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Development Model of the Die and Mold Industry in Asia: A Comparative Analysis of Japan and Republic of Korea

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Abstract

There are two main objectives of this paper. The first is to identify factors behind the successful progress of the die and mold industry in Republic of Korea. The second is to evaluate the role of digital technology in transferring process of die and mold-related techniques from Japan to Korea. Regarding the first objective the author arrived at the factors of "market", "digital technology", and "human development". The development of the die and mold industry in Korea, which satisfied these three conditions was termed the "Korean-style development model." By analyzing the case of Korea, it is possible to suggest that the introduction of digital technology made it easy for transferring process of die/mold-related techniques to other Asian countries. Further, introduction of "digital technology" alone is not sufficient condition. The requirements of "market" and "human development" conditions are also satisfied together. If all of the above mentioned requirements are satisfied, the die/mold industries of Asian countries have high potential to develop with the techniques followed by the "Korean-style development model". Finally, since the role of government was very important under the Korean-style development model, it is essential to identify the appropriate role of government in developing countries with respect to transferring technology and development of die/mold industry in Asia.

1. Introduction

This paper chose the Korean die/mold industry as the subject of analysis due to its special position in Asia. The die and mold industry of Japan has been the leader in the world, and its export has been far exceeding imports. However, the Republic of Korea (hereafter Korea in this paper) is the only country in Asia that exports to Japan more than its imports from Japan (Mizuno 2001, Egashira 2001). Same as the other Asian countries, Korea had been a net importer of die/mold from Japan until the mid-1990s. Therefore, the main purpose of this paper is to investigate reasons behind the remarkable progress of the Korean die and mold industry during the past few decades. The aim of this paper can be divided into two parts. The first is to identify main factors of success of the Korean die/mold industry. The second is to evaluate the role played by the digital technology in transferring process of the die and mold-related techniques from Japan to Korea.

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1.1. Die and Mold Industry in Japan and its Transition of Import/export

The die and mold industry is not been familiar to ordinary people. The reason for this is that although the finished products and components catch the eyes of users, the die and mold that actually make the products and components are invisible. Nevertheless, hundreds of die/mold is necessary for making vacuum cleaners and other small household electric appliances. The die/mold is the indispensable mother tool for the production of industrial goods. The die/mold industry rarely appears on stage, but the high evaluation of Japanese products in overseas markets is supported by the die/mold industry.

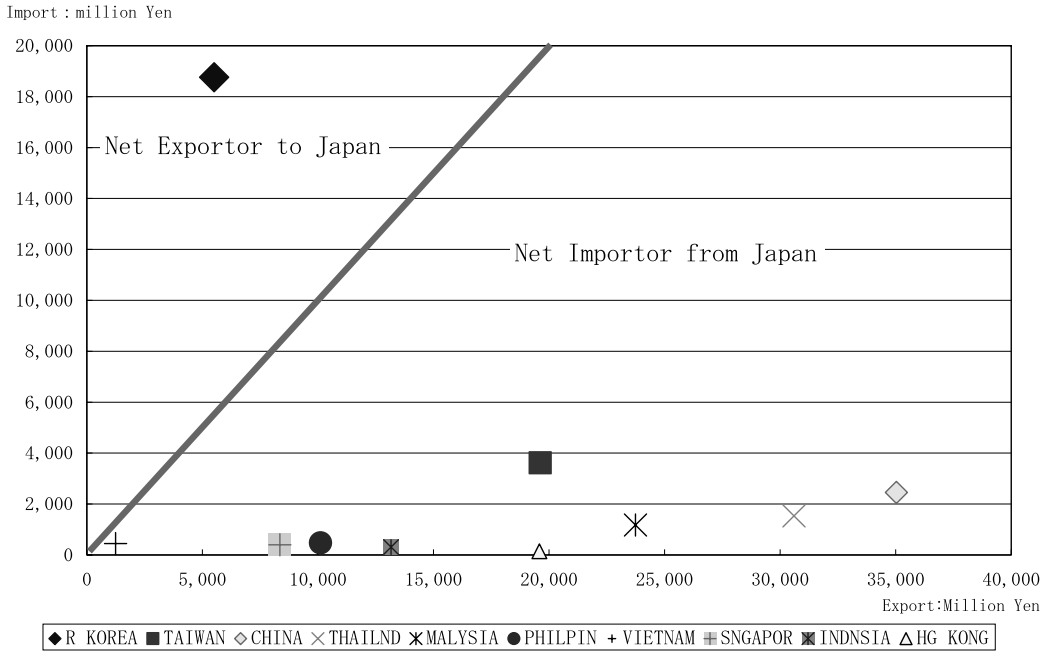
High quality and mass production became possible mainly and only because the die/mold industry of Japan kept supplying high-precision die/mold to product manufacturers. Products of high-quality design offer high performance when they are assembled with high-precision components. High-precision components, in turn, can be produced in big quantities with high-precision die/mold.

These high-precision dies/molds were said to be made exclusively by Japan, and it was estimated early in the 1990s that one-third of the world's dies/molds were produced in Japan by International Special Tooling and Machining Association. From the 1970s to the late 2005, Japan was a constant net exporter of die/mold.

1.2. The Die/mold Industry in Republic of Korea and its Transition of Export to Japan

According to Takeda (2001a), the production of die/mold started in the 1930s in Korea. In order to procure military supplies for the Japanese forces in those days, Japanese engineers made die/mold using lathes and millers. The die/mold industry of Korea was actually established in the 1960s. With the implementation of the first five-year economic development plan in 1962, Korea prepared design drawings by copying the die/mold that had been imported.

Figure1 Dies and Molds Import and Export between Japan and Asian Countries



Source: Calculated by Japan Exports and Imports each year

They began to produce die/mold based on these drawings. Afterwards, Korea placed importance on the die/mold industry, but high-quality die/mold could not be made in the country. Many die/mold products are still importing from Japan. Meanwhile, Korea attempted to obtain technology from overseas, especially from Japan, and tried to upgrade their die and mold industry. As a result, the die and mold industry of Korea had been gradually shifting from net importer position to net exporter position during the 1990s. As is shown in Figure1, Japan imported the biggest quantity from Korea in 2000, which accounted for 49.2% of the total import of die/mold. The second biggest exporter to Japan was Taiwan, but it accounted for only 9.5% in 2000. According to imports and export statistics on die and mold industry between Japan and Asian countries, only Korea was the net exporter to Japan in 2000. However, Korea had been among the Asian net importers of dies/molds from Japan until the early 1990s. By analyzing the factors of this change of the Korean die/mold industry, it is expected that the requirements of the technical transfer of related supporting industries can be clarified. A detailed result of the analysis is presented in another section.

2. Technological Transition of Die/mold Industry in Japan

One of the objectives of this paper is to investigate "whether digital technology made it easy to transfer die/mold-related technology to Korea." In order to study this issue, it is necessary to analyze the influence that digital technology had on the die/mold industry. For this purpose, by analyzing case studies of Japan's die/mold industry, which is the world leader, the author would like to review how and from when digital technology influenced the die/mold industry. The following is based on the result of interviews and summarize of pre-studies.

