

# 名城アジア研究

# MEIJO ASIAN RESEARCH JOURNAL

2022.03

VOL.11 NO.1

# 名城アジア研究

2022.03 | Vol.11 No.1

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學術論文  
Articles



# A Trust-building Approach to the Banking Industry in Myanmar

Yuri Sadoi, Ye Tun Min, and Takeshi Arai

## Abstract

Myanmar's banking sector needs a range of improvements to upgrade to international standards. A trust-building approach in Myanmar's banking system is critical to building the country's business infrastructure. The historical development of Myanmar's financial institutions has not previously supported the development of a trust-based lending system. From the mid-2010s, however, the importance of credit guarantee insurance and adequate funding for the development of local SMEs has begun to be recognised. This paper discusses two ongoing approaches: credit guaranteed loans and two-stage financing approaches. The paper first discusses the problems of Myanmar's banking industry in a historical context, and then examines two approaches to restoring credit guaranteed loans. Next, the two approaches to restoring people's trust in the banking sector will be examined. This paper is limited to the situation in Myanmar up until 2020.

**Key words** : banking sector; Myanmar; trust; SMEs; credit guarantee; two-step loan

## 1. Introduction

The purpose of this paper is to analyse the problems in Myanmar's banking sector and the improvements that can be made to solve them. Myanmar's banking system lags far behind international standards and is among the slowest in Southeast Asia. The public's trust in the banking sector is a product of Myanmar's financial history.

Myanmar's opening up under the newly elected government in 2011 was unexpected, and surprised the world. The government attempted to enact economic development and poverty alleviation, the improvement of the human rights record, the ensuring of good governance, and the resolution of the decades-long ethnic conflict. These political, economic, and social reforms are ongoing. The Myanmar Development Resource Institute (MDRI), with three centres (for economic, political, and legal affairs) and three economic advisers to lead in these areas, respectively, was established in 2011. Meanwhile, significant reforms were introduced in the trade, finance and banking, and investment sectors.

The new government's economic and political reforms in 2011 were welcomed by the West. The United States, the United Kingdom, Australia, and countries in Europe, as well as the European Union sought closer engagement with the new government administration, resulting in the suspension or lifting of most of their economic sanctions.

The Asian Development Bank (ADB) agreed to refinance and overdue debts via a bridging loan from Japan. These measures not only alleviated part of the debt burden, but also paved the way for the re-engagement of international financial institutions with Myanmar, as well as opening up opportunities for securing new loans to finance Myanmar's economic development. They also attracted more attention to Myanmar's fiscal and monetary policies and practice

from international financial institutions and creditor and donor nations.

The Central Bank of Myanmar Law was passed in 2013 and enabled the bank to operate independently while coordinating its monetary policy with the Ministry of Finance's fiscal policy. Cooperation with international financial institutions helped to facilitate measures to establish best practices, capacity, and competency. New financial banking instruments were introduced to encourage public savings, and plans were established to improve financial intermediation. The Securities Exchange Law was passed and the Financial Institutions Law amended to ensure a more robust regulatory legal framework [1]. Measures to clarify rules and regulations concerning joint ventures between foreign and local banks were drafted.

Financial institutions play a central role in a country's economic development. However, in Myanmar, the financial sector has just been reorganised, and is still lagging behind that of other countries. The development of the financial sector is highly dependent on people's trust. Because of this, one of the major problems for Myanmar's financial sector is the lack of trust citizens have had in it, as a result of its historical background.

The research question of the paper is why such a lack of public trust in the banking sector developed, and what kind of improvement practices are being implemented.

To develop a country's economy, small and medium enterprises (SMEs) play an important role, and funds for SMEs are essential. The structure of this paper is as follows: first, the historical background of Myanmar's financial industry sector is analysed; second, the credit guarantee financing system for industrial development is investigated; third, the prototype of the guarantee system for SME financing in Myanmar is introduced, and the situation from 2011 to 2020 is discussed along with

the problems that government departments have had in introducing the new system. This paper is limited to the situation in Myanmar up until 2020.

## 2. Historical Background of the Financial System in Myanmar

In order to understand the problems of Myanmar's banking system, it is first necessary to examine the history of the financial sector and how the problems were created. In this section, we will examine the problems of a financial system that has been in existence since the colonial era up to the year 2020.

Turnell [2] explained Myanmar's (Burma's) changing financial system since colonial times. In the 1920s and 1930s, the Indian Chettiars were growing in Burma as a money-lending and financial system for rice farmers. Then, in 1930, the colonial government tried to introduce a central banking division in Rangoon which aimed to give Burmese farmers a sense of the value of money and saving [3]. However, the introduction of the plan was not well received by the British government in London as they considered that the idea would not be favourably treated in India. Therefore, India's monetary policy with bank played the role of the central bank, and the profits from Burma flowed back into India [4]. Before the Second World War, only one which was Burmese-owned – Dawson Bank – was located in the rice-producing Irrawaddy Delta area. This may be because the colonial British government wanted to try and exclude local people from the financial world [5].

After the Second World War, the colonial British government set up the Burmese currency board, and brought monetary stability to Burma. It lasted until 1952 when the Union Bank of Burma (UBB) was established as the central bank and as an independent institution. The UBB succeeded in instituting monetary policies, and supervising and monitoring government financial performance [6]. Although the UBB performed quite well during the 1950s, it had problems regarding financial resources and credit allocation that had implications for the support of farmers and SMEs [7].

In 1962, the Revolutionary Council government nationalised all the privately owned banks in the country [8]. Later, the military government merged all banks into one bank, which was later divided into four separate state-owned banks, the Union of Burma Bank, Myanma Economic Bank, Myanma Foreign Trade Bank and Myanma Agriculture Bank, that later collapsed during

General Ne Win's rule.

From 1988, the socialist economy changed into a market economy under the military government. Private banks were permitted, and a new Central Bank of Myanmar (CBM) was created. However, banks rarely provided loans to private firms, but were strongly connected with military businesses and enterprises. Even worse, banks were involved in money laundering. During the military government, the central bank had no power to formulate financial policy [9]. In the early 1990s, the market was opened to privately owned banks, but the financial sector was heavily damaged by the following three crises: the Asian financial crisis of 1997, Myanmar's domestic banking crisis of 2003, and the economic sanctions that were imposed by developed countries. These subsequent serious problems in the financial sector gave it an untrustworthy image among local people. This negative reputation became rooted in the perceptions of the people of Myanmar, and has inflicted the most severe and lasting damage to Myanmar's banking system.

The role of the financial and banking sector and its importance for every economy can be stated as follows: a sound financial system is essential for every economy [10]. Turnell [11] has stated that the financial sector mobilises savings and allocates credit to other sectors to promote economic growth. It not only provides payment services, but also enables the country to cope with economic uncertainties by hedging, pooling, sharing, and pricing risks. Therefore, an efficient financial sector can assist in the reduction of the cost and risk of producing and trading goods and services, and thus makes an important contribution to raising the standard of living [12]. In Myanmar, the financial and banking sector should fulfil this role [13]. The international sanctions by foreign powers during the military rule led to the international isolation of Myanmar. Myanmar became the poorest country in Southeast Asia, with the lowest level of financial infrastructure.

In 2011, the new government enacted a financial reform to rebuild the financial sector and started to improve the situation in Myanmar. Local private banks had been operating for 25 years, but the sector did not improve without strong competitiveness. Myanmar's government permitted the entrance of foreign banks into the market, in order to help create a competitive environment. Therefore, since 2013, the central bank has approved licenses for foreign banks to establish representative offices and carry out limited business activities [14]. Gradually, the business

activities of foreign banks have been broadened to include wholesale banking services. Wholesale banking entails the provision of services between merchant banks and other financial institutions. As of 2020, there were 13 international banks – from China, Japan, Singapore, India, Malaysia, and Vietnam – operating branches in Myanmar, as well as 49 foreign banks with representative offices and 26 private domestic banks.

The moves designed to liberalise the financial sector were progressing. On 29 January, 2018, the CBM issued a regulation allowing foreign banks and financial institutions to hold equity of up to 35 % in local banks. Then, on 2 January, 2019, the Ministry of Planning and Finance (MPF) announced, that foreign companies could offer life and non-life insurance products in Myanmar. Furthermore, the MPF stated that the government would allow overseas firms to launch retail banking services in 2020 [15].

In summary, the liberalisation initiative in the financial sector has just started in recent years, opening retail banking opportunities for overseas firms. Historically, the Myanmar financial system has changed several times over the years based on the political complexion of the government. Up until 2011, several changes had damaged people's trust in banking and the financial sector. Thus, the first priority was to remove the lack of trust and to rebuild a relationship of trust between the people and the banks.

### 3. Credit Guarantee Loan System

In many countries, loan guarantee programmes are important elements of government policy with respect to SMEs [16]. Riding [17] showed that if loan guarantee schemes are to be effective, a majority of firms can act positively to obtain financial assistance from a trustworthy guarantee system. Zecchini and Ventura [18] provided an in-depth evaluation of the impact of public credit guarantees on SMEs in Italy that increased the availability of credit and reduced the cost of borrowing, without compromising their financial sustainability. The survey results showed that Italy's guarantee instrument has proved to be an effective one in this respect. Despite the pervasiveness of market forces and the supplementary role of state and civil society organisations, there are unmet social needs that remain unaddressed by the existing institutions [19] [20].

In the case of Japan, Credit Guarantee Corporations (CGCs), which are public institutions that support SMEs

by serving as guarantors for them to borrow funds, were established in 1937, just before the Second World War. Even now, SMEs play an important role in Japan's economy, and constitute 99.7% of the total number of firms in Japan. The credit guarantee system improves the creditworthiness of SMEs, which lack assets for collateral and have weak credit standings. This helps in the allocation of funds to them from private financial institutions, and helps them with access to financing. The CGC was established to provide financial assistance from local governments, as well as from the credit insurance system of the Japan Finance Corporation, which is a Japanese government institution. The combination of these two systems is the core of the credit supplementation system [21].

The current CGCs have an important role in ensuring that SMEs have easier access to financing. In 2012, there were 52 CGCs in Japan, located in each prefecture and in five cities. At the end of 2011, their total liabilities stood at approximately 34 trillion yen. The functions of the credit guarantee system in Japan have a credit guarantee and a credit insurance function, as well as the combination of these credit guarantee and credit insurance functions [22].

SMEs can apply to CGCs for credit guarantees directly or through financial institutions. After the applications are submitted, the CGCs check the SMEs directly or through financial institutions. After approval, the CGC issues a credit guarantee certificate [23]. Then, the CGC checks the credit of the enterprise. If the CGC approves the application based on the credit checks, it issues a credit guarantee certificate to the financial institution.

For the development of the SME credit guarantee system, there are three indispensable elements: the finance structure, funding resources, and a light burden of rules and regulation [24]. The first, the finance structure, should be selected based on each country's financial status, taking into account feasibility and sustainability. The choices are equity finance and debt finance, especially credit guarantee covered loans, agency loans, loan sales–loan securitisation, and two-step loans. The second, funding resources, such as deposits, support from the government, support from abroad, and investment funds, should be decided based on the amount, term flexibility, and merit. A light burden of rules and regulation are important to prevent moral hazard. For this, institutions that provide direct loans to borrowers, ones that provide indirect loans to borrowers in a financial structure, and the prevention of moral hazard arising from borrowers or institutions that provide direct



loans are necessary.

In many countries, there are four schemes for SME loans (shown in Figure 1). These are: (1) credit guarantee covered loans; these guarantee a certain portion of the loan amount. The bank and the credit guarantee corporation respectively conduct a borrower assessment. Strictness in the credit guarantee corporation's assessment affects the performance. (2) Agency loan: the agent bank implements a loan execution to the borrower, and collects the principal as well as interest from the borrower on behalf of the original bank. The agent bank has no responsibility for the loan's performance except through breach of the duty of care. (3) Loan securitisation: after securitising its loan assets, a bank has the role of originator, and sells the product to investors. The performance of the product depends on the probability of default with regard to the original loan. The bank is able to use no assets and generates profit depending on the timing of its launch. (4) The two-step loan: a sub-bank implements loan 2, the resources for which are provided by the original bank's loan 1. This scheme is effective when the sub-bank does not have enough lending resources, but has huge borrower demands. Even though the sub-bank faces difficulty in correcting the repayment, it has responsibility for the repayment of loan 1 to the original bank [25].

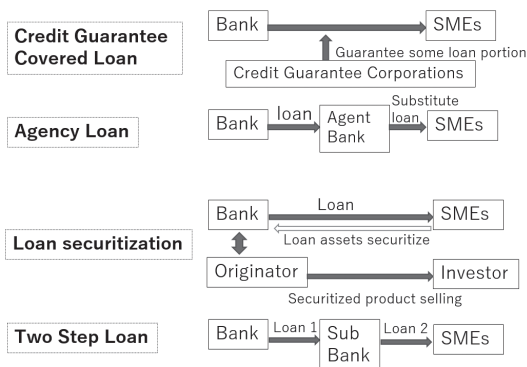


Figure 1 Major SME Loan Schemes  
Source: Information obtained from Izumi (2019) [26]

#### 4. Applying the Credit Guarantee System in Myanmar

##### 4.1. The Current Situation of Outstanding Loans for SMEs

In Myanmar, as discussion of its background has indicated above, trust in banks is still low, and the financial sector is weak. As a result, bank loans have not been widely publicised or sufficiently used. Figure 2 shows

commercial loans in the Association of Southeast Asian Nations (ASEAN) 10 countries. The percentage shown in the figure is the percentage of outstanding commercial loans per Gross Domestic Product (GDP) in each country in 2016 [27], based on a survey conducted by the IMF in 2016. The rate of SME loans in relation to GDP in Myanmar was 15.3%, which was the lowest among the ASEAN countries. The highest percentage in the ASEAN 10 was attained by Singapore with 150%, followed by Vietnam with 119.7%, Malaysia with 115.2%, Thailand with 73.5%, and Cambodia with 67.4%. The 2017 data show that the situation in Myanmar had improved to 31.1%.

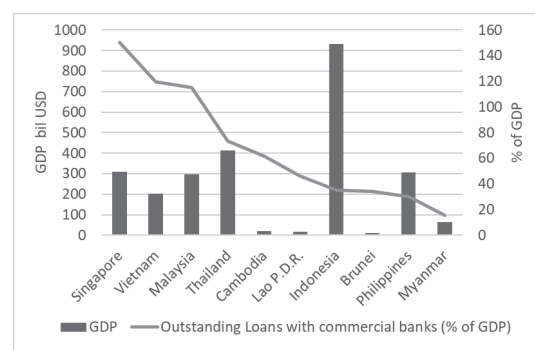


Figure 2 Outstanding Private Bank Loans vs. GDP (% billion US\$)  
Source: Data obtained from The Japanese Embassy in Myanmar (2018) [28]

The Japan International Cooperation Agency (JICA) [29] reported the results of a questionnaire survey of SMEs in Myanmar. The 42 SMEs were selected from the participants in the seminar organised at the UMFCCI on 23 August and 19 September 2013. Out of the 42 SMEs that replied, 40.5% had outstanding bank loans, while 50% had no bank loans.

The two major reasons for having no bank loans were high cost and the lack of assets for collateral. The JICA survey results in 2017 [30] showed the reasons why SMEs did not have bank loans. Overall, 81% of SMEs replied that they avoided bank loans to reduce financial costs. Instead of bank loans, they used their own funds earned from their business operations and capital investments. Their own funds were basically those they had generated themselves, but in many cases, they were provided by relatives or family members. In these cases, relatives and family members were supposed to receive part of the profits as dividends instead of receiving fixed interest repayments. None of the SMEs were borrowing from informal lenders. In total, 14.5% responded that they could not have bank loans due

to their lack of assets for collateral. They relied on loans from informal lenders and/or from relatives and friends with a fixed interest rate. The interest rates of such informal loans varied from 2 % to 6 % per month. SMEs that had sufficient profits were offered a lower interest rate of 2 % per month, but others had to accept funds at high interest rates of 5–6 % per month [31]. Almost all SMEs that had outstanding bank loans responded that these were with only one bank, although they had bank accounts at multiple banks. Only one SME had outstanding loans from more than one bank [32].

To increase SME loans with the aim of promoting the industrial development of Myanmar, two main strategies are being implemented: credit guarantee loans and the JICA two-step loans. This section may be divided by subheadings.

**4.2. Credit Guarantee Insurance (CGI) in Myanmar**

This section focusses on the case of the prototype guarantee system established in 2014 by Myanmar government advised by the SMBC in Myanmar and investigates how trust can be established in the banking sector in Myanmar. The prototype system is shown in Figure 3.

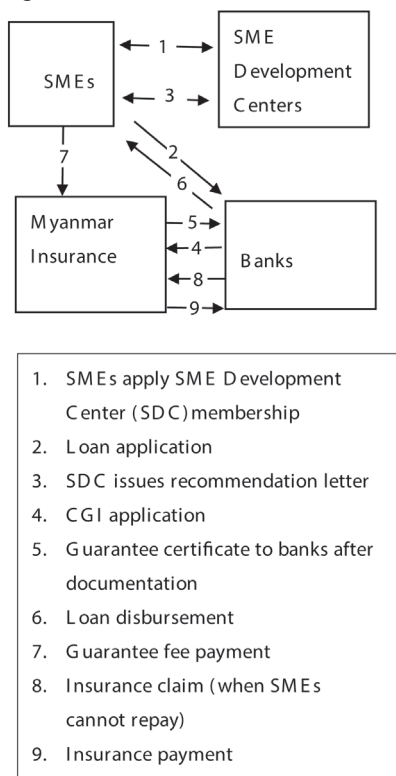


Figure 3 Interaction Chart of Credit Guarantee under the CGI Scheme

Source: JICA (2017) [33] modified by author

When the CGI was first introduced in Myanmar in 2014, there were no applicants during the initial year. As the Myanmar Times [34] showed, the state-owned Myanmar Insurance company launched a CGI for SMEs in June 2014. The CGI can be used as collateral for bank loans, with the insurer being able to reimburse up to 50 % of a loan in the event of a default. However, private banks have failed to take advantage of the scheme for their risk management strategies. As discussed in the previous historical background section, local Myanmar banks and citizens had lost trust in the financial sector over the years, and the new CGI was not at all well received at the beginning.

SMEs are a driving force for Myanmar. The Ministry of Industry report that there are more than 100,000 SMEs in Myanmar, about 80% of which are registered and the remainder are not. However, few SMEs can obtain access to capital by formal bank loans. Without collateral or assets, most SMEs have no chance of obtaining formal bank loans, and rely only on relatives and family members. In order to develop the Myanmar economy, financial support for SMEs is indispensable in order to generate local development.

The average and maximum interest rates of private banks is 13 % per year, and the Small and Medium Industrial Development Bank (SMIDB) offers SME loans at 8.5%, as dictated by the government [30]. The First Myanmar Investment and Yoma Banks are preparing a plan that loans are assessed for approval on the basis of creditworthiness rather than collateral [35].

