could use the case “ceramic powder” to illustrate it. From Figure 18 we would find the shadow area represented the 90% bootstrap confidence intervals on the estimated parameters for the growth of the “ceramic powder” case. We could find out the intervals of the estimated parameters, they were “saturation” between 17139~19769; “midpoint” between 1997.1~1999.1; and “growth time” from 23.6~27. The results of the sensitivity analysis about other cases in this study were summarized in Table 4.

The 90% bootstrap confidence intervals on the estimated parameters for the growth of the “ceramic powder” case

![Figure 18](image)

Table 4

<table>
<thead>
<tr>
<th></th>
<th>Midpoint [years]</th>
<th>Growth time [years]</th>
<th>Saturation [numbers]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic powder</td>
<td>1997.1-199.1</td>
<td>23.6-27</td>
<td>17139-19769</td>
</tr>
<tr>
<td>Nanosized ceramic powder</td>
<td>2013.1-2014.2</td>
<td>15.8-16.3</td>
<td>8196-10613</td>
</tr>
<tr>
<td></td>
<td>[2010.9-2012.2]</td>
<td>[14.6-15.1]</td>
<td>[5371-7396]</td>
</tr>
<tr>
<td>Oxide powder</td>
<td>1999.5-2001.5</td>
<td>28.3-31</td>
<td>15079-17392</td>
</tr>
<tr>
<td>Nanosized</td>
<td>2013-2014.7</td>
<td>13.7-15</td>
<td>7080-12565</td>
</tr>
</tbody>
</table>
### 7. Conclusions

New materials have been recognized as significant drivers for corporate growth and profitability in today’s fast changing environments. The nanosized ceramic powders played important parts in new materials field nowadays. However, little has been done in discussing the technology forecasting for the new materials development. Accordingly, this study applied the Logistic growth curve method to investigate the technology performances of nanosized ceramic powders. We adopted the bibliometric analysis through EI and USPTO databases to gain the useful data for this work. This study could be an important reference for technology forecasting and development of new materials field.

Several major findings could be made as follows: Firstly, the technologies of nanosized ceramic powders were all emerging technologies or in the initial growth periods of technological life cycles. Secondly, the technology performances of nanosized ceramic powders through the EI and USPTO databases were similar and verified by each other. Thirdly, the technologies of nanosized ceramic powders were all emerging technologies or in the initial growth periods of technological life cycles. Secondly, owing to the performances of technological life cycles for nanosized ceramic powders, we could boldly conceive that there were some parts of substitutions between traditional and nanosized ceramic powders. To be more elaborated, the traditional ceramic powder would attain the slow growth period (maturity period) of technological life cycle in 2011 years, but the nanosized ceramic powder would roughly simultaneously arrive the fast growth period in 2012-2014 years (Figure 19). Finally, the bibliometric analysis was proposed as the simple and efficient tools to link the science and technology activities and to obtain quantitative and historical data for helping researchers in technology forecasting, especially in rare historical data available fields, such as the new materials fields.
Comparison of the technology performances between traditional and nanosized ceramic powder

References