2.1. Transition of the Design and Production Process of the Die/mold Industry

2.1.1 Budding Period of the Die/mold Industry :1870s-1940s [1]

The die/mold has a very long history. In old Egypt, tools were made by mold-casting. About two thousand years ago in Japan, ornaments, coins, and copperware were likely already being made by mold-casting. The die/mold technique has been used in Japan since the old days, but the die/mold industry as a modern industry of Japan has a relatively short history. The first opportunity to use die/mold in Japan was when molds for making gold and silver coins were imported from England in 1871. It is said that in 1880, the Tokyo infantry division invited a German engineer namely Hale, to teach ammunition production. During the Meiji and Taisho periods, dies/molds were imported together with molding machines in many cases. The die/mold production technology accumulated by government factories or major private factories gradually spread to small factories. In this way, the production of die/mold began in Japan. However, in those days, dies/molds were not made by specialist but by "iron works," which handled anything related to metal processing. However, the technical level was not high enough to satisfy molding companies. Consequently, many big private manufacturers made die/mold in-house for their internal use.

Then the rise of the automobile industry in the 1930s, led to the development of stamping dies and forging dies for the automobile industry. After that, Japan entered a wartime economy, and military-related stamping dies and forging dies developed further. The die/mold industry for private use such as molds for glass and plastic molds, however, entered a period

[1] Regards situation of die/mold industry before 1960's, pre-studies are as follows; Japan Die & Mold Industry Association and METI (1966), Japan Die & Mold Industry Association (1987), The Medium and Small Business Research Institute (1979), Technology Research Institute of Osaka Prefecture (1994), KURODA Precision Industries Ltd. (1995), Taguchi, N., (2001) and so on.

of stagnation. As the condition became severe, both private and military sectors suffered a blow, and the war ended.

2.1.2 Formative Period of the Modern Die/mold Industry: Period of Technique-intensive era in 1950s

The restoration of Japan began after the World War II, and subsequently Japan's industry began to develop once again. However, as the mass production of molded goods became active, Japan seemed to face bottlenecks related to the low level of die/mold technology and shortage of die/mold manufacturers. Under these circumstances, the Law for Temporary Measures for Machine Industry Promotion (Machine Industry Promotion Law) was enacted in March 1956, which is said to have influenced the formation and development of Japan's die/mold industry to a great extent. This law was imposed only for a limited period of five years, but it was extended twice in 1961 and 1966, and it remained in effect until 1971. In 1971, it was combined with the Law for Temporary Measures for Electronic Industry Promotion to be the Law for Temporary Measures for the Promotion of Specified Electronic and Machine Industries (Machine Industry Promotion Law). This Law aimed to nurture the parts industry by making small and medium enterprises specialized. The die/mold industry was included as one of the 18 industries concerned. The Japan Die and Mold Industry Association was established in 1957, and the die/mold industry became a designated industry of the Machine Industry Promotion Law.

When this Machine Industry Promotion Law was enacted in the 1950s, the die/mold industry was a technique-intensive industry. Design and production were not clearly separated, and both were automobileried out together in the same workshop. The outline design was usually done based on experience and instinct. Dies/molds were made mostly by hand using files, drillers, lathes, shavers, and conical grinders. Mechanization in that period is said to occupy 20% [2] in terms of operation time. In other words, 80% relied on human hand work; it was a technician-led period.

2.1.3 Transition Period from Technique-intensive to Machine-intensive Industry: early 1960s-mid-1970s

Dies/molds were made mostly with machine tools such as drillers in the 1950s. The production of high-precision die/mold relied on the techniques of technicians. However, the die/mold made in this way varied in quality. In those days in Japan, the development of mass-production-type machines was needed, and the stable supply of good-quality die/mold was an important theme. Under these circumstances, the Ministry of International Trade and Industry reached the conclusion that it was necessary to introduce machine tools such as milling machines that could do high-precision processing (Japan Die & Mold Industry Association 1987). In this situation, through funding by the Machine Industry Promotion Law and private enterprises as a result of the “Cowbell Effect” (Itoh, M. et.al.1988 p.83), high-performance machine tools were introduced one after another in the die industry.

As a result, machine tools for the production of die/mold such as drillers, cubic millers, flat surface grinders, forming grinders, and electric discharge machines were introduced, and the mechanization of production processes progressed. In this way, the production process of die/mold changed from hand work to machine work. As a result, the mechanization rate rose

[2] The description of productive equipment and the ratio of mechanization are based on Organization for Small & Medium Enterprises and Regional Innovation (2000).

to about 50% in terms of operating time. From the mid-1960s to the mid-1970s, the design of die/mold was done separately from the processing.

2.1.4 Transition to Equipment-intensive Type and Introduction of Digital Technology: mid-1970s-mid-1980s

In the high-growth period of the 1970s, the main customers of the die/mold manufacturers such as the automobile industry and electric appliance/electronic industry developed. As a result, the die/mold industry grew steadily and became one of the "one-trillion-yen industries" in 1983. The people who the author interviewed say that the die/mold industry enjoyed a business boom in that period and had ample funds to purchase machines and equipment. During this booming economic situation the die/mold industry was heavily concentrated into equipments. A sizable change appeared in the production process of die/mold from mid-1970s to the mid-1980s. The development of computer techniques led to the introduction of information technology in the die/mold industry. Machining centers, Numerically Control (NC) jig boring machines, NC jig grinders, NC Electric Discharge Machines (EDM), NC wire EDM, and other NC instruments were introduced as equipment for the production of die/mold.

As representatives of information technology, Numerical Control (NC) machine tools, and Machining Centers (MC) became popular in this period, and the technical base of the current cutting technique was established. In other words, computer technologies were applied in production. As a result, the mechanization rate rose to 70% in terms of operating time in this period. In the design area, much know-how was accumulated through experience. Designing was done on paper on a drawing board in those days.

2.1.5 Progress of Digital Technology and Transition to Highly Equipped Industry: mid-1980s-1990s

During the mid-1980s and the 1990s, a movement became active for combining NC die/mold processing machines and designing. This was the introduction of Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM) in the designing/production process. After the 1990s, CAD/CAM became ordinary popular techniques and were developed further by becoming two-dimensional to three-dimensional. At the same time, because of the drastic progress of computer technology, NC machines were replaced by Computer-Aided NC (CNC) machines. The mechanization rate rose to 80% in terms of operating time, and the die/mold industry changed into a highly equipped industry in terms of production style. Later in this period, the introduction of a system was seen in some places where CAD/CAM design data were sent through the in-factory network directly to each machine tool.

2.1.6. Period of Transition due to the Further Development of Information Technology: mid-1990s onward

After the mid-1990s [3], a movement began to connect the already developed individual information equipment through a network and to systemize a serial flow of order receiving-development-production-delivery. When individual techniques are looked at, software functions like CAD and computer computing speed improved, processing precision improved through the introduction of linear motors and ion-coated cutting tools, and many other production techniques improved tremendously. The biggest key words for this period are "system-

[3] Regards recent situation of die/mold industry, pre-studies are as follows; The Materials Process Technology Center (1999), Egashira, H. (2000, 2001), Baba and Onishi(2001) and so on.

ization" and "integration" for consolidating and integrating individual instruments, and "automation" and "unmanned operation," which became possible as a result.