The initial introduction of CGI did not progress well. When CGI was introduced in Myanmar in 2014, under this insurance scheme Myanmar Insurance or a private firm was to reimburse lenders to SMEs up to 50 % of the loan in the event of a default. This enabled the insurance scheme to be used as collateral for bank loans. At the time of the launch, lenders welcomed the move, as it reduced the risk when lending to SMEs. However, one year later, no SMEs had taken advantage of this insurance [36].

Thus, the financial support for SMEs remained insufficient. As of April 2015, the t had offered loans to 21 businesspeople, the Kanbawza Bank (KBZ) gave loans to only three, and banks were still unable to trust the businesses under the CGI. Then, the MPF created a committee responsible for the drafting of the Credit Guarantee Corporation Law. The group is chaired by a managing director of Myanmar Insurance, and consists of approximately 10 people from the ministry, Myanmar Economic Bank (MEB), the Myanmar Agri Development

Bank (MADB), the Myanmar Banks Association, and other players [37].

In 2016, the first case started as a trial [38]. In 2017, the Credit Guarantee Corporation Law Committee was established. In July 2018, after several examinations of the plan, the CBM announced that the state-owned Myanmar Insurance, under a new CGI scheme for banks, would bear 60 % of a loan in the event of a default, which was 10 percentage point higher than the previous scheme. [39]

In Myanmar, the insurance system was very limited. Historically, Myanmar Insurance was established in 1952 and at that time exclusively provided life assurance, but started to provide other types of insurance later. However, in 1964, during the military rule, the Myanmar government integrated the insurance business into Myanmar Insurance and prohibited private sector participation in the insurance business. For more than half a century, up until 2013, the insurance business was closed to the private sector. Finally, in 2013, the insurance business was reopened to the private sector. In addition, as of June 2017, the insurance business was opened to foreign enterprises, which are only currently allowed to provide insurance within special economic zones [40].

The move was expected to encourage more domestic banks to adopt the insurance scheme, and to lend more to local businesses. When calculating the Capital Adequacy Ratio (CAR) for loans for SMEs which are under a CGI system, the ratio only needs to take into account 40 % of the actual loan [41]. If the debtor fails to repay, Myanmar Insurance will be responsible for reimbursing 60 % of the loan, while the bank only has to shoulder the remaining 40 %. As of 6 July 2018, there have been more than 600 applications for CGI, mainly to the CMB, the Small & Medium Industrial Development Bank (SMIDB), and the state-owned MEB. Meanwhile, MADB, the country's largest financial institution in terms of the provision of financial services to the rural community, started using CGI in June 2018. CGI has started to be used by businesses in both the industrial and agricultural sectors. The introduction of CGI helps to strengthen Myanmar's economy by supporting banks in funding more loans for SMEs. As of March 2019, the number of applications had reached over 1,000 [42].

The non-CGI-covered portion of any loan requires 100 % of the loan assets. This means that all loans not covered by CGI will be considered risky assets by the Central Bank. Banks with loans covered by the insurance scheme will also enjoy a higher CAR, which, in turn, will raise their value.

### 4.3. The Japan International Cooperation Agency (JICA) Two-Step Loan

The second activity for promoting SME development by increasing financial support was the JICA's two-step loan as a part of official development assistance (ODA) from Japan, which started in 2014. The two-step loan, as described in Section 3 and Figure 3 in this paper, is as follows: a sub-bank implements loan 2, the resources for which are provided by the original bank's loan 1. This scheme is effective when the sub-bank does not have enough lending resources, but has huge borrower demands. Even though the sub-bank faces difficulty in collecting the repayment, it has responsibility for the repayment of loan 1 to the original bank. Figure 4 shows the implementation scheme for the two-step loan.

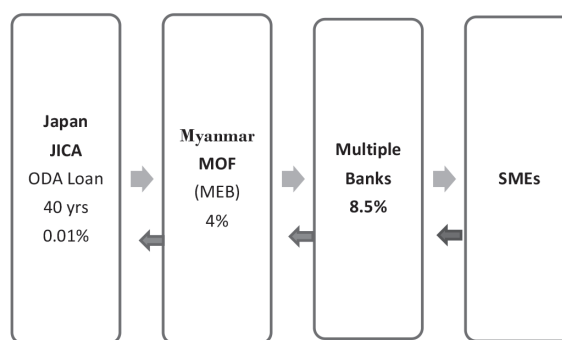


Figure 4 Two-Step Loan for SME Promotion: Implementation Scheme

Source: The author derived this from information provided by JICA (2014) [43]

In 2014, the Myanmar government announced that the Japanese government would provide ODA loans for Myanmar's SMEs through the JICA. As an agent of the Ministry of Finance in Myanmar, The MEB was expected to obtain an ODA loan from the JICA to distribute the funds to the Myanmar Citizens' Bank, the state-owned SMIDB, the Cooperative Bank, KBZ, and other private banks at an interest rate of 4%. The banks then gave loans to SMEs at 8.5% interest rate [44].

The loan is called a two-step loan, which has two steps for borrowers as shown in Figure 4. First, the JICA offers an ODA loan over 40 years with almost no interest to the Ministry of Finance (MOF) in Myanmar. Then the MOF offers 4% loans to banks, after which the banks distribute them at 8.5% to SMEs. In Myanmar, private banks offer loans at 13 %, so 8.5 % interest is still good for SMEs in Myanmar.

The gap in interest rate between 4 and 8.5% exists due

to currency fluctuation and management expenditures, as well as infrastructure and risk management costs. The deposit policy of the lending rate should be above 8% [45]. The additional loan from the JICA on the fiscal year 2018–2019 reached 11.5 billion yen in total. In addition, the JICA announced that it would offer a two-step loan of 11.5 billion yen (about 151.6 billion Myanmar Kyat) for the fiscal year 2018–2019. The JICA two-step loans were widely spread all over the country to 12 out of 14 states/regions and to Nay Pyi Taw [46].

In order to obtain the JICA two-step loan, the application procedure for SMEs is designed to improve the SMEs' business capabilities. The first requirement for applicants is to prepare a business plan. The process of writing a business plan is very important for SMEs as it compels them to reconsider business targets, principles, main products, production processes, marketing, cost analysis, and financial planning. In most cases, for these SMEs, this will be the first time they have written a formal business plan by themselves. Those who complete business plans can submit their applications to the JICA for a two-step loan. In most cases, the JICA experts examine their applications and business plans, then visit the SMEs' sites to conduct feasibility study. Then, the JICA makes a decision based on the feasibility study. After the SMEs receive the JICA two-step loan fund, they proceed to keep track of their business plan.

At the same time, several business courses for managing directors and managers have been made available by the Myanmar Japan Center (MJC), which is a human resource development centre funded and supported by JICA through Japan's ODA. Those SMEs that have received the JICA two-step loan are advised to take these business courses, such as business planning, production management, quality control, accounting, and so on. Taking business courses with other SMEs can enhance their business plans, making them more stable and with greater growth potential. In addition, taking these business courses can generate SME networking, which leads to further business collaboration.

As a result, based on the questionnaire survey conducted with 141 end-borrowers [47], about 80 % of them have achieved, or are expected to achieve, improvements in quality and increases in production and sales. Furthermore, 67 % answered that they had increased the number of employees and 61 % had purchased Japanese machines to improve their productivity and quality. As the survey showed, the JICA

two-step loan, together with the MJC, has contributed to improving SMEs' performance and quality, to a certain extent.

## 5. Conclusion

The banking sector in Myanmar requires various kinds of improvement practices to upgrade to international standards. This paper tries to shed light on the problem by analysing the important trust-building institutional approach. This approach to the Myanmar banking system is a very important issue.

The historical background of Myanmar financial institutions has been unsupportive of the institution of a trust-based loan system to foster local SMEs' development. During the junta government, the backward economic climate worsened the situation. However, the importance of credit guarantee insurance and sufficient funds to upgrade SMEs' capability has emerged in Myanmar. The JICA two-step loan has contributed to building trust in the financial sector by offering close monitoring, and by advising on a structure between banks, end-users, and human resource development agencies such as the MJC.

These two approaches that have been progressing in Myanmar – the CGI and the two-step loan – have received a positive reaction from local SMEs, as discussed in this paper. They also support industrial development, and provide trustworthy funds for the support of local SMEs.

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## ベトナムにおける低品質再生骨材を用いたコンクリートの性能評価および調合設計

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### 要 旨

ベトナム社会主義共和国（ベトナム）では、建設廃棄物の処理量は、2018年において、約148～185万tとなっているが、2025年の目標リサイクル率は60%となっており、建設廃棄物の主な用途は整地材、路盤材、非焼成れんがなどである。今後、建設廃棄物のリサイクル率を向上させるためには、コンクリート用再生骨材への使用を促進することが必要である。本研究は、製造が簡便な低品質再生骨材と普通骨材を混合使用した再生骨材コンクリートをベトナムで普及させることを目的に、相対品質値法による性能評価および調合設計について検討を行った。その結果、ベトナムにおいても日本と同様、構造用コンクリートへの適用が可能であることが判明した。

**キーワード**：低品質再生骨材、相対品質値法、構造用コンクリート、調合設計、性能評価

## Performance evaluation and mix proportion of concrete using low-quality recycled aggregate in Vietnam

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### Abstract

In the Socialist Republic of Vietnam (Vietnam), there were 1.5~1.8 million tons of construction waste which was treated in 2018, but the amount of untreated construction waste is significantly larger. According to the World Bank, as a vision to 2025 of Vietnamese Government, the recycle rate of construction waste will be 60%. By 2025 construction waste is used mostly as leveling material, roadbed material, and for non-fired brick. Therefore, to improve the recycle rate of construction waste, a measurement for discriminating the use of recycled aggregate in concrete is very necessary.

The purpose of this study is to discriminate the use of recycled aggregate concrete that is easy to manufactured in Vietnam using recycled aggregate mixed with normal aggregate by examining the performance evaluation through relative quality index method and mix proportion. As a result, when combining low-quality recycled aggregate and normal aggregate in concrete with a suitable replacement ratio, as in Japan, it is possible to apply for structural concrete in Vietnam.

**Keywords** : Low-quality recycled aggregate, relative quality index method, structural concrete, mix proportion design, performance evaluation



### 1. 研究目的

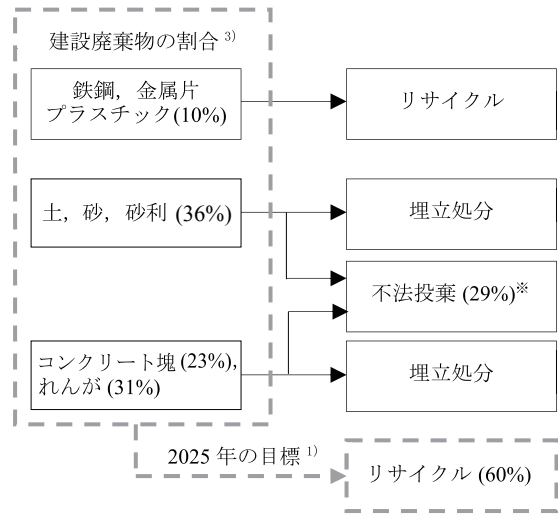
2018年に公表された世界銀行の固形廃棄物管理評価報告書<sup>1)</sup>により、ベトナム社会主義共和国(ベトナム)において処理した固形廃棄物量は740万t/年であり、このうち、約148~185万t/年は建設廃棄物である。ただし、実際の固形廃棄物の発生量は、処理量より多いと思われるが、具体的な統計資料が確認できなかったため、詳細は不明である。さらに、表1に2018年度に公表された日本国際協力機構(JICA)の都市廃棄物総合管理能力向上プロジェクトの業務完了報告書<sup>2)</sup>によると、ハノイ市の建設廃棄物発生量推計は約270~620万t/年である。このうち、民間工事、新築工事および解体工事のデータは存在するが、公共工事のデータは不明であり、実際にはさらに多くの建設廃棄物が発生しているものと推察される。ハノイ市は、建設廃棄物の埋立処分場不足に直面しており、対策として、建設材料へのリサイクル推進が検討されている。なお、世界銀行のベトナム全国の処理した建設廃棄物量(約148~185万t/年)に比べ、ハノイ市で発生した建設廃棄物量は1.8~3.4倍となっている。これにより、ベトナムにおいては処理されていなかった建設廃棄物量は膨大であることが推察される。

図1にベトナムの建設廃棄物成分および処理方法を示す。建設廃棄物の割合では、鉄鋼、金属片、プラスチックは10%、土、砂、砂利は36%、コンクリート塊は23%、れんがは31%である<sup>3)</sup>。このうち、鉄鋼、金属片、プラスチックはリサイクルされているが、土、砂、砂利およびコンクリート塊、れんがは埋立処分あるいは不法投棄されている。ベトナム国立環境研究所の調査<sup>4)</sup>により、ハノイ市では、建設廃棄物の不法投棄は29%である。なお、世界銀行の報告<sup>1)</sup>により、ベトナム政府の目標で、2025年に建設廃棄物のリサイクル率は60%となっている。

表1 ハノイ市の建設廃棄物発生量推計<sup>2)</sup>

区分	年間量 (百万t)	日量 (千t)	構成比 (%)
公共工事	不明	不明	-
民間工事	1.1~3.2	2.9~8.8	40~52
新築工事	0.23	0.62	4~5
解体工事	1.4~2.8	3.8~7.6	44~51
合計	2.7~6.2	7.3~17.0	100

ベトナムにおいてはコンクリート用再生粗骨材の規格(TCVN 11969:2018)<sup>5)</sup>が2018年に規定されたが、政府のリサイクル規制がまだ施行されていないことから、実際の構造物への適用実績はない。



※2019年の報告<sup>4)</sup>

図1 ベトナムの建設廃棄物成分および処理方法<sup>2)</sup>

本研究は、製造が簡便な低品質再生骨材と普通骨材を混合使用した再生骨材コンクリートをベトナムで普及させることを目的に、相対品質値法<sup>6)</sup>による性能評価および調合設計について検討を行った。

### 2. 建設廃棄物のリサイクル

#### 2-1 低品質再生骨材コンクリートの普及

TCVN 11969:2018(TCVN 11969)<sup>5)</sup>では、再生骨材コンクリートの調合設計方法は規定されていない。そのため、再生骨材を用いるコンクリートは、実際の構造物への適用は困難である。

日本では、日本産業規格(JIS)により、コンクリート用再生骨材H(JIS A 5021)、再生骨材コンクリートM(JIS A 5022)、再生骨材コンクリートL(JIS A 5023)が規定されている。2018年のJIS A 5022の改正においては、再生骨材Lを一定の置換率以下で普通骨材と混合使用する再生骨材コンクリートM(1種、2種)が規定された。再生骨材コンクリートの種類と骨材の組合せを表2に示す。再生骨材Lの製造は、再生骨材Hおよび再生骨材Mに比べて安価でCO<sub>2</sub>排出量も低いことから<sup>7)</sup>、経済的および環境的にも再生骨材Lの利用拡大が有効である。

#### 2-2 ベトナムにおける再生骨材

TCVN 11969<sup>5)</sup>において、再生粗骨材はI種およびII種に区分されている。I種では吸水率5%以下となっており、JIS A 5022 付属書Aに相当する<sup>8)</sup>。II種では吸水率20%以下となる。II種は、非焼成レンガの原料としてリサイクル

することを前提としたもので、レンガの混入量が多い。再生骨材の製造は、写真1に示すように、コンクリート塊とレンガを分別せずに、混合廃棄物の状態で破碎したのち、分級を行う。

表3に、ベトナムにおける骨材品質に関する既往研究による実験結果<sup>9)</sup>を示す。実際のコンクリート塊と廃れんがの混合廃棄物の状態から破碎・分級して製造した再生粗骨材RG<sub>1</sub>の吸水率は8.45%、絶乾密度は2.13g/cm<sup>3</sup>となり、再生粗骨材中に31.2%のれんがが混入している。なお、破碎・分級する前にコンクリート塊とれんがを分別し、写真2に示すように、れんがが混入していない再生粗骨材RG<sub>2</sub>の製造は可能である。RG<sub>2</sub>の吸水率は5.81%となり、JIS A 5023 附属書Aに規定されている範囲にある<sup>10)</sup>。

再生細骨材RSは、絶乾密度は1.94g/cm<sup>3</sup>、吸水率は12.15%、粗粒率は2.65である。骨材品質のうち吸水率は、再生細骨材Lの範囲内にあることから、本研究では、JIS A 5023 附属書Aに規定される再生粗骨材Lおよび再生細骨材Lを用いることとした。



写真1 ベトナムにおける再生骨材製造状況<sup>10)</sup>



れんががあり                      れんがなし

写真2 ベトナムにおける再生粗骨材の外観<sup>10)</sup>

### 3. 実験概要

セメントの主要品質は表4に、上水道水の主要品質は表5に、化学混和剤の主要品質は表6に示す。これらについて、TCVNとJISを比較した結果、JISの規制値はすべてTCVNの規定する範囲に包含されているため、本研究に満足するもので、使用したセメント、水、化学混和剤は、TCVNの規制値を用いた。なお、コンクリート用骨材の主要品質は表7に示す。

表2 再生骨材コンクリートの種類と骨材の組合せ<sup>11)</sup>

再生骨材コンクリートの種類	粗骨材	細骨材
再生骨材コンクリート H1 種	粗骨材の全部またはその一部が再生粗骨材 H	普通細骨材
再生骨材コンクリート H2 種	粗骨材の全部またはその一部が再生粗骨材 H	細骨材の全部またはその一部が再生細骨材 H
	普通粗骨材	
再生骨材コンクリート M1 種 <sup>*1</sup>	粗骨材の全部またはその一部が再生粗骨材 M	普通細骨材
	粗骨材は一部(置換率 50%以下)が再生粗骨材 L <sup>*2</sup>	
再生骨材コンクリート M2 種	粗骨材の全部またはその一部が再生粗骨材 M	細骨材の全部またはその一部が再生細骨材 M
	粗骨材は一部(置換率 50%以下)が再生粗骨材 L <sup>*2</sup>	細骨材は一部(置換率 30%以下)が再生細骨材 L <sup>*2</sup>
	普通粗骨材	細骨材の全部またはその一部が再生細骨材 M 細骨材は一部(置換率 30%以下)が再生細骨材 L <sup>*2</sup>
参考 <sup>*3</sup>	粗骨材の全部またはその一部が再生粗骨材 L	細骨材の全部またはその一部が再生細骨材 L

※1 標準品と耐凍害品がある。※2 再生骨材 L の規定を満足するとともに、不純物量は再生骨材 M の規定を満足する。  
※3 JIS A 5023による。JASS 5(2018)<sup>11)</sup>には規定されていない。

