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PATENT ANALYSIS AND TECHNOLOGICAL DEVELOPMENT FOR CONCRETE MINERAL ADMIXTURES

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Abstract. *Concrete is predominantly used in structural construction. To determine the development of technologies associated with the application of mineral admixtures to concrete production, 422 patent data were sampled from a database managed by the United States Patent and Trademark Office. This study evaluated these data for examining the characteristics of concrete, such as workability, safety, economy, durability, and ecological characteristics, developed using diverse technologies in various years. Patents that were cited more than three times were analyzed, and the results revealed that the number of patent applications peaked in 2000 and then declined annually. In addition, the technologies developed before 2000 focused on the workability and durability of concrete products, and most key patents were owned by specific companies. This study proposes that the safety and ecological characteristics of concrete products should be emphasized in future technology development processes. The findings of this study may serve as a reference for relevant technology development communities when determining future technological development directions.*

Keywords: Concrete mineral admixture, Patent analysis, Technological development

1. **Introduction.** Concrete has long been the most significant material used for the main structure of buildings. Since the 1970s, to satisfy the market demand, the construction industry has been developing new material technologies for concrete, and the research conducted internationally by industry, government and academia on proportion design theory, mechanical properties, durability, chemical admixture, concrete production quality, cement and the use of fly ash cementing materials has resulted in significant progress [1]. Depending on the content of the different materials used, the concrete produced has different applications, such as high-performance concrete, recycled concrete and eugenic concrete [2,3]. In order to analyze the R&D strategies for concrete technologies, it is necessary to understand the concrete-related technological and industrial background and contents, including the relevant processes and compositions of the materials (cement, aggregate, admixture) and engineering design of the specific product (ordinary concrete and special concrete), quality inspection, laws and regulations, technology development and materials research. Also, technological information on patents related to concrete technology must be acquired, as well as information on innovative developments, both domestic and foreign, in order to investigate their applicability by means of sorting, comparing and analyzing their effects. The aim is to construct a framework for the development of the most appropriate concrete technology and industry technology. The increasingly

competitive nature in the areas of technological development and innovation has been evidenced by the manner in which industries try to beat each other in acquiring the latest patents or innovative technology in order to gain a competitive advantage (e.g., low cost, high quality, high productivity) [4]. So, a broad and objective technological analysis designed to explain and verify the various aspects of concrete technology, together with a strategic analysis of the key technology, technical evolution, distribution, as well as trend induction and exploration direction, would be of benefit. The production of concrete depends on the ratio of cement, sand and water, with the different admixtures, such as high early strength concrete, high-strength concrete and high-performance concrete, suitable for different applications.

The aim of this study, from the perspective of patent analysis, is to analyze the classification and developing technological trends for concrete mineral admixtures so as to provide the relevant practitioners with the information which will allow them to accurately judge their investment and R&D requirements. This study will also address the development of sustainable investment strategies. The research framework includes: (1) the classification of concrete technology effects; (2) collection process of information on relevant patented technologies and corresponding analysis; (3) technological function analysis on concrete mineral admixtures; and (4) research conclusions and suggestions.

2. **Concrete Admixture Technology and Function of Concrete Admixture.** Concrete is the collective name for integrated composite materials aggregated by cementing materials, generally including cement, sand, stone and water. The cement serves as the bonding material. After water has been added, the mixture has the solid performance of hydrated bonding. The aggregates of solid gravel, sand or pebbles are then added proportionally. After stirring, molding and curing, the artificial stone [5], as shown in Figure 1, which is normally called cement concrete or ordinary concrete, is formed. Concrete is an integrated composite material made of fillers cemented by binders. The fillers include coarse and fine aggregates; the binders include cement, water and an admixture.