For example, some companies, mostly big ones, are working on introducing the Computer-Aided Engineering (CAE) system to heighten the reliability of design through the improvement of the precision and speed of functional analysis and the Computer-Aided Testing (CAT) system, which is an automatic measuring/evaluation system for inspecting, by computer, the product precision in each production process. Also, the exchange of CAD data with outsiders through a network is nothing unusual. At some companies, through such development of information transmission and means through the permeation of information equipment in production processes, concurrent engineering is possible in which the development division and manufacturing division work simultaneously. By consolidating individual information systems such as CAE/CAD/CAM/CAT, Factory Automation (FA) in the die/mold production process and Computer-Integrated Manufacturing (CIM) are being pursued.

2.2. Influence of Digital Technology on the Die/mold Industry

2.2.1 Background and Introduction of Digital Technology

The author examined the transition of the production process of Japan's die/mold industry from the 1950s to 2001. Japan's die/mold industry expanded its production together with the development of customer industries such as the automobile industry and electric appliance/electronic industry. In this process of development, the die/mold industry placed importance on investment in equipment. The profit generated by expanded sales was invested in equipment. As a result, Japan's die/mold industry changed from the original technique-intensive industry to a highly equipped industry. There seems to be two important periods in which digital technology had an influence on the production of die/mold.

The first period was from the 1970s to the 1980s when digital technology was first introduced. The influence of digital technology progressed in the form of the introduction of NC machines in the die/mold industry. This introduction of NC machines had a big influence on the production techniques of the die/mold industry. Until then, the processing of dies was done by the personal expertise of technicians, but now the introduction of NC machines led to numerical control. In other words, the personal expertise of processing techniques was digitized through the introduction of NC machines.

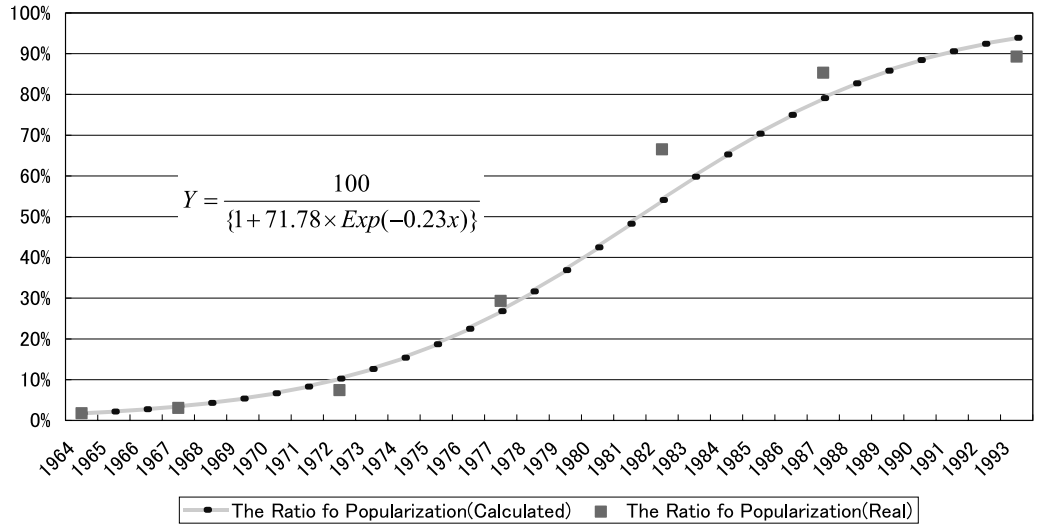
The second influence occurred from the 1980s to the 1990s. It took the form of the introduction of CAD/CAM. Design was numerically controlled by the CAD system, and the design data that were made numerical by the CAM system were converted into data for die/mold processing to be processed by NC machines. In other words, from designing to processing, numerical data were connected. Consequently, the personal expertise regarding designing as well as the interface of designing and production was most likely digitized by the introduction of CAD/CAM.

2.2.2 Influence of the Digitization of Production Technology—Influence of the Introduction of NC Machines

Through the introduction of NC machines that digitized the production techniques of die/mold, what kinds of concrete changes appeared? The popularization of NC machines in the die/mold industry progressed in the 1980s, and by the late 1980s, almost all of the manufacturers had introduced NC machines as is shown in figure 2. The change in the processing techniques of die/mold manufacturers through the introduction of NC machines was investigated by questionnaires in 1993 when the popularization was almost completed. Through the

introduction of machine tools, production efficiency was improved by 95% of die/mold manufacturers of precision die/mold, 95% of manufacturers of die/mold of complicated shapes, and 70% of manufacturers of hard-to-cut die/mold. Also, at 86% of die/mold manufacturers, nighttime automatic operation became possible. The mechanization rate of die/mold manufacturers was more than 80% in this period and it was obvious that the popularization of NC machines also made automatic processing operation possible (Technology Research Institute of Osaka Prefecture 1994 pp.75-76).

Figure 2. Regression Analysis of Popularization of NC Machines



Source: Calculated by the data of Technology Research Institute of Osaka Prefecture 1994.

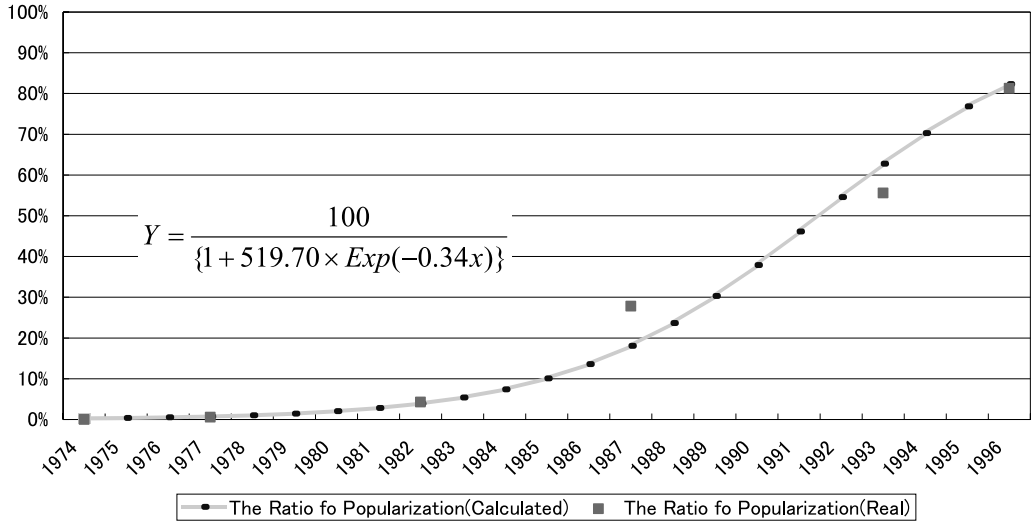
In this way, it can be said that the personal expertise of die/mold production was digitized into numerical data through the introduction of NC machines. In other words, experienced techniques were made concrete by NC machines, numerical data were put into NC machines, experienced techniques were put into machines, and high-precision automatic operation was realized. As a result, the only techniques that remained as experienced techniques for die/mold manufacturers were designing technique, input of data into NC machines, and finishing technique.