表3 ベトナムにおける骨材品質に関する実験結果

項目	碎石 <sup>*</sup>	川砂	再生粗骨材	再生細骨材	
	NG	NS	RG <sub>1</sub>	RG <sub>2</sub>	RS
絶乾密度 (g/cm <sup>3</sup> )	2.62	2.50	2.13	2.30	1.94
吸水率 (%)	0.85	1.22	8.45	5.81	12.15
粗粒率 (F.M.)		2.64			2.65
れんが混入量(mass%)			31.2		不明

※石灰岩碎石 2005

#### 3-1 使用材料

##### (1) セメント

表4より、本研究で用いた普通ポルトランドセメント(N)はTCVN 2682:2009<sup>12)</sup>に規定されているポルトランドセメント(PC40種)と比較した結果、規定を満足した。

##### (2) 水

表5より、本研究で用いた上水道水はTCVN 4506:2012<sup>13)</sup>に規定されているコンクリートおよびモルタル用水と

名古屋市上下水道局の調査結果<sup>14)</sup>を比較すると、目標品質を満足した。

(3) 化学混和剤

表6より、本研究で用いる化学混和剤の品質は、TCVN 8826:2011<sup>15)</sup>のAE減水剤およびTCVN 12300:2018<sup>16)</sup>の空気量調整剤を満足した。

(4) 骨材

表7より、TCVN 7570:2006<sup>17)</sup>には、コンクリートおよびモルタル用普通骨材の絶乾密度、吸水率、微粒分量、粒形判定実積率は規定されていないことから、JIS A 5308 附属書A (レディーミクストコンクリート用骨材) および JIS A 5005 (コンクリート用砕砂及び碎石) の規制値を用いた。再生骨材は、2. で調査した結果、れんがが混入していなければ、JIS A 5023 附属書A に規定される再生粗骨材L および再生細骨材Lの吸水率に適合している。

表8に本研究で用いた再生骨材の概要を、表9に使用骨材の主要品質を、図2に再生骨材Lの製造フロー例を示す。

普通細骨材は川砂(NS) および硬質砂岩砕砂(CS)を、普通粗骨材には硬質砂岩碎石2005の2種類(NG<sub>1</sub>, NG<sub>2</sub>)を用いた。再生粗骨材L2005(RLG)が4種類(RLG<sub>1</sub>~RLG<sub>4</sub>)、再生細骨材L(RLS)が2種類(RLS<sub>1</sub>, RLS<sub>2</sub>)である。RLG<sub>1</sub>は土木構造物(詳細不明)、RLG<sub>2</sub>は建築物(詳細不明)、RLG<sub>3</sub>およびRLS<sub>1</sub>は住基礎(原骨材:山砂利、碎石)、RLG<sub>4</sub>およびRLS<sub>2</sub>はRC構造物躯体(原骨材:山砂利、碎石)とした4種類の原コンクリートを用い、中間処理工場で破碎あるいは再生碎石(40mm ≤)を製造した後、5~20mmのRLG、0~5mmのRLSに分級し製造した。再生骨材の品質は、RLG<sub>1</sub>の不純物量を除き、JIS A 5023 附属書A相当であった。なお、RLG<sub>1</sub>およびRLG<sub>2</sub>のアルカリシリカ反応性は区分B、RLG<sub>3</sub>およびRLG<sub>4</sub>は区分Aであった。RLG<sub>3</sub>およびRLG<sub>4</sub>の400kN 破碎値はそれぞれ23.3%、24.5%、10%破碎力は134kN、148kNであった。RLG<sub>3</sub>およびRLG<sub>4</sub>のFM凍害指数は、JIS A 5022の0.08以下を満足した。

表6 化学混和剤の主要品質

項目		TCVN 8826:2011	TCVN 12300:2018	JIS A 6204		本研究	
		AE減水剤	空気量調整剤	AE減水剤	空気量調整剤	AE減水剤	空気量調整剤
凝結時間の差(分)	始発	-60~+90	-75~+75	-60~+90	-60~+60	+30	+10
	終結	-60~+90	-75~+75	-60~+90	-60~+60	+25	±0
圧縮強度比(%)	7日	110以上	90以上	110以上	95以上	126	102
	28日	110以上	90以上	110以上	90以上	117	100
長さ変化比(%)		-	120以下	120以下	120以下	97	100
凍結融解に対する抵抗性		-	80以上 <sup>※1</sup>	60以上 <sup>※2</sup>		92 <sup>※2</sup>	94 <sup>※2</sup>
塩化物イオン(Cl <sup>-</sup> )量(kg/m <sup>3</sup> )		0.1以下	-	0.02以下		-	-
全アルカリ量(kg/m <sup>3</sup> )		-	-	0.3以下		0.07	-

※1 耐久性指数 ※2 相対動弾性係数(%)

3-2 調合

表10にコンクリートの調合概要を示す。水セメント比(W/C)を45%、55%、65%の3水準、RLGの置換率を0%、50%、100%の3水準、RLSの置換率を0%、30%、50%、100%の4水準に変化させた合計27種類の試料コンクリートを用意した。単位水量は試し練りにより、W/C=45%において183kg/m<sup>3</sup>、185kg/m<sup>3</sup>とし、W/C=55%で180kg/m<sup>3</sup>、W/C=65%で175kg/m<sup>3</sup>、176kg/m<sup>3</sup>、177kg/m<sup>3</sup>とした。調合設計の基本的な考え方として、再生骨材置換率0%のコンクリート(比較用コンクリート)に対して、骨材の種類および再生骨材の置換率を変化させたコンクリートを作製した。

いずれも目標スランプは18 ± 2.5cm、目標空気量は4.5 ± 1.5%とした。化学混和剤には、AE減水剤(高性能タイプ)をセメント質量の1.0%、空気量調整剤はセメント質量の0.05~0.10%を添加した。

本研究で用いたコンクリートの相対吸水率(Q<sub>t</sub>)を算定した。Q<sub>t</sub>は、普通骨材と再生骨材の吸水率と置換率から式

表4 セメントの主要品質

品質項目		TCVN 2682:2009	JIS R 5210	本研究
		PC40種	N	
圧縮強さ(MPa) <sup>*</sup>	3日	21以上	12.5以上	30.4~32.9
	28日	40以上	42.5以上	62.4~63.7
強熱減量(%)		3.0以下	5.0以下	2.22~2.29
密度(g/cm <sup>3</sup> )		-	-	3.16
比表面積(cm <sup>2</sup> /g)		2800以上	2500以上	3300~3370
SO <sub>3</sub> (%)		3.5以下	3.5以下	2.10~2.23
MgO(%)		5.0以下	5.0以下	1.11~1.67
全アルカリ(%)		0.6以下	0.6以下	0.50~0.55
塩化物イオン(%)		-	0.035以下	0.010~0.017

※JIS R 5210, 本研究はN/mm<sup>2</sup>

表5 上水道水の主要品質

項目	TCVN 4506:2012	JIS A 5308	本研究 上水道水 <sup>*</sup>
SO <sub>4</sub> <sup>2-</sup> (mg/L)	600以下	-	-
蒸発残留物(mg/L)	200以下	500以下	69
塩化物イオンCl <sup>-</sup> (mg/L)	350以下	200以下	3.2
pH値	4.0~12.5	5.8~8.6	7.0
Ca, Mg(硬度)(mg/L)	200以下	300以下	17

※名古屋市上下水道局の緑政土木局天白土木事務所の天白区の水質調査(2021年7~8月)<sup>14)</sup>による。

(1) に示す使用骨材品質値の加重平均を算出した。

$$Q_t = \frac{Q_vG \times a + Q_vN \times b + Q_rG \times c + Q_rN \times d}{a + b + c + d} \quad (1)$$

ここに、

$Q_t$  : 骨材の相対吸水率 (%)

$Q_vG$  : 普通粗骨材の吸水率 (%)

$Q_vN$  : 普通細骨材の吸水率 (%)

$Q_rG$  : 再生粗骨材の吸水率 (%)

$Q_rN$  : 再生細骨材の吸水率 (%)

$a, b, c, d$  : 使用骨材の絶対容積 ( $L/m^3$ )

### 3-3 実験項目および実験方法

実験項目および実験方法を表 11 に示す。フレッシュ性状は、スランプ、空気量、単位容積質量、コンクリート温度および塩化物含有量を、硬化性状では、圧縮強度、静弾性係数、長さ変化、気乾単位容積質量、促進中性化および凍結融解の諸試験を実施した。

表 7 コンクリート用骨材の主要品質

項目	TCVN 7570:2006		JIS A 5308	JIS A 5005*
	細骨材	粗骨材	細骨材	粗骨材
アルカリシリカ反応性	無害	無害	-	-
絶乾密度 ( $g/cm^3$ )	-	-	2.5 以上	2.5 以上
吸水率 (%)	-	-	3.5 以下	3.0 以下
微粒分量 (%)	-	-	3.0 以下	3.0 以下
粒形判定実積率 (%)	-	-	-	56 以上
塩化物量 (%)	0.05 以下	0.01 以下	0.04 以下	-

\*JIS A 5005 により、砕砂の吸水率は 3.0%以下、絶乾密度は  $2.5g/cm^3$  以上。

表 8 再生骨材の概要

原コンクリート		再生骨材の種類		製造方法
構造物種類	原骨材			
土木構造物	詳細不明	再生粗骨材 L : RLG <sub>1</sub>	再生砕石	破碎・分級
建築物	詳細不明	再生粗骨材 L : RLG <sub>2</sub>	再生砕石	破碎・分級
住宅基礎	山砂利, 砕石	再生粗骨材 L : RLG <sub>3</sub>	再生砕石	破碎・分級
		再生細骨材 L : RLS <sub>1</sub>	再生砕石	
RC 構造物 躯体	山砂利, 砕石	再生粗骨材 L : RLG <sub>4</sub>	再生砕石	破碎・分級
		再生細骨材 L : RLS <sub>2</sub>	再生砕石	

## 4. 実験結果

### 4-1 フレッシュ性状

各種コンクリートのフレッシュ性状を表 12 に示す。

#### (1) スランプおよび空気量

AE 減水剤 (高機能タイプ) は、いずれのコンクリートにおいてもセメント質量の 1.0% とし、空気量調整剤は 0.05 ~ 0.10% で使用した。これにより、全ての試験体において目標

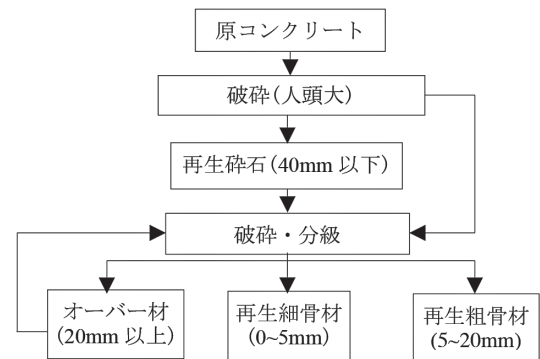


図 2 再生骨材 L の製造フロー例

表 9 使用骨材の主要品質\*1

品質項目	試験方法	NS**2	CS**3	NG <sub>1</sub> **4	NG <sub>2</sub> **5	RLS <sub>1</sub>	RLS <sub>2</sub>	RLG <sub>1</sub>	RLG <sub>2</sub>	RLG <sub>3</sub>	RLG <sub>4</sub>
絶乾密度 ( $g/cm^3$ )	JIS A 1109	2.55~2.60	2.52	2.63~2.64	2.61	2.14	2.06	2.29	2.30	2.27	2.22
吸水率 (%)	JIS A 1110	1.42~1.92	1.60	0.60~0.76	1.17~1.31	8.45	10.25	5.33	6.42	5.66	6.84
粗粒率 (F.M.)	JIS A 1102	2.50~2.73	2.63	6.65~6.66	6.57~6.62	3.37	3.09	6.39	6.74	6.57	6.46
微粒分量 (%)	JIS A 1103	1.9~4.6	4.5	-	1.1~1.8	5.5	7.0	0.2	1.4	0.3	0.6
実積率 (%)	JIS A 1104	62.8~67.2	67.1	58.7~62.1	58.6~62.8	65.2	69.8	59.2	60.1	61.0	61.6
粒形判定実積率 (%)	JIS A 5005	-	58.2	58.4~62.1	58.3~60.1	60.3	66.1	59.5	59.9	59.9	63.2
400kN 破碎値 (%)	BS 812-110									23.3	24.5
10% 破碎力 (kN)	BS 812-111									134	148
FM 凍害指数	JIS A 5022									0.03	0.05
アルカリシリカ反応性	JIS A 5021									無害	無害
不純物量 (mass%)*6	A	JIS A 5023				0	0	2.2	0.2	0.3	0.1
	B					0	0	0	0.1	0	0
	C					0	0	0	0	0	0
	D					0	0	0	0	0	0
	E					0	0	0	0	0	0
	F					0	0	0	0	0	0
	G					0	0	0	0	0	0
合計						0	0	2.2	0.3	0.3	0.1

\*1 範囲で示したものは複数ロットで採取した。\*2 揖斐川産川砂 \*3 新城産硬質砂岩砕砂 \*4 春日井産硬質砂岩砕石 2005 \*5 新城産硬質砂岩砕石 2005 \*6 A : タイル, れんが, 陶磁器類及びアスファルトコンクリート塊 B : ガラス片

表 10 コンクリートの調合概要

種類 <sup>*1</sup>	調合条件			単位量(kg/m <sup>3</sup> )								混和剤(C×%)		Qt <sup>*4</sup> (%)
	再生粗骨材 L 置換率 (%)	再生細骨材 L 置換率 (%)	W/C (%)	s/a (%)	W	C	NS	CS	NG	RLS	RLG	AE 減 水剤 <sup>*2</sup>	空気量調 整剤 <sup>*3</sup>	
NG <sub>1</sub> NS-45	0	0	45	45.0	185	411	760	0	924	0	0	1.00	0.10	0.97
NG <sub>2</sub> NS-45 <sup>*5</sup>	0	0		43.5	183	407	736	0	960	0	0	1.00	0	1.30
NG <sub>2</sub> RLS <sub>1</sub> 100-45	0	100		43.5	183	407	0	0	960	649	0	1.00	0	4.34
NG <sub>1</sub> RLG <sub>1</sub> 50NS-45	50	0		45.0	185	411	760	0	465	0	424	1.00	0.10	2.27
NG <sub>1</sub> RLG <sub>2</sub> 50NS-45	50	0		42.1	185	411	697	0	492	0	453	1.00	0.05	2.74
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-45 <sup>*5</sup>	50	30		45.4	183	407	0	523	464	199	417	1.00	0	4.10
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-45	50	50		43.5	183	407	368	0	480	324	436	1.00	0	4.08
NG <sub>1</sub> RLG <sub>1</sub> 100NS-45	100	0		45.0	185	411	760	0	0	0	848	1.00	0.10	3.57
NG <sub>2</sub> RLG <sub>3</sub> 100NS-45	100	0		43.5	183	407	736	0	0	0	872	1.00	0	3.83
NG <sub>1</sub> NS-55	0	0		45.0	180	327	797	0	974	0	0	1.00	0.10	0.97
NG <sub>2</sub> NS-55 <sup>*5</sup>	0	0	45.8	180	327	810	0	960	0	0	1.00	0	1.30	
NG <sub>2</sub> RLS <sub>1</sub> 100-55 <sup>*5</sup>	0	100	45.8	180	327	0	0	960	714	0	1.00	0	4.51	
NG <sub>1</sub> RLG <sub>1</sub> 50NS-55	50	0	45.0	180	327	797	0	487	0	445	1.00	0.10	2.27	
NG <sub>1</sub> RLG <sub>2</sub> 50NS-55	50	0	44.9	180	327	779	0	492	0	453	1.00	0.05	2.68	
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-55 <sup>*5</sup>	50	30	43.9	180	327	0	538	497	202	456	1.00	0	3.90	
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-55 <sup>*5</sup>	50	50	45.8	180	327	405	0	480	357	436	1.00	0	4.12	
NG <sub>1</sub> RLG <sub>1</sub> 100NS-55	100	0	45.0	180	327	797	0	0	0	889	1.00	0.10	3.57	
NG <sub>2</sub> RLG <sub>3</sub> 100NS-55 <sup>*5</sup>	100	0	45.8	180	327	810	0	0	0	872	1.00	0	3.74	
NG <sub>1</sub> NS-65	0	0	47.5	175	269	871	0	964	0	0	1.00	0.10	0.99	
NG <sub>2</sub> NS-65	0	0	47.4	177	272	863	0	960	0	0	1.00	0	1.31	
NG <sub>2</sub> RLS <sub>1</sub> 100-65	0	100	47.4	177	272	0	0	960	761	0	1.00	0	4.62	
NG <sub>1</sub> RLG <sub>1</sub> 50NS-65	50	0	47.5	175	269	871	0	482	0	440	1.00	0.10	2.23	
NG <sub>1</sub> RLG <sub>2</sub> 50NS-65	50	0	47.6	176	271	855	0	484	0	446	1.00	0.05	2.63	
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-65	50	30	49.2	177	272	0	610	464	232	417	1.00	0	4.11	
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-65	50	50	47.4	177	272	432	0	480	381	436	1.00	0	4.14	
NG <sub>1</sub> RLG <sub>1</sub> 100NS-65	100	0	47.5	175	269	871	0	0	0	880	1.00	0.10	3.47	
NG <sub>2</sub> RLG <sub>3</sub> 100NS-65	100	0	47.4	177	272	863	0	0	0	872	1.00	0	3.67	

\*1 NG, RLG, RLS の数字は使用骨材の種類, 再生骨材の置換率および W/C を示す。\*2 変性リグニンスルホン酸化合物とポリカルボン酸系 \*3 樹脂酸塩系陰イオン界面活性剤 \*4 式(1)による。\*5 凍結融解試験実施

表 11 コンクリートの試験項目および試験方法

種類	試験項目	試験方法	備考
フレッシュ 性状	スランブ	JIS A 1101	-
	空気量	JIS A 1128	
	単位容積質量	JIS A 1116	
	温度	JIS A 1156	
硬化性状	塩化物含有量	JIS A 5308 JIS A 5023 JASS 5 T-502	イオン電極法 電極電流測定法 モール法
	圧縮強度	JIS A 1108	材齢 4 週, 13 週
	静弾性係数	JIS A 1149	材齢 4 週, 13 週
	気乾単位容積質量	JIS A 1129-3	材齢 13 週時
	長さ変化率		-
	促進中性化深さ	JIS A 1153	-
耐久性指数	JIS A 1148	A 法	

スランブ 18 ± 2.5cm および目標空気量 4.5 ± 1.5% を満足した。なお、骨材修正係数は、再生粗骨材 L を用いた場合で 0.3 ~ 0.6%, 再生細骨材 L を用いた場合は 0.9 ~ 1.6%, 両者を用いた場合は 0.3 ~ 1.2% となり、再生骨材置換率が増加するのに伴い大きくなる傾向がみられた。