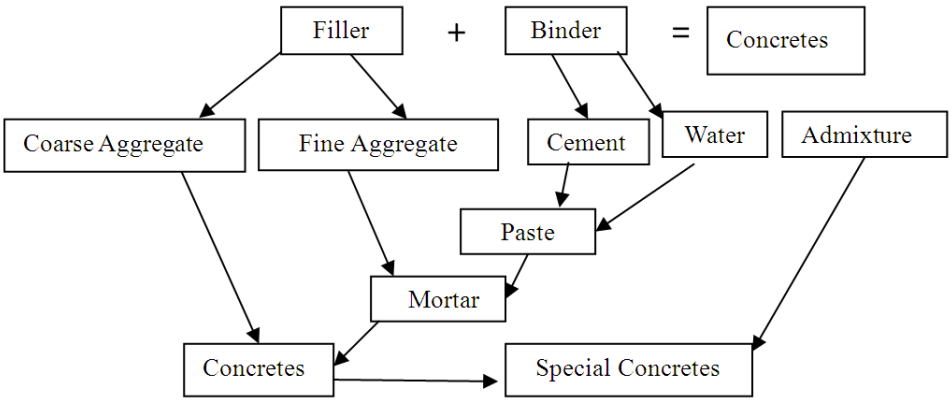

FIGURE 1. Illustration of concrete components [4]

If some specific quality of original concrete is required, such as with eugenic concrete, the workability, safety, durability, as well as the economic, ecological or other special considerations must still be satisfied. So it is necessary to add what is referred to as an admixture to produce this special concrete [6]. Admixtures, according to the definition of the ASTM (American Society for Testing and Materials), are the other materials which make up the concrete, except for the basic components of cement, sand, stone and water. The purpose of using admixtures is to enhance the performance of the original concrete in some way, such as improving the workability, strength, durability, economy, ecology, volume stability or ability to control the coagulation time of the concrete in order for its quality to meet the construction requirements.

3. **Patent Collection and Analysis of Concrete Admixture Technology.** M-Trends is a global Patent Search and Analysis System which possesses the complete database of global patents [7]. The humanized patent source software is used to examine the applied patent mechanism and trend analysis. Accordingly, this study selected the USPTO-PATENTDATABASE to source mineral admixture and concrete data in order to conduct an extensive combination source between them. The source conditions are indicated in Table 1, with a total of 541 patents. In the next stage of sourcing, we retained concrete admixtures and excluded patents unrelated to this study. In the end, 422 cases remained as the samples for this study's analysis.

Table 1. Patent search conditions and results

Patent search condition	Source year range	Number of patents	Number of patents after filtering
(Mineral admixture* <IN> CLMS) AND (concrete <IN> ABST)	1971∼2014	541	422
Note: CLMS: Claim; ABST: Abstract			

3.1. **Analysis of number of patent applications in the years 1971∼2014.** The number of patent applications for concrete mineral admixtures over the years is shown in Figure 2. The development cycle can be divided into 4 major stages: the first from 1971∼1984 with 83 applications; the second from 1985∼1999 with 148 applications; the third from 2000∼2008 with 134 applications; and the fourth from 2009∼2014 with 57 applications. The peak period was from 2000∼2002 with 60 patent applications. Since 2003, the related patent technology applications have declined. While it appears that concrete mineral admixture technology has been at a standstill, developments in recent years while facing bottlenecks, should be noted.

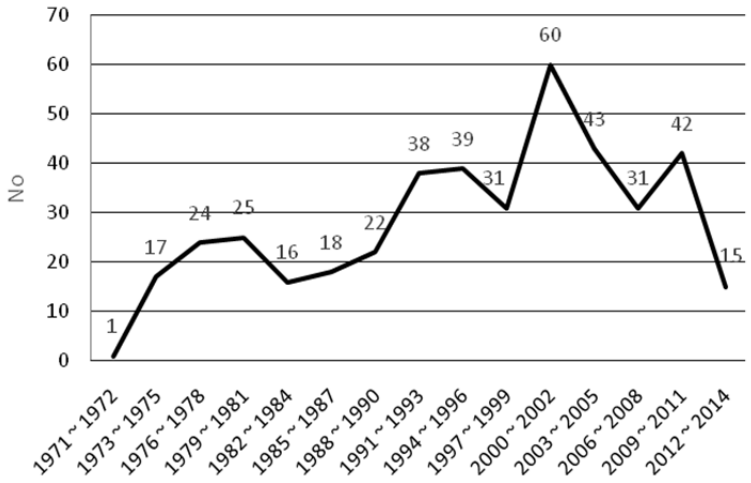

Figure 2. Patent application number during 1971∼2014 (unit: each 3 years)

3.2. **Patents most cited in projects.** The top 10 patents being cited in projects are listed in Table 2. The patent at the top of the list was for "04210457 Portland cement-fly ash-aggregate concretes", which was cited 12 times. This patent was applied for by W. R. Grace & Co-Conn, a world famous manufacturer of concrete and chemical materials. Of the cited Top Ten patents, 5 were applied for by W. R. Grace & Co., which makes this company the core patent owner and manufacturer of concrete mineral admixtures. In Number 2 position was the patent for "04640715 Mineral binder and compositions employing the same", which was applied for by Lone Star Industries, Inc. This company has 3 of the Top 10 patents most cited.