Through the introduction of NC machines, Japan's die/mold industry realized leveling of high-level quality, cost reduction, and reduction of delivery time, all of which constitute the important elements of quality, cost, and delivery in business. Judging from interview of an association of the die/mold industry, this fact was most likely the reason why Japan’s die/mold industry became the leader in the world. Many die/mold manufacturers in Japan invested their earned profit in equipment and tried to introduce digital technology such as NC machines.

2.2.3 Influence of Digitization of Design Techniques: A Case of CAD/CAM

The popularization of CAD/CAM machines in the die/mold industry progressed rapidly in the 1990s, and by the mid-1990s, almost all of the die/mold manufacturers had introduced these tools as shown in Figure 3.

Figure 3. Regression Analysis of Popularization of CAD/CAM



Source: Calculated by the data of Technology Research Institute of Osaka Prefecture 1994, 1997.

In order to analyze the digitization of die/mold designing related techniques due to the popularization of CAD/CAM as well as the influence on die/mold manufacturers, the author checked the cumulative numbers of patents, utility models, patent specifications, utility model specifications, and journal of technical disclosure. In terms of the co-occurrence patents of die/mold and computers, 88 patents and one utility model were approved by 2001. Many of them were related to design.

From the late 1980s to the early 1990s, there were cases of the technological fusion that dealt with the utilization of the computer for the design and production of the die/mold. Then, until the early 1990s, there were patents of die/mold production and fluidity analysis using two-dimensional computer data and two-dimensional CAD/CAM. After 1995, there were an increasing number of descriptions of three-dimensional drawings on the computer using three-dimensional CAD/CAM and descriptions of using that three-dimensional drawings, as they are, for production. In other words drawing changed from two-dimensional to three-dimensional, and three-dimensional information was used, as it was, for the production of die/mold. By the passage of time, these events can be summarized as follows: ①Fusion of the computer and die/mold techniques: 1980s-early 1990s, ②Three-dimensional model→ two-dimensional drawing→ die/mold production: early 1990s, ③Three-dimensional model→ three-dimensional drawing→ die/mold production: 1995 onward.

Because of the technical advancement of the computer as represented by CAD/CAM, the design knowledge was put into numerical figures. The subsequent advancement made it possible to process order receiving to delivery in the three-dimensional format without reducing the dimension. At present, CAD/CAM is used in almost all of the companies.

2.2.4. Influence of the Introduction of Digital Technology on Die/mold Production

Let me review, in further detail, the influence that the introduction of NC machines and CAD/CAM had on the production of die/mold. From the time a die/mold is ordered until delivery, the flow can be simplified as follows: 1) order→2) design→3) production→4) product→5) delivery. The die/mold-related techniques required in this flow are as follows:

①Interface technique from order to design:1)-2), ②Design technique:2), ③Interface technique from design to processing: 2)-3), ④Processing technique: 3), ⑤Finishing technique: 3)-4) .

First, technique ④ above was digitized through the introduction of NC machines. Later, techniques ② and ③ were digitized through the introduction of CAD/CAM. Then, technique ① was digitized through the digitization of order contents and communication technology. Also, as a result of the improvement in machining precision, finishing work can be spared depending on the precision of a die/mold: Technique ⑤ is also being digitized.

With the introduction of NC machines and CAD/CAM and with the advancement of communications technology, the die/mold-related techniques in the whole process of order to delivery are being digitized. With the recent advancement of communications technology, it has become a common practice to exchange drawing data by e-mail. Die/mold data designed in Japan can be sent to Korea by e-mail for processing overseas.

2.3. Influence of Digital Technology on the Die/mold Industry of Developing Countries

It is clear that digital technology such as NC machines and CAD/CAM have had a big influence on the design/production of die/mold. How does this influence affect the die/mold industry of developing countries? In order to analyze this problem, interview surveys were conducted on the bottlenecks of die/mold production in developing countries. They are summarized as follows. The same is also true of the die/mold industry of Korea before Japan's import increased. ; ①Designing cannot be done, ②Two-dimensional drawings cannot be developed into 3-D, ③The precision of processing techniques is poor, ④Finishing work cannot be done, ⑤Maintenance cannot be done.

Let me think about what kind of a role the introduction of digital technology plays in the solution of these bottlenecks. First, the introduction of NC machines can bring improvement in ③ above. If finishing-less work progresses through improved machining accuracy, improvement can be expected in ④. Through the introduction of 3-D CAD/CAM, improvement can be expected in ②. Further, if a customer prepares a digitized drawing, the bottleneck of ① will be solved. In others words, through the introduction of digital technology such as NC machines and CAD/CAM, the bottlenecks in ① to ④, from the order receiving of a die/mold to delivery, can be eliminated.

3. History of the Development of Korea's Die/mold Industry and Factor Analysis

The development of Japan's die/mold industry owes a lot to increased business with the growing customer industries of automobiles and electric appliances/electronics. Through increased business with these customers, Japan's die/mold industry accumulated the know-how of design/production of die/mold. By investing earned profit in equipment, the die/mold industry introduced digital technology. Through the accumulation of know-how in the design/production of die/mold and introduction of digital technology, Japan's die/mold industry came to be the world leader.

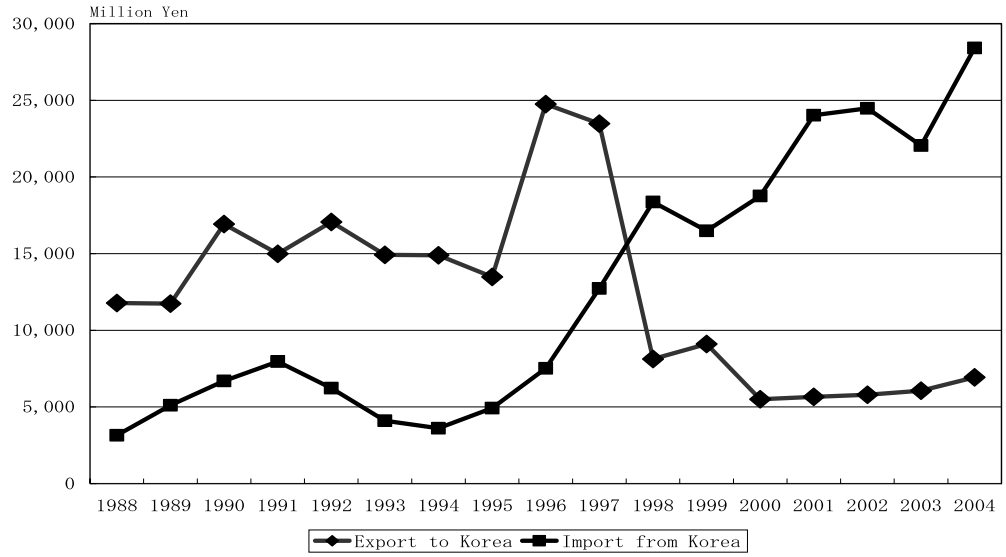
Bearing this success model of Japan in mind, let us analyze the factors in the development of Korea's die/mold industry. In this chapter, first to confirm facts and figures, let us clarify how Korea changed into a net exporter of die/mold to Japan from a net importer from Japan. The author also conducted interview surveys about the use of Korean die/mold in Japan. Based on this analysis, let us go on to review the background behind the change of Korea's die/mold industry.