(2) 塩化物含有量

塩化物含有量は、全体的に再生骨材 L の置換率が増加するのに伴い大きくなる傾向がみられた。普通コンクリートは 0.02 ~ 0.10kg/m<sup>3</sup>, RLS を 100% 置換した場合は最大で 0.12kg/m<sup>3</sup>, RLG を 100% 置換した場合は最大で 0.30kg/m<sup>3</sup>

表 12 各種コンクリートのフレッシュ性状

種類	スランブ (cm)	空気量 (%) <sup>*1</sup>	単位容積質量 (kg/m <sup>3</sup> )	温度 (°C)	塩化物 含有量 <sup>*2</sup> (kg/m <sup>3</sup> )
NG <sub>1</sub> NS-45	20.0	3.4(0.1)	2356	13.7	0.09
NG <sub>2</sub> NS-45	19.5	4.4(0.2)	2299	28.0	0.03
NG <sub>2</sub> RLS <sub>1</sub> 100-45	16.5	3.9(1.6)	2250	25.8	0.12
NG <sub>1</sub> RLG <sub>1</sub> 50NS-45	19.5	3.2(0.3)	2323	13.4	0.21
NG <sub>1</sub> RLG <sub>2</sub> 50NS-45	19.0	5.0(0.4)	2230	17.4	0.03
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-45	20.5	3.6(0.4)	2250	27.6	0.14
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-45	18.0	4.4(0.6)	2226	24.8	0.11
NG <sub>1</sub> RLG <sub>1</sub> 100NS-45	19.0	3.4(0.5)	2274	13.7	0.24
NG <sub>2</sub> RLG <sub>3</sub> 100NS-45	20.0	5.0(0.5)	2184	28.0	0.06
NG <sub>1</sub> NS-55	20.0	3.6(0.1)	2374	14.1	0.10
NG <sub>2</sub> NS-55	18.0	4.1(0.2)	2336	28.4	0.02
NG <sub>2</sub> RLS <sub>1</sub> 100-55	19.0	5.2(0.9)	2084	30.1	0.09
NG <sub>1</sub> RLG <sub>1</sub> 50NS-55	20.0	3.8(0.3)	2331	12.8	0.29
NG <sub>1</sub> RLG <sub>2</sub> 50NS-55	20.5	4.9(0.5)	2260	18.8	0.03
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-55	20.0	4.9(0.4)	2141	16.8	0.13
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-55	19.5	4.1(0.3)	2099	29.2	0.08
NG <sub>1</sub> RLG <sub>1</sub> 100NS-55	20.0	3.5(0.5)	2288	13.4	0.30
NG <sub>2</sub> RLG <sub>3</sub> 100NS-55	16.5	4.6(0.5)	2208	27.7	0.09
NG <sub>1</sub> NS-65	18.0	4.2(0.1)	2271	10.7	0.09
NG <sub>2</sub> NS-65	18.0	4.6(0.2)	2288	24.6	0.02
NG <sub>2</sub> RLS <sub>1</sub> 100-65	18.0	4.5(1.5)	2142	22.8	0.12
NG <sub>1</sub> RLG <sub>1</sub> 50NS-65	18.0	3.5(0.3)	2299	9.3	0.27
NG <sub>1</sub> RLG <sub>2</sub> 50NS-65	17.5	5.2(0.4)	2180	18.6	0.02
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-65	19.5	5.3(0.5)	2161	24.3	0.11
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-65	18.0	4.5(1.2)	2163	23.5	0.11
NG <sub>1</sub> RLG <sub>1</sub> 100NS-65	19.0	3.3(0.5)	2250	8.4	0.29
NG <sub>2</sub> RLG <sub>3</sub> 100NS-65	16.0	4.2(0.5)	2189	22.0	0.10

\*1 ( )内は骨材修正係数を示す

\*2 再生骨材コンクリートの算定は JIS A 5022 10.5 による。

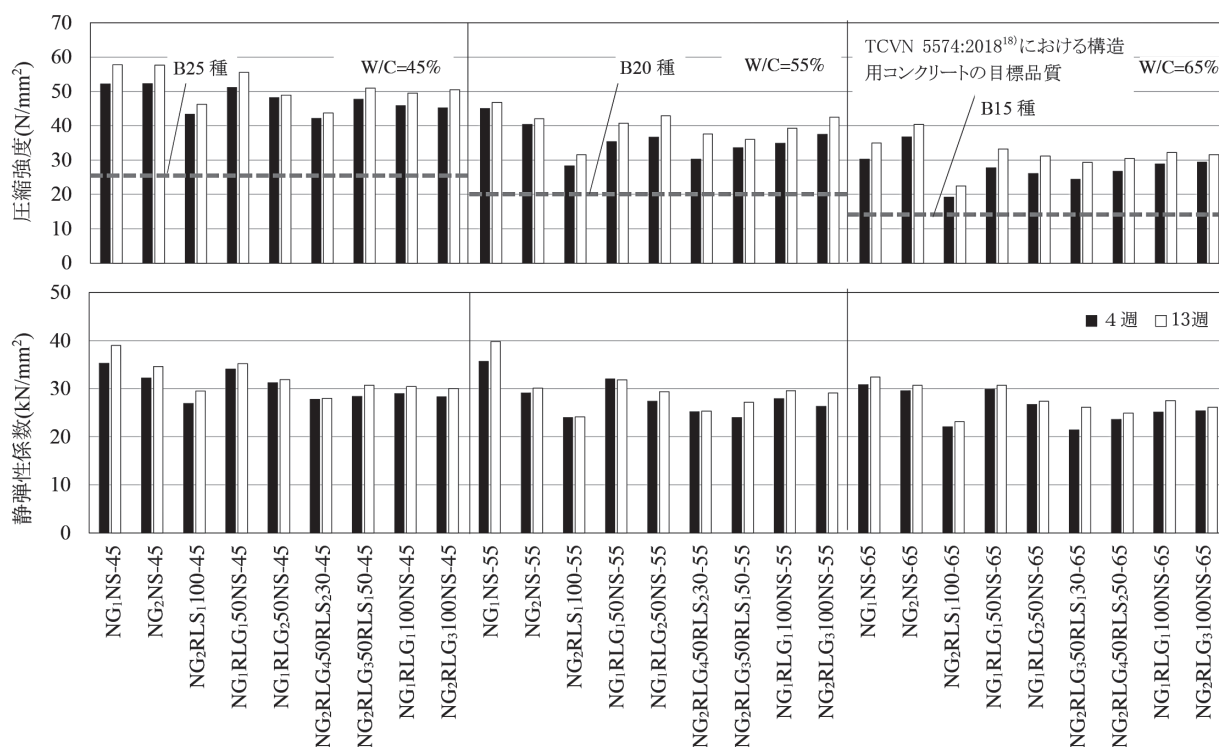


図3 各種コンクリートの圧縮強度および静弾性係数

となった。ベトナム規格では塩化物含有量に関する規定がないため、JIS A 5308の規定である $0.30\text{kg/m}^3$ 以下を規制値とした。なお、再生骨材コンクリートの塩化物含有量は、JIS A 5022 10.5により求めた。全ての試験体は $0.30\text{kg/m}^3$ 以下を満足した。

### (3) 単位容積質量

表9より、再生骨材Lの絶乾密度は、付着モルタルおよび付着ペーストの影響により、普通骨材に比べて小さくなる。そのため、再生骨材置換率の増加に伴いコンクリートの単位容積質量は小さくなる傾向がみられた。

### (4) コンクリート温度

試料コンクリートはいずれも $35^\circ\text{C}$ を下回った。再生骨材置換率の影響はみられなかった。

## 4-2 硬化性状

### (1) 圧縮強度

図3より、全体的に再生骨材の置換率の増加に伴い圧縮強度は減少する傾向がみられた。特に、RLSを100%置換したもの、あるいはRLGを100%置換したものはその傾向が顕著である。材齢4週から13週までの強度発現傾向は、再生骨材の置換率の増加に伴い低下する傾向がみられた。

TCVN 5574:2018<sup>18)</sup>では、コンクリートをB1.5種～

B100種のグレードに分類しており、15～100は呼び強度を示す。普通コンクリートを構造体で使用する場合、品質はB15種の調合強度 $15\text{N/mm}^2$ 以上、クレーン荷重を受ける柱、高層建物の低層階の柱のように大きい荷重を受ける構造はB25種の調合強度 $25\text{N/mm}^2$ 以上となっていることから、本研究で作製したコンクリートの4週圧縮強度は、TCVNの目標品質と比較すると、W/C=65%ではB15種の $15\text{N/mm}^2$ 以上、W/C=55%ではB20種の $20\text{N/mm}^2$ 以上、W/C=45%ではB25種の $25\text{N/mm}^2$ 以上となった。

### (2) 静弾性係数

図3より、静弾性係数については、圧縮強度と同様、全体的に再生骨材の置換率の増加に伴い静弾性係数は小さくなる傾向がみられた。材齢4週から13週までの発現傾向は、再生骨材の置換率の増加に伴い低下する傾向がみられた。

TCVN 5574:2018<sup>18)</sup>では、普通コンクリート( $\gamma = 2.2 \sim 2.5\text{t/m}^3$ )として標準強度と静弾性係数が規定されているが、圧縮強度と静弾性係数の関係式は定められていないことから、式(2)に示す再生骨材コンクリート指針式(指針式)<sup>20)</sup>により評価した。

各種コンクリートの4週圧縮強度と4週時静弾性係数の関係を図4に示す。コンクリートの気乾単位容積質量は、材齢13週時の長さ変化用試験体から測定した。普通コンク

リート ( $\gamma = 2.3\text{t/m}^3$ ), 再生骨材コンクリート ( $\gamma = 2.1 \sim 2.3\text{t/m}^3$ ) の実測値は, それぞれ New RC 式 ( $k_1 = k_2 = 1.0$ )<sup>11)</sup>, 指針式の範囲を上回る傾向がみられた。図中には, TCNV 5574:2018<sup>18)</sup>の標準強度と静弾性係数の関係を示す。TCNV 5276:1993<sup>19)</sup>の静弾性係数試験方法は, 角柱試験体 ( $G_{\max} = 20\text{mm}:100\text{mm} \times 100\text{mm} \times 400\text{mm}$ ) を用いており, 推定される静弾性係数は New RC 式に比べ大幅に大きくなり, JIS A 1149 による実験結果とは整合していない。

$$E = 3.35 \times 10^4 \times \left(\frac{\gamma}{2.4}\right)^2 \times \left(\frac{\sigma_B}{60}\right)^{1/3} \quad (2)$$

ここに,

$E$ : 再生骨材コンクリートのヤング係数(静弾性係数) ( $\text{kN/mm}^2$ )

$\gamma$ : 再生骨材コンクリートの単位容積質量 ( $\text{t/m}^3$ )

$\sigma_B$ : 再生骨材コンクリートの圧縮強度 ( $\text{N/mm}^2$ )

### (3) 乾燥収縮

ベトナム規格の 22TCN 60-84<sup>21)</sup>によると, 普通コンクリートの乾燥収縮率は  $1 \times 10^{-4} \sim 15 \times 10^{-4}$  の範囲に制限されて

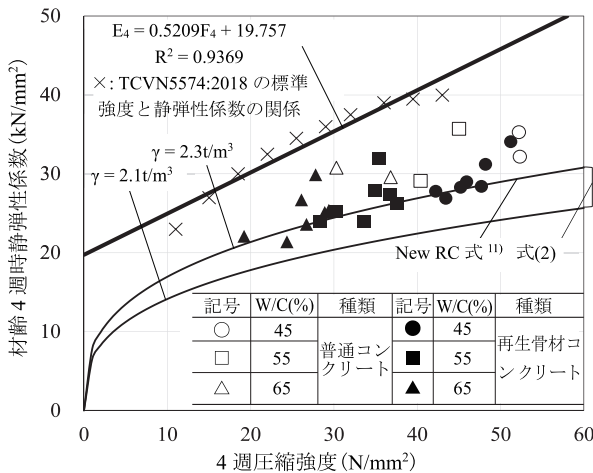


図4 圧縮強度と静弾性係数の関係

いる。一方, JASS 5 (2018)<sup>11)</sup>では, 計画供用期間の級が長期および超長期の乾燥収縮率は  $8 \times 10^{-4}$  以下となっており, この範囲に含まれ, かつ中央値に該当することから, 本研究では  $8 \times 10^{-4}$  以下を目標品質の閾値とした<sup>8)</sup>。

図5より, 再生骨材 L を用いたコンクリートの乾燥収縮率は, 全体的に RLG および RLS を併用し, いずれかを 50% 以上置換したものが大きくなる傾向がみられた。特に, RLG と RLS 両方を 50% 置換したものと RLG を 100% 置換したもので  $8 \times 10^{-4}$  を超えるものもみられた。

### (4) 促進中性化

TCNV 9343:2012<sup>22)</sup>では, 3 本以上のコア試験体の破断面にフェノールフタレイン溶液を噴霧して測定し, 中性化深さは鉄筋から 10mm 以上離れなければならないと規定されている。JIS A 1153 では, 試験体の寸法は  $100\text{mm} \times 100\text{mm} \times 400\text{mm}$  であることから, 図6に示すように TCNV による中性化深さの閾値は, 仮に鉄筋径を D19 とした場合は約 30mm となる。日本建築学会「高耐久性鉄筋コンクリート造設計施工指針(案)・同解説」<sup>23)</sup>の目標品質は 25mm 以下であることから, 安全側として 25mm 以下を目標品質の閾値とした<sup>8)</sup>。

図7より, 促進期間 26 週における促進中性化深さ(材齢 26 週時促進中性化深さ)は, 相対的に RLS を 100% 置換し

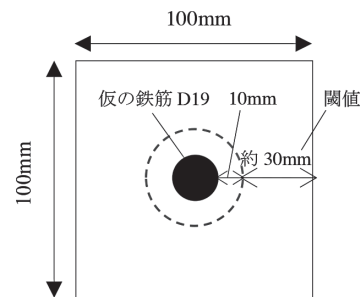


図6 TCNV 9343:2012<sup>22)</sup>による中性化深さの閾値の考え方

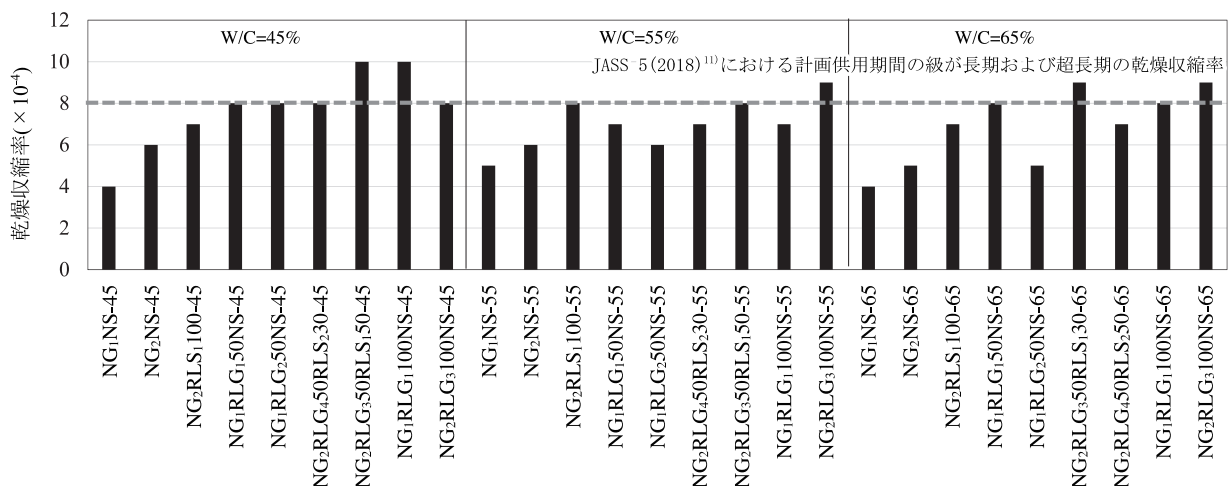


図5 各種コンクリートの乾燥収縮率

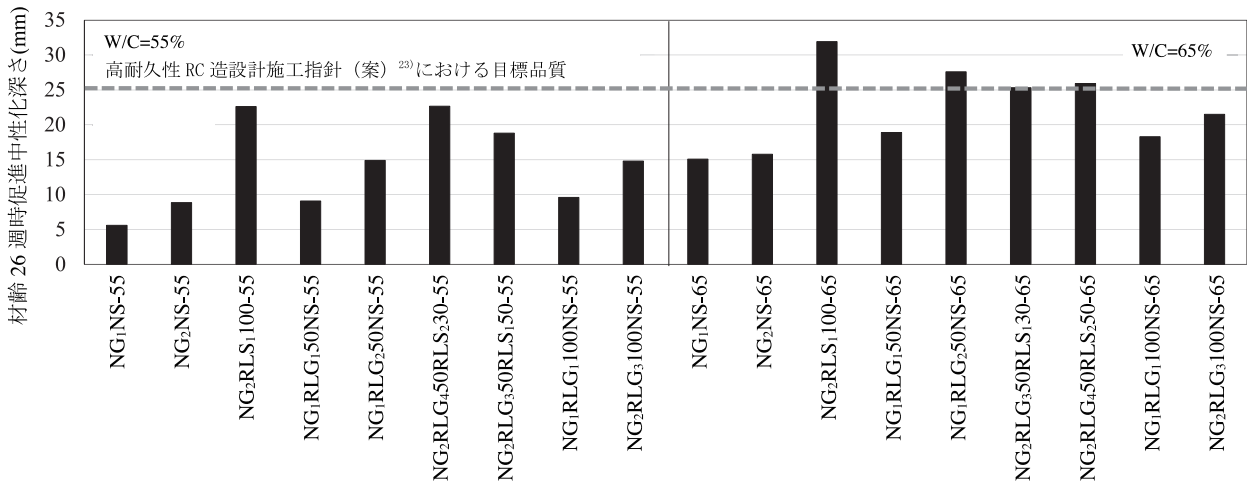


図7 各種コンクリートの材齢26週時促進中性化深さ

たものが大きくなる。また、W/Cの影響が大きく、W/C = 65%の場合では、25mmを超えたものがみられた。

図8より、4週圧縮強度と材齢26週時促進中性化深さの関係を示す。これによると、両者の間には比較的明確な相関がみられ、圧縮強度が28N/mm<sup>2</sup>以上では全ての試験体で25mm以下となった。

(5) 凍結融解

ベトナムでは、都市部では凍害は発生しないが、北部の山岳地方で発生する場合がある。このため、本研究では凍害に対する検討を行った。なお、TCVNに規定はないことから、JASS 5 (2018)<sup>11)</sup>に規定されている目標品質を用いた。