Table 2. Top 10 patents most cited in projects

PPNO	Name of Patent	Applicant	No. of Self-Cited	No. of Cited by Others	No. of Cited by Patent
04210457	Portland cement-fly ash-aggregate concretes	W. R. GRACE & CO.-CONN.	1	11	12
04640715	Mineral binder and compositions employing the same	LONE STAR INDUSTRIES, INC.	1	7	8
04961790	Concrete admixture device and method of using same	FRITZ CHEMICAL COMPANY	1	7	8
04842649	Cement composition curable at low temperatures	LONE STAR INDUSTRIES, INC.	1	6	7
04997484	Hydraulic cement and composition employing the same	LONE STAR INDUSTRIES, INC.	0	7	7
05203629	Method for modifying concrete properties	W. R. GRACE & CO.-CONN.	0	8	8
05779788	Cement composition	W. R. GRACE & CO.-CONN.	1	7	8
05618344	Cement composition	W. R. GRACE & CO.-CONN.	1	5	6
05938835	Cement composition	WELLS FARGO BANK, NATIONAL ASSOCIATION, AS COLLATERAL AGENT	0	7	7
05626663	Composition and method for inhibiting drying shrinkage of concrete	W. R. GRACE & CO.-CONN.	1	4	5

4. **Technological Function Analysis on Concrete Mineral Admixture.** In order for a technological function analysis on concrete mineral admixture patents to be conducted efficiently, this study focused on the 34 patents which were each cited more than 3 times. Then, according to the main technological content of each patented mineral admixture, the abstract, technical means and patent application range of each patent were determined. The analysis focused on the main effects claimed for the mineral admixture and the corresponding effects, including workability, safety, economy, durability, ecological impact and others. The related contents are arranged and listed in Table 3. The analysis results, as noted in Table 4, show the major target effects of the concrete mineral admixtures in the related patents to be workability (31.08%), durability (28.37%) and safety (24.32%). The claims of effects for the related patents were identical to past

Table 3. Main effects and contents of concrete

Effects	Description	Relevant Index
A/Workability	Improve the mobility of concrete during construction and make concrete fully fill all corners.	Mobility
B/Safety	Safety during construction and satisfaction of design strength demand after hydrating	Good early strength, easy to satisfy design strength
C/Economy	Reduce cost related to concrete construction or materials	Reducing cost
D/Durability	Improve concrete's durable nature to environment to prevent from subsequent deterioration.	Material stability after hydrating
E/Ecology	Reduce the influence on environment or environmental way to save energy.	Environmental, energy-saving
F/Others	Features besides above 5 items	Lightweight, porous...

TABLE 4. Patent list, content and effects description of patents cited more than 3 times