3.1. History of Increased Import of Korean Die/mold and Actual Status of Their Use

3.1.1. History of Increased Import of Korean Die/mold into Japan

It is better to investigate when did the Korean die/mold industry began to import and how did imports grow? Figure 4 shows the history of Japan-Korea trade of die/mold products. According to that figure, imports from Korea was increased from the late 1980s to the early 1990s, but decreased after it peaked in 1991. During this period, Korea was always a net importer of die/mold. However, after it touched bottom in 1994, imports from Korea increased again. Korea turned into a net exporter after 1998, and since then it has been remaining in the same position

Figure 4. Transition of Die/mold Trade between Japan and Korea



Source: Calculated by the data of Japan Exports and Imports each year

By analyzing trade statistics, it is found that the import of die/mold from Korea has not been increasing for a simple reason. How should it be interpreted? According to interviews, it has become clear that there were a few booms in the trade of die/mold between Korea and Japan after the late 1980s. When the history of the trade of die/mold between Korea and Japan is examined, two characteristics are apparent. One is the change in the business parties, and the other is the improvement of Korean quality and consciousness of delivery after the mid-1990s.

The first characteristic, the change of the business parties from the die/mold user to the die/mold manufacturer, occurred from the late 1980s to the early 1990s. The reason for this is that although Japanese die/mold users bought die/mold from Korea to save cost at first, they faced many troubles and avoided doing business directly with Korean die/mold manufacturers. In order to avoid troubles, Japanese users of die/mold placed orders through Japanese die/mold manufacturers and left the guidance of Koran manufacturers and final adjustments in the hands of the Japanese die/mold manufacturers.

The second characteristic, the improvement of the quality of Korean die/mold and improvement of consciousness, came after the mid-1990s. Until the early 1990s, their quality and delivery were not up to the expectations of Japan. However, after the late 1990s, they reached the expectations of Japan.

Based on the above, the following can be said. That is, the phenomenon of the increased import of die/mold from Korea occurred suddenly in the late 1990s. There was always demand from Japan from the 1980s, but until the mid-1990s, Korea, the supplier, could not meet the Japanese demand. For some reason in the 1990s, a change was made in the supplier side of Korea, and the import of die/mold from Korea became conspicuous.

3.1.2. Status of Korean Die/mold in Japan and the Background behind their Expanded Quantity of Use

What is the status of the use of Korean die/mold in Japan like? According to interviews, the die/mold imported from Korea has been mostly plastic molds for injection molding. According to Japan Exports and Imports Statistics 2000, molds for rubber or plastic molding (injection or compression) account for 80% of the total imported from Korea, confirming the research data of my interviews. According to interviews, Japan's imports from Korea take the form of outsourcing. The die/mold imported from Korea get finishing touches in Japan before they are delivered to customers. Korean die/mold manufacturers deliver their die/mold as "finished products," but Japanese die/mold manufacturers receive them as "semi-finished products." There is a gap of consciousness on both sides.

The reason why plastic molds account for most of the imports from Korea is explained by interview, "The big difference between the plastic molds and the stamping dies is heat treatment. Heat treatment is technically difficult, and we are not at a stage where we can outsource high-precision stamping dies to Korean die manufacturers. In terms of plastic molds, ultra-precision molds are not ready to be outsourced to Korea."

Through interviews and analysis of trade statistics, the status of the use of Korean die/mold in Japan has been determined to be as follows: Orders with Korean die/mold manufacturers are placed, in many cases, in the form of outsourcing to reduce cost. In many cases, imported Korean die/mold are finally adjusted by Japanese die/mold manufacturers and then delivered to customers. In many cases, the second and subsequent die/mold was ordered from Korean die/mold manufacturers. Die/mold outsourced to Korea was mostly plastic molds. Early in the 1990s, Korean die/mold manufacturers could not meet the quality and delivery requirements demanded by Japan. After the mid-1990s, the Korean die/mold industry became able to meet the quantity and delivery requirements demanded by Japan. By the late 1990s, the Korean die/mold industry seemed to introduce CAD/CAM and NC machines that were at a higher level than those in Japan. When Japanese companies placed orders, the CAD/CAM data was generally sent to Korea by e-mail, etc. When "the second and subsequent die/mold" were ordered to Korea, both "the original die/mold" and CAD/CAM data were supplied to Korean die/mold manufacturers in order to make it easy for Korean manufacturers to learn. In Korea, the nurturing of die/mold workers was more active than in Japan. Late in the 1990s, the quality of Korean die/mold went up.

The Korean die/mold industry could not meet the requirements of Japanese users before the early 1990s. However, in the period to the mid-1990s, the quality and delivery levels of the Korean die/mold industry improved for some reason. Then, toward the late 1990s, this change was more apparent. From the interviews, this change is presumed to have come from the introduction of digital technology, learning by Korean die/mold manufacturers through business, nurturing of die/mold workers, etc. At this stage, however, it seems that Korean die/mold was not good enough to satisfy Japanese customers and some corrections have to be made.

3.2. An Analysis of Factors behind the Development of the Korean Die/mold Industry

It is clear that in the 1990s, the Korean die/mold industry upgraded rapidly. In the case of Japan, the die/mold industry expanded its production together with the development of the customer industries of automobiles and electric appliances/electronics, and it accumulated design/production know-how through the expansion of business. Further, the earned profit was actively invested in equipment to introduce digital technology. Through the accumulation of know-how and the introduction of digital technology, the die/mold industry of Japan has grown.

Did the Korean die/mold industry also accumulate know-how of design/production through expanded business and grow by investing the earned profit in equipment? Based on the hints from the development of the Japanese die/mold industry and from the interviews, the author would like to review three points, that is, the learning and accumulation of know-how through business, the status and influence of the introduction of digital technology, and the status of nurturing of human resources.

3.2.1 Market: Expansion of Learning Opportunities and Source of Capital Investment

(1) Learning and accumulation of know-how through business with domestic customer industries

The main Japanese customers of the Korean die/mold industry are the electric appliance/electronic industry and the automobile industry. According to the 1996 data of the Korea Die & Mold Industry Cooperative, the main users of the Korean die/mold industry are the automobile industry and the electric appliance/electronic industry. The total amount of die/mold production in Korea is one trillion eight hundred billion won, with 38.3% for the transportation machine industry and 35.7% for the electronic (electric) industry. These two industries account for 74% of die/mold production and it was far higher than any other industry.