図9に練上がり時の空気量と耐久性指数の関係を示す。練上がり時の空気量は、凍結融解作用を受けるコンクリートの目標空気量4.0～6.0%(4.5±1.5%かつ空気量の下限值4.0%<sup>11)</sup>)の範囲であれば再生骨材置換率に係わらず、耐久性指数は60以上であった。

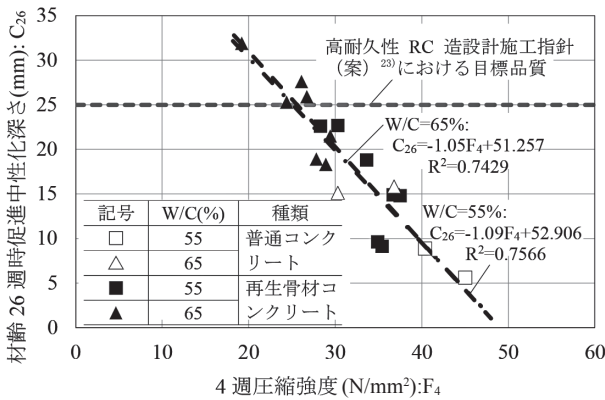


図8 圧縮強度と促進中性化深さの関係

4-3 相対品質法による性能評価

圧縮強度、静弾性係数、長さ変化および促進中性化の実験結果から得られたコンクリートの主要な性能と表10に示したQtとの関係から性能評価を行った。

TCVN 11969<sup>5)</sup>によると、再生粗骨材I種の吸水率は5%以下、再生粗骨材II種は20%以下であり、置換率の上限値は規定されていない。

図10にQtとコンクリートの主要な性能の関係を示す。図中に閾値としてTCVN 11969<sup>5)</sup>による再生粗骨材I種を100%置換したコンクリートのQt:4.35%、JIS A 5022によりRLGを50%置換した再生骨材コンクリートM1種のQt:4.37%、RLGを50%およびRLSを30%置換した再生骨材コンクリートM2種のQt:5.49%を示す。なお、再生骨材Lおよび普通骨材の吸水率は、JISに規定される上限値により算出し、再生粗骨材I種はTCVNによる。

Qtの増加に伴いコンクリートの性能が低下する傾向がみられた。両者の間には、性能によってはばらつきがみられたが、総体的には比較的明確な関係が得られた。

4週圧縮強度および材齢4週時静弾性係数は、再生骨

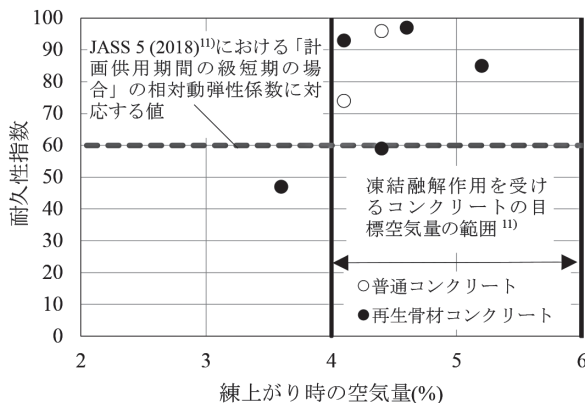
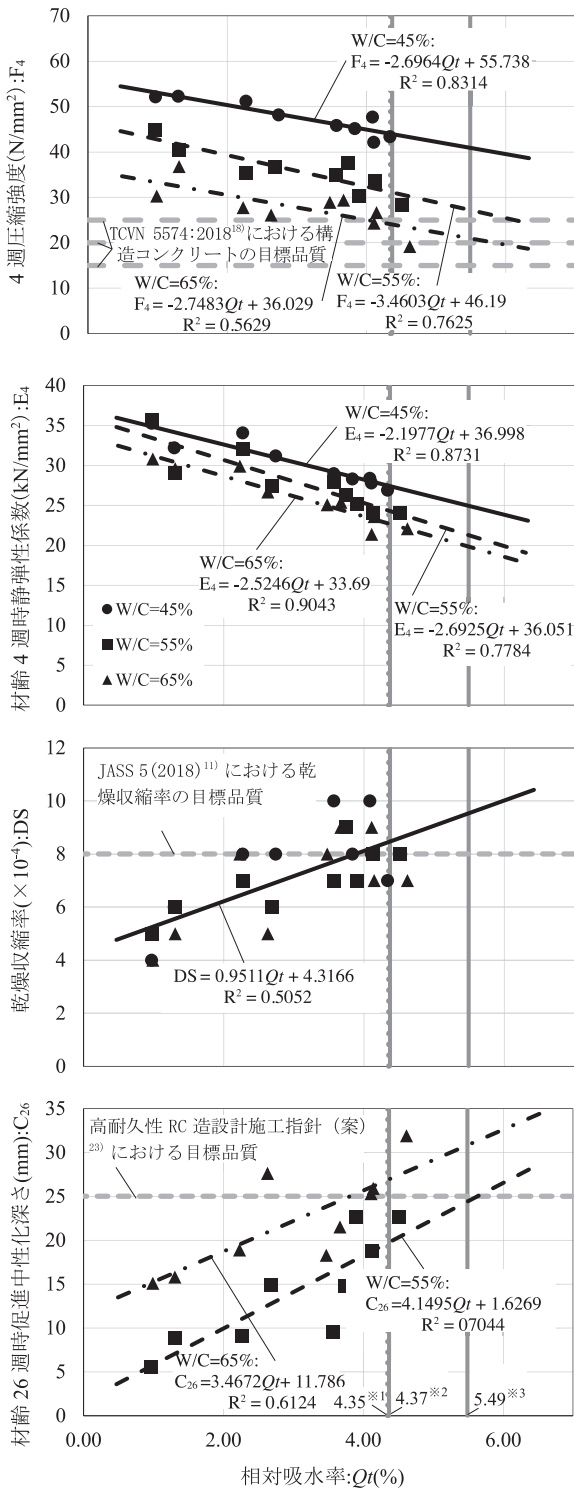


図9 練上がり時の空気量と耐久性指数の関係





※1 TCVN 11969<sup>5)</sup>より、再生粗骨材I種 100%置換率として吸水率の上限值で算定した  $Q_t$  を示す。  
 ※2 JIS A 5022 より、再生骨材コンクリート M1 種として RLG の吸水率と置換率の上限值で算定した  $Q_t$  を示す。  
 ※3 JIS A 5022 より、再生骨材コンクリート M2 種として RLG と RLS の吸水率と置換率の上限值で算定した  $Q_t$  を示す。

図 10 相対吸水率とコンクリートの主要な性能の関係  
 材コンクリート M1 種の 4.37% および再生粗骨材 I 種の  $Q_t$ : 4.35% より小さい場合において、W/C=45%, 55%, 65% に

おいて、それぞれ TCVN 5574:2018<sup>18)</sup>における構造用コンクリートの B25 種, B20 種, B15 種の閾値を満足した。また、乾燥収縮率は、 $Q_t$  が再生骨材コンクリート M1 種の 4.37% およびベトナムの再生粗骨材 I 種の  $Q_t$ : 4.35% より小さい場合においても、3.50% を超えると品質目標値  $8 \times 10^{-4}$  を超えるものも多くみられたが、3.50% 以下では全て目標品質を満足した。なお、材齢 26 週時促進中性化深さは W/C の影響が大きい。W/C=65% では、再生骨材コンクリート M1 種の  $Q_t$ : 4.37% およびベトナムの再生粗骨材 I 種の  $Q_t$ : 4.35% より小さい場合でも一部 25mm を超えたものがみられた。

したがって、再生骨材 L を普通骨材に置換して用いる場合、 $Q_t$  と再生骨材コンクリートの主要な性能の関係に基づいて、再生骨材置換率の調整、使用する普通骨材の選定により、TCVN の目標品質を満足し、所要のコンクリート性能を得ることが可能となる。

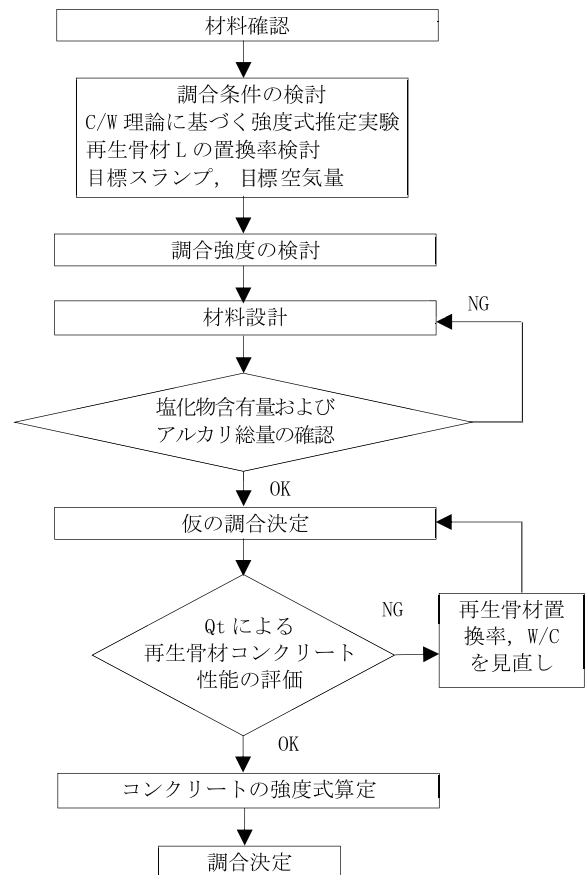


図 11 再生骨材コンクリートの調査設計フロー例

表 13 調査強度の算定結果

セメントの種類	θ の範囲(°C)	F <sub>q</sub> (N/mm <sup>2</sup> )	28S <sub>91</sub> (N/mm <sup>2</sup> )	F <sub>m</sub> = F <sub>q</sub> + 28S <sub>91</sub> (N/mm <sup>2</sup> )	σ (N/mm <sup>2</sup> )		F (N/mm <sup>2</sup> )		
					グループ		(4)式	(5)式	設定値
					A	B			
普通ポルトランド セメント	8 ≤ θ 0 ≤ θ < 8	18.5	3	21.5	2.5	2.5	25.8	25.8	25.8
			6	24.5	2.5	2.5	28.8	28.3	28.8
		15.0	3	18.0	2.5	2.5	22.3	22.8	22.8
			6	21.0	2.5	2.5	25.3	25.4	25.4
		11.0	3	14.0	2.5	2.5	18.3	19.4	19.4
			6	17.0	2.5	2.5	21.3	22.0	22.0

表 14 コンクリートの塩化物含有量およびアルカリ総量の算定結果

種類	グループ	塩化物含有量 <sup>*1</sup>					アルカリ総量 <sup>*2</sup>				
		セメントの塩化物イオン (%)	混和剤の塩化物イオン量 (%)	再生粗骨材の塩化物量 (%)	再生細骨材の塩化物量 (%)	合計 (kg/m <sup>3</sup> )	セメントに含まれる全アルカリ量 (%)	混和剤に含まれる全アルカリ量 (%)	再生粗骨材に含まれる全アルカリ量 (%)	再生細骨材に含まれる全アルカリ量 (%)	合計 (kg/m <sup>3</sup> )
NG <sub>1</sub> NS-45	A	0.02	0	0	0	0.07	0.50	0	0	0	2.1
NG <sub>1</sub> NS-55		0.02	0	0	0	0.06	0.50	0	0	0	1.6
NG <sub>1</sub> NS-65		0.02	0	0	0	0.05	0.50	0	0	0	1.3
NG <sub>1</sub> RLG <sub>1</sub> 100NS-45		0.02	0	0.02	0	0.24	0.50	0	0.21	0	3.8
NG <sub>1</sub> RLG <sub>1</sub> 100NS-55		0.02	0	0.02	0	0.23	0.50	0	0.21	0	3.5
NG <sub>1</sub> RLG <sub>1</sub> 100NS-65		0.02	0	0.02	0	0.22	0.50	0	0.21	0	3.2
NG <sub>1</sub> RLG <sub>2</sub> 50NS-45		0.01	0	0.02	0	0.13	0.48	0	0.24	0	3.0
NG <sub>1</sub> RLG <sub>2</sub> 50NS-55		0.01	0	0.02	0	0.12	0.48	0	0.24	0	2.6
NG <sub>1</sub> RLG <sub>2</sub> 50NS-65		0.01	0	0.02	0	0.11	0.48	0	0.24	0	2.4
NG <sub>2</sub> NS-45		B	0.01	0	0	0	0.04	0.51	0	0	0
NG <sub>2</sub> NS-55	0.01		0	0	0	0.04	0.51	0	0	0	1.7
NG <sub>2</sub> NS-65	0.02		0	0	0	0.05	0.52	0	0	0	1.4
NG <sub>2</sub> RLS <sub>1</sub> 100-45	0.01		0	0	0.02	0.17	0.51	0	0	0.35	4.3
NG <sub>2</sub> RLS <sub>1</sub> 100-55	0.01		0	0	0.02	0.18	0.51	0	0	0.35	4.1
NG <sub>2</sub> RLS <sub>1</sub> 100-65	0.01		0	0	0.02	0.18	0.51	0	0	0.35	4.0
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-45	0.01		0	0.02	0.02	0.20	0.51	0	0.22	0.35	4.1
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-55	0.01		0	0.02	0.02	0.19	0.51	0	0.22	0.35	3.8
NG <sub>2</sub> RLG <sub>3</sub> 50RLS <sub>1</sub> 50-65	0.01		0	0.02	0.02	0.16	0.53	0	0.25	0.41	3.6
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-45	0.01		0	0.02	0.02	0.16	0.53	0	0.25	0.41	4.0
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-55	0.02		0	0.02	0.02	0.19	0.52	0	0.22	0.39	3.5
NG <sub>2</sub> RLG <sub>4</sub> 50RLS <sub>2</sub> 30-65	0.01		0	0.02	0.02	0.19	0.51	0	0.22	0.35	3.4

※1 普通骨材は 0 で算出, 上水を使用する場合は試験を省略した。 ※2 普通細骨材は 0 で算出した。

#### 4-4 調査設計

ベトナム規格では、普通コンクリートの調査設計方法が規定されていないことから、使用している方法は ACI 211.1-91 Standard practice for selecting proportions for normal, heavyweight, and mass concrete<sup>24)</sup> であり、再生骨材コンクリートの調査設計方法および再生骨材の置換率は規定されていない。ACI 211.1-91<sup>24)</sup> と JASS 5 (2018)<sup>11)</sup> の調査設計方法はほぼ同じ手順であることから、本研究は JASS 5 (2018)<sup>11)</sup> に基づいて再生骨材コンクリートの調査設計について検討を行った。

本研究では、強度低下の影響を調査設計に反映するため、再生骨材を置換したコンクリートは比較用コンクリートと圧縮強度の比較を行い、その影響を確認した。なお、検討は、再生粗骨材のみを置換した場合 (A)、再生細骨材を置換した場合 (B) の 2 グループに分類して行った。

コンクリートの調査強度の算定結果を表 13 に、コンクリートの塩化物含有量およびアルカリ総量の算定結果を表 14 に示す。

#### (1) 調査設計のフロー

再生骨材コンクリートの調査設計フロー例を図 11 に示す。まず、使用材料の確認 (材料確認) を行い、続いて調査検討を行う。セメント水比 (C/W) 理論に基づく強度式推定実験のため、W/C を 45%、55%、65% の 3 水準、RLG の置換率を 0%、50%、100%、RLS の置換率を 0%、30%、50%、100% に変化させて検討を行った。なお、目標スランプは 18 ± 2.5cm、目標空気量は 4.5 ± 1.5% とした。調査強度の検討後、材料設計として再生骨材コンクリートのアルカリ総量 (≤ 3.0kg/m<sup>3</sup>) および塩化物含有量 (≤ 0.30kg/m<sup>3</sup>) を確認する。これらから、仮の調査を決定する。作製した再生骨材コンクリートについて相対品質値法による性能評価を行い、コンクリートの強度式を算定し、調査を決定する。

#### (2) 調査強度

表 13 にコンクリートの調査強度の算定結果を示す。調査強度は式 (3) により得られた調査管理強度 F<sub>m</sub> から、式 (4) および式 (5) を満足するように設定した。

$$F_m = F_q + mS_n \quad (3)$$

$$F \geq F_m + 1.73 \sigma \quad (4)$$

$$F \geq 0.85F_m + 3 \sigma \quad (5)$$

ここに、

$F$ : コンクリートの調合強度 (N/mm<sup>2</sup>)

$F_m$ : コンクリートの調合管理強度 (N/mm<sup>2</sup>)

$F_q$ : コンクリートの品質基準強度 (N/mm<sup>2</sup>)<sup>\*</sup>

<sup>\*</sup>本研究は  $F_c$  (設計基準強度) を  $F_q$  とした。

$mS_n$ : 標準養生した供試体の材齢  $m$  日における圧縮強度と構造体コンクリートの材齢  $n$  日における圧縮強度の差による構造体強度補正值 (N/mm<sup>2</sup>),  $m=28, n=91$   
 $\sigma$ : JASS 5 (2018)<sup>11)</sup> に基づき、使用するコンクリートの圧縮強度の標準偏差 (N/mm<sup>2</sup>): 2.5N/mm<sup>2</sup> または 0.1 $F_m$  の大きいほうの値

調合管理強度  $F_m$  は、品質基準強度  $F_q$  と構造体強度補正值  $_{28}S_{91}$  により設定した。コンクリートの打込みから 28 日までの期間の予想平均気温  $\theta$  の範囲に基づき、 $8^\circ\text{C} \leq \theta$  の場合は  $_{28}S_{91}=3\text{N/mm}^2$ ,  $0^\circ\text{C} \leq \theta < 8^\circ\text{C}$  の場合は  $_{28}S_{91}=6\text{N/mm}^2$  である。

本研究では、W/C=45%, 55%, 65% はそれぞれ B25 種の標準強度 18.5N/mm<sup>2</sup>, B20 種の 15.0N/mm<sup>2</sup>, B15 種の 11.0N/mm<sup>2</sup> に対応させて検討を行った。なお、標準強度は JASS5 (2018)<sup>11)</sup> においては設計基準強度に該当する。コンクリートの品質基準強度  $F_q$  は、それぞれ 18.5N/mm<sup>2</sup>, 15.0N/mm<sup>2</sup>, 11.0N/mm<sup>2</sup> となる。これにより、表 13 に示す調合管理強度  $F_m$  はそれぞれ 21.5N/mm<sup>2</sup> および 24.5N/mm<sup>2</sup>, 18.0N/mm<sup>2</sup> および 21.0N/mm<sup>2</sup>, 14.0N/mm<sup>2</sup> および 17.0N/mm<sup>2</sup> と算定される。調合強度  $F$  は、調合管理強度  $F_m$  に、比較用コンクリートの標準偏差  $\sigma$  を用い、式 (4) および式 (5) を満足するように設定した。