No.	Patent No.	Cited Times	Date of App.	Technology (Admixture)	Effects					
					A	B	C	D	E	F
1	4210457	12	1978.10	ash		◯	◯	◯		
2	4640715	8	1985.3	ash, calcined shale, calcined clay	◯	◯				
3	4961790	8	1989.5	powdered concrete admixture contained in a water-soluble container	◯		◯			◯
4	4997484	7	1990.6	ash, alkali metal activator		◯		◯		
5	5203629	7	1991.4	calcium chloride, triethanolamine, sodium thiocyanate, calcium formate, calcium nitrite, and calcium nitrate	◯			◯		
6	4842649	7	1987.10	ash, slag, potassium carbonate	◯	◯				
7	5779788	7	1996.8	oxyalkylene adducts with a sulfonated organocyclic material	◯	◯				
8	5618344	6	1995.11	mixture of certain lower alkyl ether oxyalkylene adducts with certain higher alkylene diols		◯		◯		
9	5938835	6	1997.10	mixture of certain alkyl ether oxyalkylene adducts with certain oxyalkylene glycols		◯		◯		
10	5626663	5	1995.8	polyol compound		◯		◯		
11	6224250	5	2000.2	material production method	◯		◯			
12	6875266	5	2002.7	organic polymeric material	◯		◯			
13	7386368	5	2007.9	mix design and monitoring methods		◯	◯			
14	4588443	5	1981.12	inorganic solid silica dust particles		◯		◯		
15	4111711	5	1977.7	alkaline-earth mineral such as a slag	◯			◯		
16	4513040	4	1983.4	(concrete tiles) fine metal fibers, Metallic, inorganic aggregate				◯		
17	5173115	4	1991.7	quicklime	◯			◯		
18	4992102	3	1988.8	cement kiln dust (CKD) class C fly ash, class F fly ash	◯	◯		◯		
19	6881257	3	2003.7	perlite, short sisal fibers	◯		◯			
20	7044170	3	2003.7	prestressed concrete method of production	◯			◯		
21	6548589	3	2001.3	water-soluble acrylic copolymer with cement dispersing	◯	◯		◯		
22	6080234	3	1997.7	admixture of metal fibers	◯			◯		◯
23	5804175	3	1995.10	cement produced method		◯		◯		
24	5840114	3	1996.5	calcium salt, calcium nitrate, calcium chloride, calcium formate	◯	◯		◯		
25	7815728	3	2008.5	infrared reflective pigment composition comprising					◯	
26	5735947	3	1997.4	glass, slag, silica fume	◯		◯			
27	5266111	3	1992.10	class F fly ash, cement kiln dust	◯	◯				
28	5413819	3	1993.11	phosphonic acid	◯					
29	5460648	3	1994.4	water-insoluble oil selected				◯		
30	5466289	3	1993.9	silica fume, blast-furnace slag and fly ash	◯	◯		◯		
31	4559881	3	1983.8	Portland cement, fly ash, fine aggregate, gravel or crushed stone, water, high range superplasticizing water-reducing admixture, and steel fibers	◯			◯		
32	4019918	3	1976.2	plaster of paris, lignosulfonate comprises calcium lignosulfonate.	◯	◯		◯		
33	4683003	3	1985.4	calcium aluminate, rapid-hardening cement	◯			◯		◯
34	4306912	3	1980.5	slag, technical fly ash and/or natural fly ash	◯	◯	◯			
				Subtotal (74)	23	18	8	21	1	3

claims for high-performance concrete and eugenic concrete. However, the related technological development of the above 3 effects has tended to be more gradual. In other words, the early technology of concrete production placed less emphasis on issues relating to ecological and economic impact. Over the past decade, the increasing awareness of environmental issues has resulted in a corresponding increase in the development of

ecological technology. For example, Patent No. 7815728 (applied for in May 2008) is for an admixture which can improve the heat reflectivity and insulating effects of concrete [8]. Such technological developments indicate the future direction of concrete material production. On the other hand, determining how to promote the production process of eugenic concrete and monitoring system can be viewed as an important short-term goal. For example, Patent No. 7386368 emphasizes the monitoring technology of the concrete production process [9].

5. **Conclusions.** Concrete technology is an indispensable technology for the construction industry, the success of which depends on project costs, progress, quality, safety and sustainability. This study, based on a patent analysis view, analyzed the development and direction of concrete mineral admixture technology and reached the following conclusions.

1. For nearly 40 years the number of patent applications in the field of concrete mineral admixture technology showed a steady increase, but that growth has slowed in recent years. The technology relating to mineral admixtures has leveled out, and will remain so until new technologies or developments bring about a change. The analysis of the concrete mineral admixture technological functions showed workability and durability to be the subjects of most concern in past patent applications. In the future, safety and ecological impact will prove to be the important points for patent technological development.
2. The analysis of patent technical applicants (owners) and the situations of multiple citations in projects showed that most of the key patents were applied for by a particular group of companies, giving them a distinct advantage, both technologically and in terms of market competitiveness. Future analyses will focus on patent trends in emerging markets, in order to compare patent applications in different areas and to create a technological development index.

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