It is important to analyze production transition in Korean automobile industry and electronic industry by using data obtained from the Korea Automobile Manufacturer Association and Electronic Industries Association of Korea. First, the automobile industry expanded production greatly in the 1990s. In 1998, automobile production dropped due to the currency crisis, but the following year, production took an expanding turn. Next, the electronic industry greatly expanded production of industrial electronics and electronic parts after the mid-1990s.

By setting the number of automobiles produced and the production amounts of the electronic industry of 1990 at 1.0, it is possible to examine the rates of expansion of both industries after that year. The automobile industry stood at 1.9 in 1995 and 2.4 in 2000, expanding production continuously through the early 1990s and the late 1990s. The electronic industry stood at 2.3 in 1995 and at 4.6 in 2000, expanding production throughout the early and late 1990s. Outstanding growth was seen in industrial electronics and electronic parts, which were at 8.4 and 5.0 respectively in 2000. Their production expanded especially in the late 1990s.

As explained above, the main customers of the Korean die/mold industry, the automobile and electronic industries, made great progress in the early and late 1990s. Due to this increased business, the Korean die/mold industry is presumed to have accumulated design/production know-how of die/mold. Also, the expanded business contributed to more funds to be invested in equipment.

(2) Learning and accumulation of know-how through business with Japan

As mentioned above, demand for Korean die/mold products has been increased in Japan from the 1980s. It was continued until the early 1990s. Due to frequent troubles, the import of

Korean die/mold did not expand a great deal. However, after experiencing business failures, Korean die/mold manufacturers learned the necessary techniques, knowledge, and know-how to cope with the demand of Japan.

The Japanese business partners changed from users to manufacturers of die/mold in the early 1990s. For this reason, the technical transfer of the know-how of Japanese die/mold manufacturers became easier. Due to the expanded introduction of digital technology in the 1990s, it became easier for Korea to learn Japan's design/production know-how relating to die/mold. My guess is that this ease of learning had a big influence on the promotion of technical transfer.

Late in the 1990s, Korea suffered a temporary recession, and the Korean die/mold industry made efforts to develop overseas markets. My guess is that this drove the Korean die/mold industry to learn the necessary requirements to develop the Japanese market.

3.2.2 Digital Technology: Improvement of Design/production Abilities and Promotion of Technical Transfer

(1) Status of digital technology introduction

In the 1990s, the main customer industries of the Korean die/mold industry, the automobile and electronic industries, expanded rapidly. Japan succeeded by investing profit actively in equipment. Did Korea invest profit actively in equipment as Japan did? To analyze this point, let me look, based on the leading research, at the status of the introduction of NC machines and CAD/CAM by Korean die/mold manufacturers in 1994 and 2000, and at the trade balances of die/mold between Japan and Korea in 1994 and 2000.

As of 1994, Korea's introduction of NC machines was at the same level as Japan, but the rate of CAD/CAM introduction was 38% in comparison with Japan (Saito 1996). In other words, as of 1994, the introduction of digital technology was common in production, but not in design-related areas. As of 1994, Korea's import of die/mold from Japan far exceeded its export to Japan. The introduction of NC machines or the introduction of digital technology alone in production did not contribute to the expansion of the export of die/mold to Japan.

In 2000, it became common to take orders from users in the form of 3-D data, convert 3-D data, as it was, into CAD data, and give instructions, by CAM in 3-D, to NC machines (Egashira 2001, Mizuno 2001). In other words, from 1994 to 2000, the introduction of digital technology in the design field as well as the interface of design and production became common. In 2000, Korea's export of die/mold to Japan far exceeded its import from Japan. In addition to the introduction of digital technology in production, the introduction of digital technology in the design-related area of 3-D CAD/CAM contributed to Korea's expanded export to Japan.

From the above, the introduction of digital technology in the Korean die/mold industry and the change in the trade of die/mold between Korea and Japan can be summarized as follows: In the Korean die/mold industry, the introduction of NC machines progressed before 1994. As of 1994, the introduction of CAD/CAM had not progressed yet. As of 1994, Korea was a net importer of die/mold from Japan. The digitization of production alone in the form of the introduction of NC machines did not contribute to the expansion of the export of die/mold to Japan. From 1994 to 2000, the introduction of 3-D CAD/CAM progressed in the Korean die/mold industry. In 2000, Korea was a net exporter of die/mold to Japan. In addition to the digitization of production, the introduction of 3-D CAD/CAM in the design-related area contributed to the expansion of the export of die/mold to Japan.

Based on these phenomena, it is clear that the Korean die/mold industry automobileried

out active investment in equipment in the 1990s. This investment in equipment solved the bottlenecks of the Korean die/mold industry in the following process. Until the mid-1990s, the introduction of digital technology in production in Korea progressed in the form of the introduction of NC machines. The bottlenecks in production were solved in this way, but the bottlenecks in the design-related area remained unsolved. Further, after the mid-1990s, design-related digital technology was introduced into the Korean die/mold industry in the form of the introduction of 3-D CAD/CAM. The last remaining design-related bottleneck was thus solved, and the bottleneck of design/production of the Korean die/mold industry was solved. The solution of this design/production bottleneck contributed to the expansion of the export to Japan.

(2) Influence of introduction of digital technology on technical transfer

After the 1960s when the Korean die/mold industry established itself as an industry, Korea introduced techniques from Japan actively. For example, the Samsung's die/mold factory of Korea started the production of die/mold in 1976 by receiving the support of Japanese engineers. However, it was only after the late 1990s that Korea increased its exports to Japan rapidly. What was the difference between the conventional technical transfer and the technical transfer of the 1990s? As the theme was set, did the introduction of digital technology make technical transfer easy? Not to come to an early conclusion, but after reviewing case studies, the author would think that the introduction of digital technology such as NC machines and CAD/CAM brought about an unexpectedly rapid technical transfer to the Korean die/mold industry.

It was common, after the mid-1990s, for Japan to send digitized die/mold drawings and processing data to Korea when orders were placed. In the case of the second and subsequent die/mold, there were many cases in which the original die/mold and drawings/processing data were supplied to Korea. The most difficult part that requires know-how in die/mold production is the detailed drawing and layout drawing. When these drawings are digitized and given together with "a perfect textbook" called the actual "original die/mold", Korean die/mold manufacturers can learn know-how very easily. As a die/mold is made specifically for one product, it was necessary to make many similar die/mold in order to acquire the know-how of the production of die/mold that could be applied. However, by getting many digitized die/mold drawings, Korea could learn very easily about these applications.