### (3) 材料設計

#### (a) 塩化物含有量およびアルカリ総量

ベトナム規格にコンクリートの塩化物含有量およびアルカリ総量は規定されていないことから、JIS A 5308 および

JIS A 5022 の規制値により検討を行った。表 14 より、算出した塩化物含有量では、全ての試験体は JIS A 5308 の規制値である 0.30kg/m<sup>3</sup> 以下を満足した。

アルカリ総量については、再生骨材の置換率は増加に伴い大きくなるが、RLG の置換率を 50% 以下とした場合は JIS A 5022 の規制値である 3.0kg/m<sup>3</sup> 以下となった。一方、再生骨材の置換率が RLG を 50% 以上あるいは RLG と RLS を併用した場合には、規制値をこえるため、フライアッシュまたは高炉スラグ微粉末の使用が前提となる<sup>25), 26)</sup>。なお、RLG<sub>3</sub> と RLG<sub>4</sub> については、表 9 より区分 A と判定されている。

#### (b) コンクリートの圧縮強度

再生骨材コンクリートでは、RLG50% まで置換、RLS 30% まで置換の場合は再生骨材コンクリート M とし、RLG100% 置換、RLS50% および 100% 置換の場合は、再生骨材コンクリート L とする。各種コンクリートの調合概要および  $Q_t$  は表 10 に示した通りである。

比較用コンクリートでは、管理材齢 28 日における再生骨材コンクリートの圧縮強度と  $Q_t$  の関係は、式 (6)<sup>27)</sup> で示す。

$$F_{28} = I + m \times Q_t \quad (6)$$

ここに、

$F_{28}$ : 材齢 28 日における圧縮強度 (N/mm<sup>2</sup>)

$I, m$ : 実験定数 (図 10 にある圧縮強度と  $Q_t$  の関係式の切片と傾き)

$$\text{W/C}=45\% : F_{28} = 55.74 - 2.70 \times Q_t$$

$$\text{W/C}=55\% : F_{28} = 46.19 - 3.46 \times Q_t$$

$$\text{W/C}=65\% : F_{28} = 36.03 - 2.75 \times Q_t$$

式 (6) に、表 10 に示した  $Q_t$  を代入し、再生骨材コンクリートと比較用コンクリートの強度比として強度低減率 (R) を算定した結果を表 15 に示す。

比較用コンクリートに R を乗じて式 (7) とした。再生骨材コンクリートの製造は、この式に基づき調合設計が可能となる。なお、セメントは普通ポルトランドセメント、化学混和剤は AE 減水剤の使用を前提とした。

表 15 圧縮強度と強度低減率

グループ	W/C (%)	NGNS	NGRLS100		RLG50NS		RLG50RLS30		RLG50RLS50		RLG100NS	
		置換率 0%	置換率 RLS 100%	強度低減率 R	置換率 RLG 50%	強度低減率 R	置換率 RLG 50% RLS 30%	強度低減率 R	置換率 RLG 50% RLS 50%	強度低減率 R	置換率 RLG 100%	強度低減率 R
A	45	53.1	-	-	48.4	0.91	-	-	-	-	46.1	0.87
	55	42.8	-	-	36.9	0.86	-	-	-	-	33.8	0.79
	65	33.3	-	-	28.8	0.86	-	-	-	-	26.5	0.80
B	45	52.2	44.0	0.84	-	-	44.7	0.86	44.7	0.86	-	-
	55	41.7	30.6	0.73	-	-	32.0	0.77	31.9	0.77	-	-
	65	32.4	23.3	0.72	-	-	24.7	0.76	24.6	0.76	-	-

表 16 再生骨材コンクリートの定数

グループ	品質基準強度 (N/mm <sup>2</sup> )	強度式(管理材齢 28 日)の定数(普通ポルトランドセメント, AE 減水剤)											
		NGNS		NGRLS100		RLG50NS		RLG50RLS30		RLG50RLS50		RLG100NS	
		置換率 0%		置換率 RLS 100%		置換率 RLG 50%		置換率 RLG 50%, RLS 30%		置換率 RLG 50%, RLS 50%		置換率 RLG 100%	
		a	b	a	b	a	b	a	b	a	b	a	b
A	18.5	-10.34	28.73	-	-	-9.41	26.15	-	-	-	-	-8.97	24.94
	15.0			-	-	-8.91	24.75	-	-	-	-	-8.17	22.69
	11.0			-	-	-8.94	24.84	-	-	-	-	-8.22	22.84
B	18.5	-11.38	28.77	-9.59	24.26	-	-	-9.73	24.60	-9.74	24.63	-	-
	15.0			-8.35	21.12	-	-	-8.73	22.07	-8.72	22.04	-	-
	11.0			-8.18	20.69	-	-	-8.68	21.94	-8.64	21.85	-	-

$$C/W = (F_{28} - a) / b \quad (7)$$

ここに,

C/W: セメント水比

F<sub>28</sub>: 材齢 28 日における圧縮強度 (N/mm<sup>2</sup>)

a, b: 表 16 に示す定数

(4) 再生骨材 L と普通骨材を混合使用する再生骨材コンクリートは, Qt の増加に伴いコンクリート性能が低下する。Qt とコンクリートの主要性能の間には, 総体的には比較的明確な関係が得られた。

(5) 調合設計は, 再生骨材 L と普通骨材を混合する場合, Qt の評価結果および材料設計に基づき, 再生骨材コンクリートの強度式を算定することで, TCVN の要求性能を満足する再生骨材コンクリートの製造が可能である。以上から, 低品質再生骨材を用いたコンクリートは, 日本と同様, ベトナム規格の要求性能に応じた構造用コンクリートへの適用が可能である。

## 5. まとめ

低品質再生骨材と普通骨材を混合使用した再生骨材コンクリートをベトナムで普及させることを目的に, 性能評価および調合設計について検討を行った。その結果, 以下のことがいえる。

- (1) ベトナムのハノイ市で発生した建設廃棄物量は, 全国の処理した量に比べて 1.8 ~ 3.4 倍となっている。これにより, ベトナムにおいては処理されていなかった建設廃棄物量は膨大であることが推察される。建設廃棄物のリサイクル率を向上させるためには, 再生骨材 L の利用拡大が有効である。
- (2) 使用材料はベトナム規格を満足した。再生骨材 L を用いたコンクリートのフレッシュ性状は, 再生骨材の置換率が大きい場合でも, 化学混和剤量の調整により, スランプおよび空気量は目標値を満足する。なお, 塩化物含有量は RLG を 100% 置換した場合は最大で 0.30kg/m<sup>3</sup> であった。
- (3) 再生骨材 L を用いたコンクリートの硬化性状は, 再生骨材置換率の増加に伴い圧縮強度および静弾性係数は低下する。一方, 圧縮強度はベトナム規格の閾値を満足した。乾燥収縮率は, RLG と RLS の両方を 50% 置換したものの, RLG を 100% 置換したものが大きく, 一部は閾値を超えた。促進中性化深さでは, RLS を 100% 置換したものが大きくなるが, W/C の影響が大きく, 圧縮強度が 28N/mm<sup>2</sup> 以上で目標品質を満足した。耐久性指数は, 適切に空気が連行されていれば, 再生骨材置換率に係らず 60 以上が得られた。

## 謝辞

本研究は, JSPS 科研費 JP16K06593, 名城大学アジア研究所公募型プロジェクト「アジアの建設工事における再生骨材コンクリートの普及展開 (研究代表者: 道正泰弘)」の助成を受けたものである。また, 本研究の実施において, ベトナム国立交通運輸大学 Nguyen Thanh Sang 准教授に多大な協力を得た。ここに厚く謝意を示す。

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# Japan's Postwar Path from the Paradigm of National Security: The Shifting Patterns of Japan-US Strategic Relations in the Indo-Pacific Region

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## Abstract

This paper aims to reveal how Japan exploited its newly created regional order principles and geostrategic leverage to build an alliance with the U.S. After regaining confidence in the Cold War period, Japan renegotiated its security role with the U.S., which marked the beginning of the Japanese ascent to power. This paper argues that Japan tried to find its new identity as an Asian power by pursuing policies to arrange relations with the U.S. The exploration of declassified documents provides insightful conclusions regarding timely and capable application in the case of present-day issues, particularly regarding U.S.-Japan relations in the Indo-Pacific area.

**Key words** : US-Japanese Relations, PRC, Indo-Pacific Region, Foreign Policy

## 1. Introduction

The United States' consent to security arrangements with Japan in 1960 meant achieving a stable number of U.S. bases in Japan while preventing a potential break with the U.S. on political and military questions in East Asia caused by Japan's neutrality. That decision brought attention to the argument over whether Japan should act as an Asian nation or seek to become a Western, civilized one, which had been a recurring issue throughout the nineteenth century.

In other words, postwar Japan chose to place the relationship with the United States at the center of their diplomatic posture. Japan was effectively remade as a pro-American state belonging to the Western camp in international politics, and domestically, they fostered a liberal democracy. While the agreement reached between them could be called a result of the Second World War, it extended far beyond the conflict, setting the framework for Japan's foreign relations after its independence.

Within this context, the present paper considers the progress of Japanese foreign policy toward the new order and its geostrategic leverage gained by building an alliance with the U.S. in the Indo-Pacific area.

## 2. U.S.-Japanese Security Relations in the Cold War Period

The Treaty of Peace with Japan had made provisions for the right to enter into collective self-defense arrangements, permitting the stationing of U.S. forces in Japan not only for Japan's defense against outside

aggression but also the maintenance of an "American-led" peace and security in East Asia. The U.S. Army was able to use military operations in Japan, including on the high seas, against the Union of Soviet Socialist Republics and the People's Republic of China (hereafter USSR and PRC, respectively)<sup>1</sup>.

In other words, the Treaty of Peace left out the issues of returning Okinawa's administrative rights to Japan and making peace with the USSR and the PRC, but the U.S. admitted that Japan maintained residual sovereignty over Okinawa<sup>2</sup>. Moreover, to promote the nation's early recovery as a member of the Western-aligned powers, it did not impose an enormous amount of war reparations on Japan<sup>3</sup>.

The United States intended to seek the approval of the Japanese government to add a military containment policy against the expansionism of the PRC. Therefore, the U.S. government promoted collective security arrangements in 1952 amongst allied militaries they thought could help deter any perceived communist aggression<sup>4</sup>. It was desirable to make a counterweight to the PRC and grow the power of free nations in the region.

U.S. government thus required the Japanese government to rearm ten divisions based upon Japan's political and economic stability. Accumulating economic difficulties and the reluctance or inability of the Japanese government to adopt energetic economic and rearmament policies were then seen as prolonging Japanese dependence on the U.S. and delaying Japan's development as a counterweight to communist power in East Asia<sup>5</sup>.

The Japanese government amended the national

safety agency law in 1954 to convert the national safety forces into the Self-Defense Forces (*Jieitai*) and give it the duty of defense against direct aggression<sup>6</sup>. Due to the spread of communism and the PRC's desire to retake Taipei, Washington requested that Tokyo rebuild its military equipment and decrease the military gap in the Far East<sup>7</sup>.

The U.S. military also placed an atomic artillery battalion in Okinawa as part of the U.S. Army's reorganization in 1955. Later that year, it deployed a ground-to-air interceptor missile named Nike Hercules in Okinawa. However, the anti-base movement was gradually intensifying in Japan. This movement was best demonstrated by the Uchinada incidents and the Sunagawa struggle. Furthermore, the Lucky Dragon (*Fukuryū-maru*) incident in 1954 caused anti-nuclear sentiments to snowball<sup>8</sup>.

Nobusuke Kishi, the Japanese prime minister in 1957, tried to mitigate anti-American sentiments in the country<sup>9</sup>. The Japanese Diet resolution prohibited the overseas dispatch of the Self-Defense Forces in 1954. U.S. government was given high praise for his political ability in Japan, having arranged the merger of the conservative party and strengthened the political base of the Liberal Democratic Party in 1955<sup>10</sup>. However, Dwight D. Eisenhower's administration did not accept the Japanese government's demands for approval of the deployment of U.S. forces stationed in Japan.

Instead, Eisenhower agreed to consult Japanese authorities regarding the use of U.S. forces in Japanese territories at the Japan-American Security Committee<sup>11</sup>. This bargaining demonstrated that the U.S. still feared that the Japanese government would limit American use of bases. Furthermore, the U.S. government was concerned that Japan was unwilling to share the burden of defense spending, relying heavily on the United States' contributions<sup>12</sup>.

Before the 1958 Taiwan Strait Crisis outbreak, U.S. government requested that the Japanese government share the defense burden by maintaining America's right to free use of its bases in Japan and contributing to the defense of non-communist nations as required by the security revision. Finally, the U.S. military demonstrated political cooperation with Japan by proposing a limited agreement to use the base as a concession in 1960<sup>13</sup>.

### 3. The Normalization of Japan's Defense and Security Policy

As mentioned in the previous section, Japanese security policy constraints were infused with some exceptionalism, as they were believed to demonstrate Japan's unique pacifism. In the early Cold War period, Japan was contrasted with the Empire of Japan, along with postwar militarizing states. However, those pushing for identity and policy changes today seek to distinguish contemporary Japan from postwar Japan's alleged weakness, masochism, and abnormality<sup>14</sup>.

Former Japanese Prime Minister Shinzo Abe's call for Japan to 'break out of the postwar regime' is typical of this differentiation between a weak past and a strong future<sup>15</sup>. Changes to Japanese security policy have been adopted recently due to threats posed by the PRC and the Democratic People's Republic of Korea (hereafter DPRK). Especially in the long term, the PRC has increasingly become a security concern for Japan<sup>16</sup>. This shift is often portrayed as a logical reaction to China's rise and aggressiveness. However, Japan did not respond similarly to the Soviet Union threat during the Cold War.

The Soviet Union's destructive capacity far surpassed that of contemporary PRC, whose nuclear arsenal is far more modest. Moreover, the intense rivalry between the American and Soviet superpowers produced international tensions that ran much higher than those present in the competitive but interdependent relationship between the U.S. and the PRC. Despite these facts, the threat of the Soviet Union did not lead to the military build-up taking place in response to China's rise. On the contrary, Japan responded during the Cold War by adopting military restrictions. These restrictions evoked exceptionalism, a stark contrast to how Japan is viewed and remembered in 2022.

It is only if Japan's national identity changes are overlooked that these widely differing responses to the postwar security policy appear mystifying. The Cold War example demonstrates that not all potentially threatening developments are necessarily construed as such. After the PRC conducted its thermonuclear test in 1967, Japan responded by introducing the three non-nuclear principles of not possessing, not producing, and not permitting the introduction of nuclear weapons. By contrast, Japan's response to North Korea's 2017 nuclear test has been to push for preemptive strike capabilities.

A self-constraining response along the lines of 1967 was simply unthinkable, especially under Shinzo Abe's government in Japan. The aggressiveness of the PRC and the DPRK cannot be viewed in isolation but must be seen against the backdrop of Japan's already changing self-understanding. According to this understanding, Japan is perceived as peaceful, democratic, and law-abiding, whereas the PRC and the DPRK are viewed as hostile, authoritarian, and anti-Japanese. Japan understands the actions of the PRC and the DPRK as they pertain to those countries and its own past. This understanding has changed tremendously in the 2000s, thus enabling the recent far-reaching changes in Japanese security policy<sup>17)</sup>.

In 2015, due to the confrontation between the polarized nature of pacifism and rearmament narratives domestically, the Japanese government passed a package of controversial security bills that made it possible for Japan to participate in collective self-defense—that is, to respond militarily to an attack on a country as though Japan itself had been attacked. These bills overturned the interpretation that Japan's constitution forbids the country from engaging in collective self-defense, a view the Japanese government had held since 1957.

The legislation on collective self-defense means that Japan can now do everything other, more defended countries do in the security field. Still, this is not normal among U.S. allies<sup>18)</sup>. Indeed, the 2015 security legislation and the 2014 Cabinet Resolution it is based on are replete with references to the security environment that has been fundamentally transformed for the worse<sup>19)</sup>.

#### 4. US-Japanese Relations in the Indo-Pacific Region

In 2011, the Obama Administration initiated its pivot to Asia-Pacific, which is perceived as one of the most critical strategic reorientations in the recent history of American foreign policy<sup>20)</sup>. American rebalances to Asia were linked to a "strategic handshake," which represented a convergence of geopolitical interests alongside India's Act East Policy<sup>21)</sup>.

The Indo-Pacific Economic Corridor (hereafter IPEC) project aimed to promote the stability and prosperity of South and Southeast Asian economies. Amongst the essential activities under IPEC, there is the advancement of regional economic connectivity. The IPEC may thus

be considered through the prism of a hegemonic rivalry with the PRC's Belt and Road Initiative, a challenge for influence in the Indian Ocean Rim, Asia-Pacific, and Eurasia regions. Therefore, the IPEC is a framework within which the U.S. is in close cooperation with India and one where Japan would attempt to determine the future economic and geopolitical order while countering the PRC's ambitions.

Since the former U.S. President's Indo-Pacific speech in November 2017, the Free and Open Indo-Pacific (FOIP) has drawn international attention. The FOIP is a strategic vision that primarily aims to maintain the existing international order based on principles such as the rule of law, a free-market economy, and fundamental rights in the Indo-Pacific region.

In maintaining peace and stability, it is imperative for Japan to ensure the U.S. strategic commitment to the region, particularly in responding to the PRC's potential challenges to the existing international order in the context of its strategic outreach to Eurasia, Africa, and Eastern Europe<sup>22)</sup>. Securing the vast geographical areas of the Indo-Pacific region requires cooperation with Japan's regional partners, ASEAN, India, and Australia<sup>23)</sup>.

As a democratic state, India is an essential player in safeguarding the existing international order covering the Indian Ocean and Southern Pacific. The origin of Japan's role within the regional stability via the existing international order dates back to the Former Japanese Prime Minister Abe's 2007 speech at the parliament of India<sup>24)</sup>.

Abe's communicated Japan's continued commitment to the Indo-Pacific region in his speech at the Sixth Tokyo International Conference on African Development in August 2016, emphasizing the importance of economic development, the need for quality infrastructure, and the sea lanes of communication between "the seas of Asia and the Indian Ocean<sup>25)</sup>."

Therefore, the FOIP's core elements were freedom of navigation and overflight by enhancing the rule of law and the infrastructure and economic development adhering to international standards in the Indo-Pacific region. On the other hand, only East Africa is involved in the Indian Ocean development. The more significant connection between the seas of Asia and the Indian Ocean is obviously through Southeast Asia. Tokyo has yet to indicate whether the FOIP is intended to be competitive against the PRC, signifying why the strategy is vague by design.



However, such vagueness allows Japan flexibility in its policy response to the rapidly changing strategic environment. Discussions at the November 2017 Japan–U.S. summit highlight three reasons for the significance of flexibility. First, Tokyo got the U.S. on board with the concept of the FOIP to keep the PRC in check. Second, both countries emphasized the importance of freedom of navigation and economic development, which have been Japan's primary concerns. Finally, they agreed to the strategy's non-exclusive nature, leaving Japan options for future cooperation with the PRC<sup>26)</sup>.

American policies toward the PRC mainly lead to more competitive and antagonistic interactions, while Japan attempts to engage with and shape the PRC's behavior. To maintain strategic consistency and avoid misunderstandings, continual and close communication is critical in achieving agreed-upon objectives. Japan needs to identify the details of the FOIP for the involvement in infrastructure projects and maritime security in the two oceans with India.

## 5. Concluding Remarks

The 1960 revision was less interested in what could be gained technically in a mutual security treaty than what could be won from Japan's psychological alignment with the free world<sup>27)</sup>. As a result, the revisions to the security treaty between the U.S. and Japan, signed in January 1960, although not covering arrangements to bring nuclear weapons to Japan or U.S. combat operations in military conflicts in East Asia, were essential for the U.S. in the maintenance of its relationship with Japan<sup>28)</sup>. Currently, Asia's growing importance as the world's leading economic center initiated a change in the United States' perception of the region<sup>29)</sup>. Therefore, the U.S. has suggested the Indo-Pacific as an area of cooperation in politics, security, and economy.

The engagement of American allies with India and Japan in developing the Indo-Pacific region concept is seen as a countermeasure for the U.S. to the PRC's growing strength and influence. The Maritime Silk Road concept, first unveiled to the Indonesia Parliament by Xi Jinping in 2013, was also an attempt to counterbalance the negative imagery Chinese policies and actions caused in the Indo-Pacific<sup>30)</sup>. However, given that the Indo-Pacific strategy is a revival of one dating back to the 2007 initiative of the Former Japanese Prime Minister

Abe, the FOIP also likely includes a strong coalition of like-minded regional democracies in Asia, extending from Japan in the East to India in the West.

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研究ノート  
Research Note





## 環境材料を用いた二酸化炭素回収・隔離システムの開発に向けた基礎研究

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### 要旨

キングモンクット工科大学およびタイ国科学技術研究所からの国際協力を得て、真空加熱処理およびマグネトロンスパッタリング装置を用いたプラズマ表面処理により、ポーラス状のリチウム複合酸化物セラミックス表面を活性化させ、常温で大気中の二酸化炭素 (CO<sub>2</sub>) を選択的に吸収させて、長期保管および再生可能エネルギーとして利用するための新規な環境材料の開発を目指している。本研究では、この材料におけるCO<sub>2</sub>吸収および蓄積過程を明らかにするための基礎実験が実施された。

**キーワード** : 環境材料, 二酸化炭素, 吸収過程, 蓄積過程, CO<sub>2</sub>回収・隔離システム

### 1. はじめに

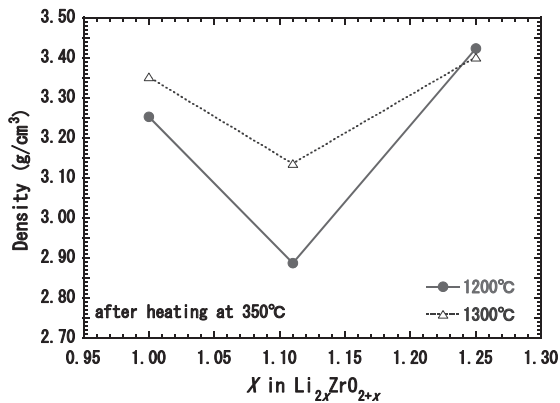
現在、二酸化炭素 (CO<sub>2</sub>) の排出に伴う地球温暖化の防止対策の一つとして、大気中からCO<sub>2</sub>の回収および隔離が挙げられる。その目標を達成するためには、大気中に排出されたガスから、最小限の動力でCO<sub>2</sub>を分離および回収して隔離する技術を確認する必要がある。これまで、リチウム-ジルコニウム酸化物 (Li<sub>2</sub>ZrO<sub>3</sub>) およびリチウム-シリコン酸化物 (Li<sub>4</sub>SiO<sub>4</sub>) セラミックス材料が二酸化炭素吸収材料 (CO<sub>2</sub> 吸収材料) として利用可能であることが報告されている<sup>1,2)</sup>。これらのリチウム複合酸化物は、通常約 200 ~ 700°C の温度範囲においてCO<sub>2</sub>ガスと反応してリチウム炭酸塩 (Li<sub>2</sub>CO<sub>3</sub>) を生成してCO<sub>2</sub>を貯蔵し、さらにこの捕獲されたCO<sub>2</sub>を700°C以上の温度で放出させることが可能である。しかしながら、CO<sub>2</sub>の再生に多大なエネルギーが必要となる。

本研究では、キングモンクット工科大学ラドクラバン校 (King Mongkut's Institute of Technology, Ladkrabang) およびタイ国科学技術研究所 (Thailand Institute of Scientific and Technological Research) の協力を得て、これまで各研究所において培われてきたポーラス状の高表面積セラミックス作製技術およびプラズマ処理技術を利用して、「約 1 nm 以下のリチウム複合酸化物セラミックス表面のみに電荷を帯びたラジカルを形成させ、CO<sub>2</sub>の分極分解効果を進ませる」とともに、「CO<sub>2</sub>蓄積容量を 30 wt% 以上に増加させること、さらに蓄積されたCO<sub>2</sub>を 200°C 以下の低温で放出させること」などが可能な環境材料を作製し、CO<sub>2</sub>回収および隔離システム開発の基礎を築くことを目的とした。

### 2. 国際交流研究の計画および実施内容

#### 2.1. リチウム複合酸化物セラミックス材料の作製

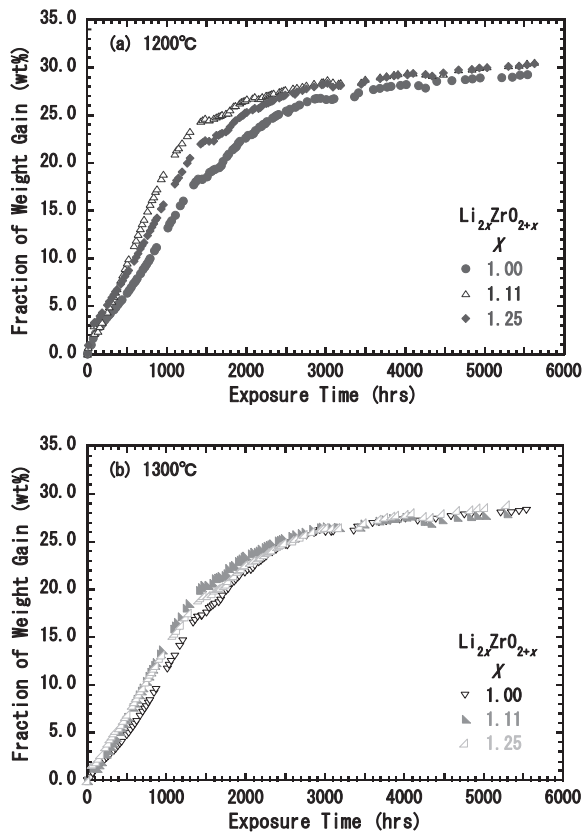
タイ国バンコク市 (Bangkok in Thailand) の北地区に位置するタイ国科学技術研究所では、電気炉を用いて微粉末を焼結する際に温度を調節してポーラス状のセラミックス材料を作製している。この研究所に所属するチュムボン・ブサボク (Chumphol Busabok) 研究員の協力により、炭酸リチウム (Li<sub>2</sub>CO<sub>3</sub>) および酸化ジルコニウム (ZrO<sub>2</sub>) 粉末を 1 気圧の空気雰囲気において、焼結温度を 1200°C および 1300°C、Li<sub>2</sub>CO<sub>3</sub> および ZrO<sub>2</sub> の比を 1:1, 1.11:1, 1.25:1 として、6 種の密度および組成の異なるリチウム-ジルコニウム複合酸化物セラミックス (Li<sub>2x</sub>ZrO<sub>2+x</sub> (x=1.00, 1.11, 1.25)) 試料を作製した。これらの試料内部には、作製時に吸収された水 (H<sub>2</sub>O) や CO<sub>2</sub> 等による残留水素および様々なガス種が多く含まれているため、真空雰囲気において 350°C、10 分間の熱処理が実施された。この熱処理により、リチウムおよび酸素空孔等の電荷を帯びたラジカルを含む CO<sub>2</sub> 吸蔵貯蔵材料が作製された。Li<sub>2x</sub>ZrO<sub>2+x</sub> 中の Li 濃度  $x$  に対する体積密度を Fig. 1 に示す。体積密度については、重量および体積を測定することによって求めた。Fig. 1 より、 $x=1.25$  を除いて、1200°C の焼結温度で作製した Li<sub>2x</sub>ZrO<sub>2+x</sub> 試料の体積密度は、1300°C の焼結温度で作製した Li<sub>2x</sub>ZrO<sub>2+x</sub> 試料の体積密度より低いことがわかる。また、 $x=1.11$  のとき、体積密度は 1200°C および 1300°C の両焼結温度に対して最も低くなることもわかる。



**Fig. 1** Composition dependence of volume density for  $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.00, 1.11, 1.25$ ) fabricated at sintering temperatures of 1200 and 1300°C.

2.2. CO<sub>2</sub> 吸収および貯蔵特性評価

恒温恒湿器を用いて、各  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料を温度 20°C、相対湿度 80%R.H. の条件下に置き、各空気暴露時間後に精密電子天秤を用いて測定された各試料の重量増加の割合を Fig. 2 (a) および (b) に示す (焼結温度: (a) 1200°C、(b) 1300°C)。横軸は空気暴露時間 [hour]、縦軸は各試料の重量増加の割合 [wt%] を表す。Fig. 2 (a) および (b) よ

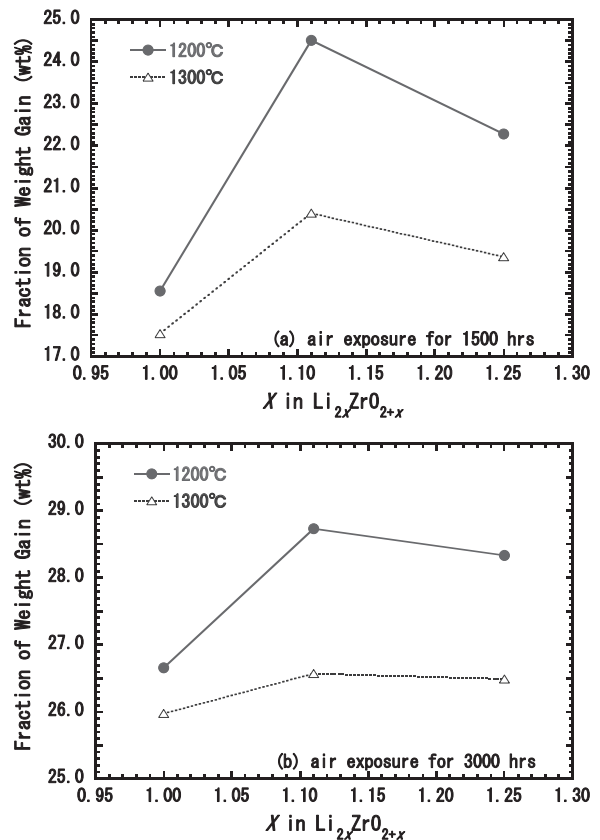


**Fig. 2** Changes in weight gain of  $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.00, 1.11, 1.25$ ), fabricated at sintering temperatures of (a) 1200 and (b) 1300°C, as a function of exposure time in air at 20°C and 80 R.H.%.

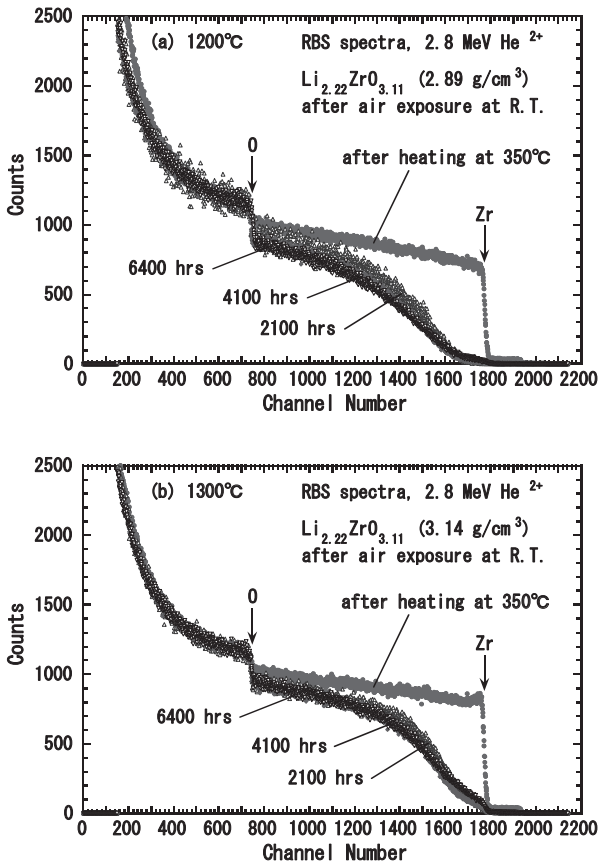
り、焼結温度および組成に関係なく、各試料の重量増加の割合は約 1500 時間までは時間に対して比例に増加し、その後は徐々に増加して約 4000 時間でほぼ一定の値 (約 28 wt%) に達することがわかる<sup>3-4)</sup>。

次に、Fig. 2 より、1500 および 3000 時間まで空気に曝された各試料の重量増加の割合をそれぞれ Fig. 3 (a) および (b) に示す。1200°C および 1300°C の焼結温度で作製された各試料の重量増加の割合を比較すると、1200°C の  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料の重量増加の割合は 1300°C の  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料の重量増加の割合よりも高いことがわかる。また、各焼結温度の組成の異なる  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料の重量増加の割合を比較すると、 $x=1.11$  の  $\text{Li}_{2.22}\text{ZrO}_{3.11}$  試料の重量増加の割合が最も高いことがわかる。これらの結果は、Fig. 1 の体積密度における焼結温度および Li 濃度依存性に大きく関わると考えられる。体積密度の低い  $\text{Li}_{2.22}\text{ZrO}_{3.11}$  試料は表面積が大きいため、大気中の H<sub>2</sub>O や CO<sub>2</sub> 等を試料内部に取り込み易いと考えられる。

これらの重量増加の要因および密度の Li 濃度依存性を明らかにするため、イオンビーム分析法であるラザフォード後方散乱 (RBS: Rutherford Backscattering Spectrometry) 法によって、室温において空気中に曝さ



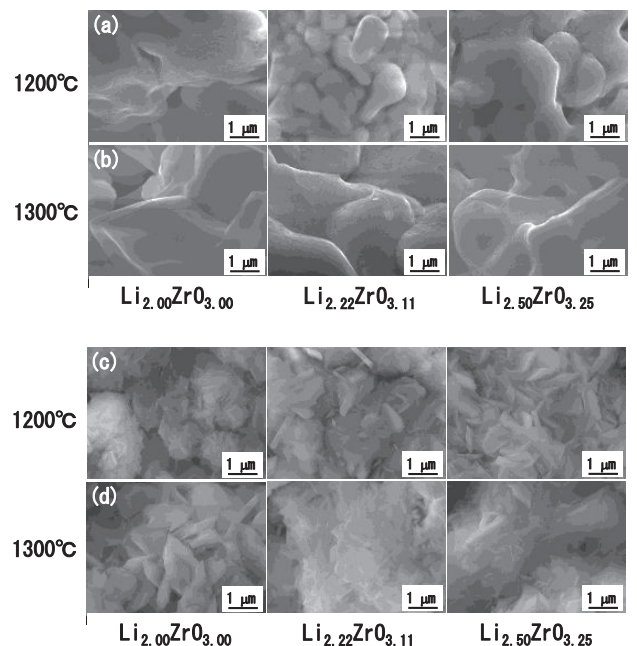
**Fig. 3** Composition dependence of weight gain for  $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.00, 1.11, 1.25$ ), fabricated at sintering temperatures of 1200 and 1300°C, after air exposure for (a) 1500 and (b) 3000 hrs in Fig. 2.



**Fig. 4** RBS spectra of  $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.11$ ), fabricated at sintering temperatures of (a) 1200 and (b) 1300°C, after heating at 350°C in vacuum and air exposure for 2100, 4100, and 6400 hrs.

れた  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料表面の元素分析を行った。RBS法は、核融合研究所に既設されたタンデム加速器からの 2.8 MeV の  $^4\text{He}^{2+}$  イオンをプローブビームとして用い、入射方向に対して 165° 後方に散乱された  $\text{He}^+$  イオンの運動エネルギーとその個数を測定することで構成元素とその深さに対する濃度分布を表面障壁型半導体検出器 (SSD) により測定する手法である<sup>5)</sup>。真空加熱後、2100、4100 および 6400 時間の空気暴露後に得られた  $\text{Li}_{2.22}\text{ZrO}_{3.11}$  (焼結温度: 1200°C、1300°C) の RBS スペクトルをそれぞれ Fig. 4 (a) および (b) に示す。横軸はチャンネル数 (ch) であり、後方散乱された  $\text{He}^+$  イオンのエネルギーに相当し、 $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料表面からの深さの情報を与える。縦軸は後方散乱された  $\text{He}^+$  イオンの個数であり、 $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料内を構成する Zr (約 1780 ch) および O (約 740 ch) の深さに対する濃度を表す。O 濃度は深さに対して一様に分布していると仮定して、すべてのスペクトルを規格化して表している。Fig. 4 (a) および (b) より、組成および焼結温度の異なる  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料における RBS スペクトルでは、Zr のピーク強度が空気暴露時間の増加により減少することがわかる。これは何らかの析出物が  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料表面から約 600 nm の深さまで形成されていると考えられる。

次に、電界放出形走査型電子顕微鏡 (FE-SEM: field emission - scanning electron microscope) を用いて、真空加熱および 5600 時間の空気暴露後に観測された各  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料 (焼結温度: 1200°C、1300°C) の FE-SEM 像をそれぞれ Fig. 5 (a) ~ (d) に示す。各試料において大きな隙間および空隙等は形成されていないことがわかる。また、1200°C で焼結された試料の粒径は 1300°C で焼結された試料の粒径より小さいように見える。これは、焼結温度が低いほど粒子同士が溶解しないことを示す。次に、各焼結温度において Li 濃度の異なる試料について比較する。 $x=1.11$  の  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料における粒径 (焼結温度 1200°C (約 2  $\mu\text{m}$ )、1300°C (約 3  $\mu\text{m}$ )) が最も小さいことがわかる。従って、粒子の表面積は、粒径が小さい程大きくなり、Figs. 1 および 3 の結果より、 $x=1.11$  の  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料における体積密度が最も低く、重量増加が最も高いことから、大気中の  $\text{H}_2\text{O}$  や  $\text{CO}_2$  等が吸収され易い状態になっていると考えられる。Fig. 5 (c) および (d) より、大気中に 5600 時間経過させると、草状の結晶成長がどの  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料の表面においても観測された。これらの粒径の形状は約 1  $\mu\text{m}$  であり、真空加熱後の粒径より小さいことがわかる。従って、 $\text{LiOH}$  および  $\text{Li}_2\text{CO}_3$  などの結晶成長が  $\text{H}_2\text{O}$  や  $\text{CO}_2$  との反応により生じている可能性がある。この事実を明らかにするため、X 線回折 (XRD: X-ray diffraction) を用いて、 $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料表面に成長した生成物の組成を調べた。真空加熱および 5000 時間の空気暴露後に観測された各  $\text{Li}_{2x}\text{ZrO}_{2+x}$  試料 (焼結温度: 1200°C、



**Fig. 5** FE-SEM images of  $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.00, 1.11, 1.25$ ), fabricated at 1200 and 1300°C, after (a),(b) heating at 350°C in vacuum and (c),(d) air exposure for 5600 hrs.