In this way, the improved efficiency of learning achieved through acquiring digitized die/mold drawings/processing data is causing the Japanese industry to have a sense of crisis. For example, on May 17, 2002, the Japan Die & Mold Industry Association presented its "Request regarding the prevention of unintentional outflows of die/mold blueprints and processing data" submitted to the Minster of METI (Ministry of Economy, Trade and Industry) in which the association sounded a warning bell about illegal transfer to neighboring countries. It stated, "Die/mold drawings contain the production know-how of die/mold manufacturers. If they flow out to overseas die/mold manufacturers, not only do the long-cherished die/mold techniques of Japan flow out, but they are also the main causes of management failure in the Japanese die/mold industry due to the worsened competitive power which leads to fewer orders. (Excerpt)"

As explained above, Korea was actively transferring technology from Japan. It is not a mistake to say that this active introduction of technology in past years is one of the factors in the development of the Korean die/mold industry. In the 1990s, the Korean die/mold industry caught up with Japan drastically. In addition to the accumulation of technology introduced so far, the introduction of digital technology made technical transference easier.

3.2.3. Human Resources: Producing Die/mold Workers through Education and Development

(1) Necessity of nurturing die/mold workers

The factors in the development of the Korean die/mold industry in the 1990s were thought to be the introduction of digital technology and the accompanying technical transfer. However, if these were the only factors, why didn't other countries catch up with Japan as rapidly as Korea did? In 1999, the author visited a certain companies in Indonesia. These companies had introduced CAD/CAM and NC machines for die/mold production. Nevertheless, their die/mold production did not succeed. Upon being asked why, they replied, "CAD/CAM and NC machines were introduced, but we do not know how to use them to make die/mold. We are at a loss because there is no organization to teach us to make high-precision die/mold using these machines." As we see from this case, the enrichment of human resources for making die/mold using digital technology is the precondition for "gaining the advantage of technical transfer, which is made easy through the introduction of digital technology."

(2) Nurturing of die/mold workers in Korea

According to interviews in Korea, Korea is making nationwide efforts to nurture die/mold workers. Let me review, more concretely, the status of nurturing die/mold workers in Korea. Let me take a look at the 1997 research by Seoul Industrial University to see the number of die/mold-related educational organizations and the annual number of graduates. In Korea, there are 33 educational institutions that produce about 3,000 graduates a year. At Engineering Research Center for Net Shape and Die Manufacturing (ERC/NSDM), which was established in Busan University in April 1994, they develop human resources, and promote a collaboration of industry and university as well as collaboration with the research/educational institutions of Japan, the USA, UK, Germany, and China. At this center in 2000, 78 post-graduates and 12 doctors emerged.

It is generally conceived in Korea that design/production techniques were made common by the introduction of digital technology. The curricula of Korean die/mold educational institutions are based on this consciousness, and efforts seem to be being made to practice design/production of designs by using digital technology.

Thus, Korea is nurturing die/mold workers at die/mold-related departments of higher education institutions. Their curricula include die/mold design/production using digital technology, and thousands of people, educated practically about die/mold design/production, enter the workforce every year. The existence of these graduates of the die/mold profession will contribute to the effective use of introduced digital technology. Based on the above, the continuous nurturing of die/mold workers since the 1980s in Korea is one of the factors in the Korean die/mold industry catching up with Japan rapidly in the 1990s.

4. Summary

4.1. Summary of Analysis of Japan's Die/mold Industry: "Japanese-style development model"

From the analysis of Japan's die/mold industry, it is clear that the die/mold industry was greatly influenced by digital technology such as NC machines and CAD/CAM. NC machines greatly influenced production-related techniques, and CAD/CAM greatly influenced design-related techniques.

During the process of expanded business with growing customer industries, Japan's die/mold industry accumulated the experience and know-how of die/mold design/production,

and invested profit actively in the introduction of digital technology. In particular, the digital technology that contributed to the success was the NC machine tool. The introduction of NC machines brought leveling of high-level quality, cost reduction, and reduction of delivery lead time to Japan's die/mold industry. The accumulation of the experience and know-how and introduction of digital technology were the big factors for Japan's die/mold industry to become the world leader.

In summary, the "Japanese-style development model" in the development of the die/mold industry can be characterized as follows: ① Automation, improvement of abilities for the precision processing and processing of difficult materials and improvement of productivity, through the use of NC machines and CAM in die/mold production; ② Accumulation of experience and know-how through interactive learning between die/mold users and manufacturers; ③ "Manufacturing spirit of dedication" of die/mold manufacturers; ④ Market expansion through the development of die/mold users; and ⑤ Existence of excellent "industries that support the die/mold industry" which supply machines, materials, and parts to the die/mold industry and which implement joint research and development. In particular, by looking beyond immediate profit, as indicated in ② and ③, experience and know-how were accumulated in pursuit of higher-grade and more efficient construction or layout in the stage of design. This was one of the factors in the competitive power of Japan. For that purpose, of course, the conditions of ④ and ⑤ are also considered to be indispensable.

4.2. Summary of Analysis of the Korean Die/mold Industry: "Korean-style development model"

In the late 1990s, Korea turned into a net exporter of die/mold to Japan. Checking this history, it became clear that after the 1980s, demand for cheap Korean die/mold continued to exist in Japan. First, Japanese users of die/mold, then die/mold manufacturers imported die/mold from Korea. However, these imports from Korea faced many troubles, and failures were repeated. The situation changed after the mid-1990s, and ever since then, Korea has been a net exporter of die/mold to Japan.

This fact may be explained by the accumulation of experience and know-how achieved by learning from business with Japanese and Korean customer companies, the introduction of digital technology, technical transfer from Japan, and the human resources development. When seen from the viewpoint of the introduction of digital technology, which is the theme of this paper, the introduction of digital technology could be the factor, on two aspects, for the development of the Korean die/mold industry. These two aspects are the influence that the introduction of digital technology itself had on die/mold design/production and the influence of the introduction of digital technology that made technical transference easy. As for the introduction of digital technology, die/mold production was digitized before the mid-1990s in the form of the introduction of NC machines. After the mid-1990s, the design-related area was digitized by the introduction of 3-D CAD/CAM. Digitization of production became a necessary condition, and digitization of the design-related area became a satisfactory condition—the bottlenecks in the design/production of the Korean die/mold industry were presumably solved. At the same time, through the introduction of digital technology in design/production, learning became easy and technical transfer from Japan was accelerated, thus having a big influence on the expansion of exports to Japan.

In summary, the "Korean-style development model" in the development of the die industry can be characterized as follows: ① Use of the technical stock of leading countries by learning techniques actively from leading countries; ② Accumulation of know-how and

expansion of the market that generates funds for management and the introduction of equipment; ③ Overcoming of bottlenecks by digitization of design/production equipment; and ④ Education and development of human resources who can use digital devices for die/mold production.

5. Review

5.1. Factors in the Development of the Korean Die/mold Industry

In the 1990s, the Korean die/mold industry gained power rapidly. This process of development can be classified into three steps. By the early 1990s, it gained abilities. By the mid-1990s, it acquired the ability to meet the requirements of quality and delivery demanded by Japan. In the late 1990s, it strengthened its abilities further.

The driving force of the improved abilities before the early 1990s are as follows: Opportunities of learning increased due to the expansion of customer industries (expansion of market), resulting in the accumulation of know-how and experience. Due to expansion of the market, funds for the introduction of digital technology were acquired. Through the introduction of NC machines, processing precision improved. Lessons were learned from business failures with Japan. Education of die/mold workers was automobileried out continuously, and there was an abundance of human resources. Technical transfer from Japan and other countries was actively promoted.

In the mid-1990s, the ability to meet the Japanese requirements improved for the following reason in addition to the above-mentioned reasons: The introduction of 3-D CAD/CAM progressed. Design-related bottlenecks were solved, and bottlenecks of die/mold design/production were entirely eliminated.

In the late 1990s, the following factor was added: Through the introduction of digital technology, learning became easy and technical transfer progressed.

From the above, it can be assumed that Korea caught up with Japan rapidly due to the key reasons of “market,” “digital technology,” and “human resources.” Sales by the expanded market prompted the introduction of digital technology. The introduction of digital technology solved design/technique bottlenecks, and the efficiency of technical transfer improved. From the viewpoint of learning, market expansion increased opportunities for learning, digital technology improved learning efficiency, and the nurturing of human resources improved latent learning abilities. Presumably, these three factors generated a multiplying effect and contributed to the development of the Korean die/mold industry.

Consequently, the “Korean-style development model” of the die/mold industry can be summarized with the following key words: ① Active technical transference from leading countries; ② Market; ③ Digital technology; and ④ Education and development of human resources. In this paper, however, ① is a precondition, and the author considers other conditions to achieve it. Therefore, the conditions of the “Korean-style development model” are ① market, ② digital technology, and ③ education and development of human resources.

5.2. Influence of Digital Technology on the Die/mold Industry

From the analysis of the die/mold industries of Japan and Korea, it became clear that digital technology had a very big influence on the die/mold industry both in the “Japanese-style development model” and the “Korean-style development model.” By introducing NC machines, Japan caught up with Europe and the USA. Korea is catching up with Japan by introducing NC machines and 3-D CAD/CAM. Through the introduction of NC machines and CAD/CAM and the advancement of communications technology, the digitization of die/mold-

related techniques is progressing in all steps from order to delivery. These digital technology gave die/mold-related techniques direct effects such as efficiency in designing, automation of processes, leveling of quality, and improved processing precision. These effects realized the production of die/mold of stable high quality, improvement of production efficiency, and short delivery time. Further, the storage of data made the accumulation of experiences easy, and the exchanging of data made the transfer of experience easy. In this way, digital technology had a big effect to both design and production in the die/mold industry. An unexpected effect appeared with the easy technical transfer.

5.3. Factors in the Development of the Die/mold Industry in Developing Countries

Technical transfer by the "Japanese-style development model" in the die/mold industry was not successful because the "Japanese-style development model" has a strong characteristic of reliance on the personal expertise of technicians. In the design of construction, layout, or materials, they tried to offer more than that requested by customers. It was prepared in the mind, and then turned into a drawing by hand. Later, drawings by CAD became popular, but it was still regarded as "software for drawing pictures" until recently. This thinking is still strong among experienced workers. The mechanization rate by the introduction of NC machines was advanced, but processing precision in the early days was unbelievably worse than it is today, and there were many troubles with machines. Workers used their five senses (e.g., eyes and ears) to achieve better precision than machines could give. The input of data into NC machines was first done by punching holes in paper, and it took time and needs know-how. As for maintenance, workers asked themselves, "Why is it abraded so much here? Why did a crack or a break occur here?" They thought it through, and then they made repairs based on the assumptions. This know-how was used in subsequent drawings. Behind the design/production was always the "manufacturing spirit of dedication." These examples are just a few of many others. They piled one upon another, and as a result, no high-grade die/mold industry was established for a long time in any Asian country except Japan.

In Korea in the 1990s, the die/mold design/production bottlenecks were solved by the "Korean-style development model." Judging from the successful case of Korea, digital technology plays a big role in the solution of these bottlenecks. However, human resources are necessary to make effective use of the introduced digital technology in die/mold production. Of course, funds are also necessary for introducing digital technology, and progress cannot be expected without opportunities for learning. Consequently, for the development of the die/mold industry in developing countries, the following three factors are important, as in the case of the "Korean-style development model": Increased opportunities for learning through business, and the existence of a market that is bigger than a certain size which generates funds for the introduction of digital technology. Introduction of digital technology to remove design/production bottlenecks. Existence of human resources who can use introduced digital technology, and the education/development of such human resources.

5.4 The Role of Government for the Development of Die/mold Industry

Both Japan and Korea started as developing countries comparing with USA and Europe in die/mold industry. In many cases, the role of government is important to develop industry in developing countries. What about die/mold industry? The author would like to consider this point from cases of Japan and Korea by comparing with USA and Europe.

The author surveyed die, stamping and machine tool industries in USA in 2005 and Europe in 2006. In some thriving area of precise die and precise stamping industries in

Switzerland and French, it was founded that they voluntary developed and were sophisticated to meet with their customers as one of supporting industries of watch industry. In some thriving area of die and stamping industries in USA and United Kingdom, it was founded that they voluntary developed and were sophisticated in the effort of how to process metals near by industrial complex of steel. Thus, in USA and Europe, die/mold industry seems to voluntary emerged, developed and sophisticated in areal industrial complexes.

In the case of Japan, as mentioned, Japanese industry faced bottlenecks related to the low level of die/mold technology and shortage of die/mold manufacturers in 1940s and 1950s. Japanese government made effort to develop die/mold industry. For example, she established Machine Industry Promotion Law in 1950s and it remained in effect until 1970s. In the case of Korea, Korean government started promotion policy of heavy industry around 1970s, and faced same bottleneck as of Japan. Korean government made effort to develop die/mold industry as mentioned previous section.

Thus, the role of government is not small in developing countries to develop die/mold industry according to Japan's and Korean cases.

6. Conclusion

There were two main objectives of this paper. The first was to identify succeeding factors of the die/mold industry in Republic of Korea during the 1990s. The second was to investigate the role of digital technology in transferring process of die/mold-related techniques from Japan to Korea. With respect to the first objective the author arrived at the factors of "market", "digital technology", and "education (development of human resources)", as follows. The development of the die/mold industry that satisfies these requirements was termed the "Korean-style development model." ①Increased opportunities for learning through business, and the existence of a market that is bigger than a certain size which generates funds for the introduction of digital technology, ②Introduction of digital technology that removed design and production bottlenecks made easy to transfer technical and the effective use of digital technology, ③Existence of human resources who can use introduced digital technology, and the education/development of such human resources.

This factor analysis contains the reply to the second question "Did digital technology make it easy for die/mold-related techniques to be transferred to Korea?" By analyzing the case of Korea, it was possible to identify that the introduction of digital technology make it easy for transferring die/mold-related technique from one country to the other. However, introduction of "digital technology" alone is not sufficient, and that "digital technology" can be used effectively only when the requirements of "market" and "human development" are also satisfied. In other words, the "Korean-style development model" is universally true. Therefore it is possible to replicate that in other developing countries. Therefore, it is possible to suggest that if all of three requirements are satisfied, the die/mold industry of a country has big potential to develop. In addition, appropriate role of government is essential condition to replicate "the Korean-style development model" to other developing countries.

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