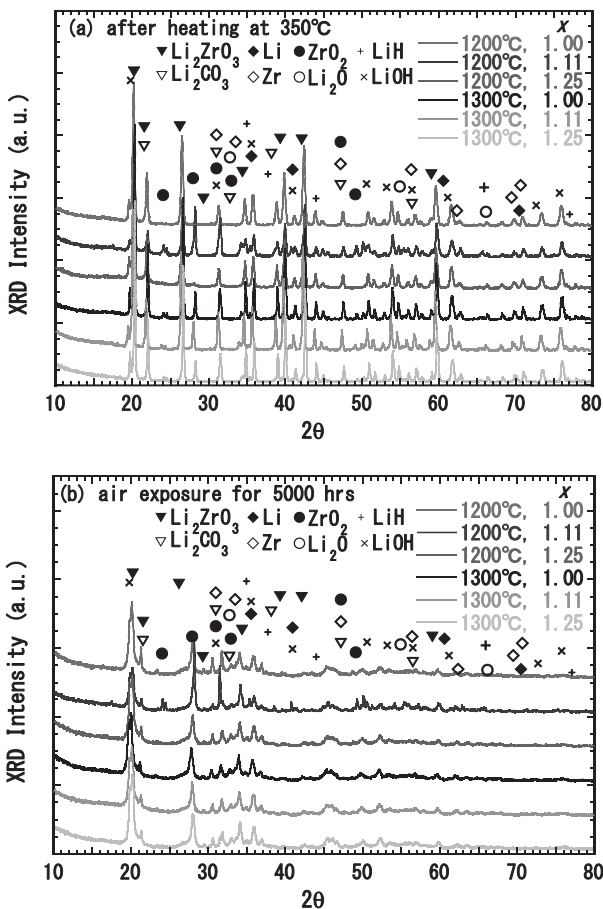


Fig. 6 XRD patterns of  $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.00, 1.11, 1.25$ ), fabricated at 1200 and 1300°C, after (a) heating at 350°C in vacuum and (b) air exposure for 5000 hrs.

1300°C)におけるXRDパターンをそれぞれFig. 6 (a) および (b) に示す。 $\text{Li}_2\text{ZrO}_3$ のピークが20.87°, 21.91°, 26.27°, 30.68°の2θの角度に現れることを確認した。その他に、 $\text{ZrO}_2$ 、 $\text{Li}_2\text{CO}_3$ 、 $\text{Li}_2\text{O}$ 、 $\text{LiOH}$ 等のピークが観測された。1200°Cの焼結温度で作製された $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料では、 $\text{Li}_2\text{CO}_3$ および $\text{ZrO}_2$ のピークが1300°Cの焼結温度よりも大きく現れ、 $\text{Li}_2\text{ZrO}_3$ のピークが小さく検出された。これは、焼結温度が低いため粒子同士が溶解せず、 $\text{Li}_2\text{ZrO}_3$ が生成されなかったことが考えられる。また、1200°Cおよび1300°Cの焼結温度で作製された $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料に対しても、 $\text{Li}_2\text{ZrO}_3$ のピークは空気暴露時間の増加により減少することがわかる。これは $\text{Li}_2\text{CO}_3$ 、 $\text{ZrO}_2$ 、 $\text{LiOH}$ 、 $\text{LiH}$ 等が大気中の $\text{H}_2\text{O}$ や $\text{CO}_2$ と反応して、 $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料表面に形成され、 $\text{Li}_2\text{ZrO}_3$ を覆ったためと考えられる。これらの結果は、Fig. 4 (a) および (b) のRBSスペクトル中のZrピークの強度が空気暴露時間の増加とともに減少したことから、草状の結晶成長がFig. 5 (a) ~ (d) のFE-SEM像に観測されたことと一致する。従って、観測した草状の結晶は、 $\text{ZrO}_2$ 、 $\text{Li}_2\text{CO}_3$ 、 $\text{LiOH}$ 等であると考えら

れ、また、これらの生成物が大気中の $\text{H}_2\text{O}$ および $\text{CO}_2$ 吸収を抑制すると考えられる。

これまで、タイ国バンコク市の東地区に位置するスワンナプーム国際空港近郊のキングモンクット工科大学ナノテクノロジー研究所に訪問し、ナットナン・ムールスラデュー (Nutthanun Moolsradoo) 准教授、ウイナダ・ウオンウィリヤパン (Winadda Wongwiriyan) 講師と会い、 $\text{CO}_2$ 回収および隔離システム開発のための研究打ち合わせを実施して来た。キングモンクット工科大学では、既設のマグネトロンイオンスパッタリング装置を用いたプラズマ処理技術により、100 eVのプロトン、ヘリウムおよびアルゴン等の各イオン種を金属、半導体および絶縁体等の各材料表面に約 $10^{16-17}$  ions/cm<sup>2</sup>の低照射量まで照射して、約1 nm以下の電荷を帯びたラジカルを形成させる表面改質を行うことができる。今後は、このプラズマ処理技術を利用して、これまで作製してきたポーラス状のリチウム複合酸化物セラミックス表面を活性化させて、常温において大気中からより多量の $\text{CO}_2$ を回収および貯蔵を可能とする新規な環境材料の作製を行う予定である。

### 3. まとめ

キングモンクット工科大学およびタイ国科学技術研究所の協力を得て、ポーラス状のリチウム複合酸化物セラミックスを用いた $\text{CO}_2$ 回収および隔離システムの確立を目指した国際交流プロジェクトを実施した。

本研究では、焼結温度 (1200°Cおよび1300°C)、 $\text{Li}_2\text{CO}_3$ および $\text{ZrO}_2$ の混合比を組み合わせて、密度およびLi濃度の異なるラジカル含有 $\text{Li}_{2x}\text{ZrO}_{2+x}$  ( $x=1.00 \sim 1.25$ ) 試料を作製した。これらの $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料を恒温恒湿器内の20°Cおよび80%RH.の相対湿度における大気雰囲気曝露し、電子天秤、RBS、FE-SEMおよびXRD等のそれぞれの測定方法を用いて、空気暴露時間に対する重量増加、元素分析、表面形態、構成元素および組成を測定して、 $\text{CO}_2$ 吸収特性における表面積およびLi濃度依存性について調べた。 $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料の重量増加の割合および $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料中の $\text{CO}_2$ 濃度は空気暴露時間の増加とともに増加し、約4000時間でほぼ一定の値(約28 wt%)に達することがわかった。また、両焼結温度に対して $x=1.11$ の $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料における重量増加が最も高いことがわかった。これは、 $x=1.11$ の $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料における体積密度(粒径)は $x=1.00$ および $x=1.25$ の $\text{Li}_{2x}\text{ZrO}_{2+x}$ 試料における体積密度

(粒径) よりも低く (小さく)、空気に曝される面積がより大きいため、多くの CO<sub>2</sub> が吸収され易い状態であると考えられる。また、Li 含有量の増加は、大気中の CO<sub>2</sub> との反応による、Li<sub>2</sub>CO<sub>3</sub> の生成物形成を促進することから、自由に動けるわずかな Li が CO<sub>2</sub> 蓄積過程に大きな影響を与えると考えられる。

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## Fundamental Study on Development of System on Collection and Accumulation of Carbon Dioxides Using Environment Materials

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### Abstract

International collaborative studies with King Mongkut's Institute of Technology as well as Thailand Institute of Scientific and Technological Research have been performed to develop new environmental lithium-complexed oxide materials with surface activated using annealing-vacuum and plasm-sputtering treatments, which have excellent absorption and desorption characteristics of carbon dioxides (CO<sub>2</sub>) from air at normal atmospheric pressure and room temperature. Our aim is to establish CO<sub>2</sub>-collection and -separation as well as energy-recycling systems using the modified materials and to protect the global environment. In the present study, fundamental surface analysis experiments for lithium-zirconate (Li<sub>2</sub>ZrO<sub>3</sub>) specimens during air exposure at 293 K and relative humidity of 80 R.H.% were carried out to clarify the absorption and accumulation processes of CO<sub>2</sub> from air into Li<sub>2</sub>ZrO<sub>3</sub>.

**Key words** : Environmental materials, Carbon dioxides, Absorption and accumulation processes, CO<sub>2</sub> collection and separation systems

# 台湾由来イボタクサギより抽出したヒスピジュリンの社会性行動障害モデルマウスに対する作用

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## 要旨

本研究では、ヒスピジュリンが社会性行動障害に有効であるか行動薬理的及び神経化学的に検討した。実験には6週齢のddY系雄性マウスにフェンシクリジン (PCP; 10 mg/kg, s.c.) を14日間連続投与した。4日間退薬後に社会性行動試験を行い、社会的離脱 (引きこもり) 行動を観察した。ヒスピジュリン (10 mg/kg, i.p.) を社会性行動試験の15分前に投与した。ヒスピジュリンはPCP連続投与誘発社会的離脱 (引きこもり) 行動を有意に緩解し、その作用はドーパミンD<sub>1</sub>受容体拮抗薬 (SCH-23390) によって有意に拮抗された。また、ヒスピジュリンは、前頭皮質の細胞外ドーパミン量を有意に増加した。

これまでの研究成果及び予備検討結果を合わせて考えると、ヒスピジュリンは、COMT阻害による前頭皮質のドーパミンレベルの上昇を介してドーパミンD<sub>1</sub>受容体を間接的に活性化することにより、社会的離脱を緩解した可能性が示唆された。ヒスピジュリンは、社会的離脱 (引きこもり) 行動の治療に有効であるかもしれない。

**キーワード:** イボタクサギ (*Clerodendrum inerme*)、ヒスピジュリン、社会的離脱 (引きこもり) 行動、統合失調症陰性症状

## 1. はじめに

*Clerodendrum inerme* (CI, 和名: イボタクサギ) (図1A) は、台湾をはじめ中国南部、東南アジアおよびインドの河口および海岸に分布する低木であり<sup>1)</sup>、民間療法として皮膚病や発熱を和らげる目的で用いられる漢方植物である<sup>2)</sup>。また、イボタクサギ抽出物には、抗侵害受容作用<sup>3)</sup>、抗ウイルス作用<sup>2)</sup>、抗真菌作用<sup>4)</sup>があることも報告されている。

イボタクサギの葉から単離されたヒスピジュリン (図1B) はフラボノイド<sup>5)</sup>であり、難治性チック障害に治療効果があると報告された<sup>6)</sup>。これまでに我々のグループは、このヒスピジュリンにはGABA<sub>A</sub>受容体 $\alpha_6$ サブユニットの正のアロステリックモジュレーター作用およびcatechol-O-methyltransferase (カテコール-O-メチル基転移酵素; COMT) 阻害作用を有していること、精神疾患における感覚運動ゲーティング障害に対する有効な薬となりうることを明らかにしてきた<sup>7)</sup>。

本研究では、精神疾患の統合失調症の主たる症状の陰性症状に着目した。陰性症状は、自閉 (引きこもり)、意欲の低下、感情の平板化を示し、有効な治療が困難な症状の1つである。そこで、これまでに確立されているフェンシクリジン (PCP) 連続投与誘発統合失調症陰性症状モデルマウス<sup>8,9)</sup>を用いて、ヒスピジュリンの有効性を行動薬理的及び神経化学的に検討した。

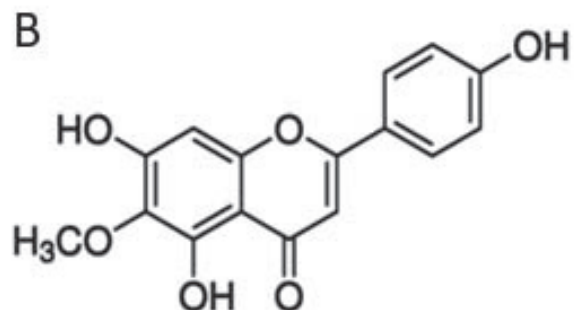
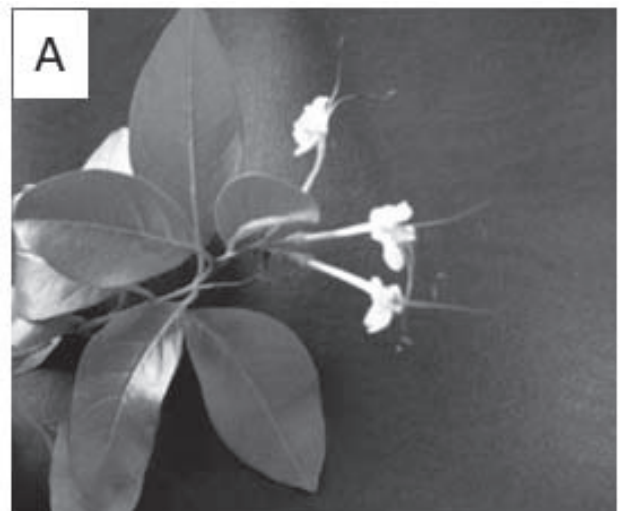


図1 イボタクサギ (*Clerodendrum inerme*) の葉および花 (A: 共同研究者の邱麗珠教授より提供) 及び抽出されたヒスピジュリンの構造式 (B)

## 2. 方法

実験には ddY 系雄性マウス（6 週齢、日本 SLC、静岡）を用いた。マウスは 1 ケージ 5 匹とし、12 時間の明暗サイクル（9:00 点灯、21:00 消灯）、室温 23℃ 下で飼育した。PCP（古川宏 名城大学名誉教授より供与；10 mg/kg, s.c.）を 14 日間連続投与後 4 日間休薬し、その後行動試験を開始した。なお、実験内容を、事前に名城大学動物実験委員会に申請し承認を受けて実施した（承認番号：PE-11）。

### 社会性行動試験

装置は、灰色の非反射性アクリル製板で作られた箱（25 × 25 × 30 cm）で、間接的に照明した。社会性行動試験訓練日の前日に、各マウスを単独で装置に 10 分間入れて、馴化させた。社会的相互作用テストの前に、ヒスピジュリン（邱麗珠 教授より供与；10 mg/kg, i.p.）と R (+)-SCH-23390 (D-054, Sigma-Aldrich, USA; 0.02 mg/kg, i.p.) を各 15 分および 45 分前に投与し、装置内に入れた。その直後に同様に馴化させた同週齢の ddY 系雄性マウスを装置内に入れ、初めて出会ったパートナーに対する行動を録画した。10 分間の社会性行動（追尾、においかぎ、身繕い、マウンティング）時間を測定した。実験結果について、Mann-Whitney U test を用いて統計学的に検定した。

## 3. 結果

PCP（10 mg/kg）を 14 日間投与され、その後 4 日間退薬したマウスは、社会性行動時間が対照群（コントロール群）マウスのそれよりも有意に短かった。この処置をしたマウス群に、ヒスピジュリン（10 mg/kg）を投与すると、社会性行動時間の短縮が、コントロール群マウスのレベルにまで有意に回復した（表 1）。一方、ヒスピジュリンは、生理食塩液を長期投与したマウスの社会的相互作用時間に影響を与えなかった。したがって、ヒスピジュリンは、PCP 連続投与誘発社会的離脱（引きこもり）行動を有意に緩解した。

	社会性行動
PCP連続投与マウス	↓ ↓
+ ヒスピジュリン (10mg/kg)	緩解

表 1 現在までの結果のまとめ

## 4. 考察

この研究は、2005 年に邱麗珠 教授（国立台湾大学）が鍋島俊隆 前教授（現藤田医科大学特任教授）のもとを訪問されたことに始まる。当時、邱麗珠 教授が米国留学から台湾に戻られ、新たな研究テーマの一つとして、台湾由来の植物から抽出される有効成分の薬効評価に取り組まれた。数十種類の候補成分について、動物実験を用いた基礎研究を始められたが、十分な成果は得られなかった。そこで、共通の恩師である IK HO 教授の紹介で鍋島教授を訪問し、共同研究が始まった。これまでに邱麗珠 教授の研究室に所属する李欣蓉 研究員が 2 回にわたって来日し合計約 6 か月間、名城大学薬学部（薬品作用学研究室）で主に行動薬理学を学ばれた。2018 年 7 月の京都における国際薬理学会、2019 年 10 月の国際シンポジウムにおいて、綿密な打ち合わせや議論を行い、研究を進めてきた。この報告書で示した結果は、そうして積み重ねた基盤があってこそ得ることができた。

本研究で用いた行動障害モデルである、PCP 連続投与誘発社会的離脱（引きこもり）行動は、統合失調症の陰性症状モデルとして確立されている。統合失調症は、現在の抗精神病薬に対する治療抵抗性が高く（～30%）、また患者の長期的なアドヒアランスの悪化や高い再発リスクなどが、医療問題の 1 つとなっている<sup>10,11</sup>。この問題解決のために、より広い治療域または、より副作用の少ない新薬を開発することが急務である。

イボタクサギは、台湾人にとってなじみのある半つる性常緑低木であり、沖縄にも分布している。本研究で用いたヒスピジュリンは、邱麗珠教授および李欣蓉研究員らが、そのイボタクサギの葉から抽出し精製したものである。また、ヒスピジュリンには、GABA<sub>A</sub> 受容体  $\alpha_6$  サブユニットに対するアロステリックモジュレーター作用及び COMT 抑制作用を有する<sup>7</sup> ことから、新たな行動障害抑制作用を検出することを目的にして、このプロジェクトを始めた。

まとめ（表 1）に示したように、ヒスピジュリン（10 mg/kg）は PCP 連続投与誘発社会的離脱（引きこもり）行動を有意に緩解した。このことから、新規統合失調症（陰性症状）治療薬となる可能性が示唆された。次にこの作用がどのようなメカニズムを介しているか検討した。先の報告<sup>7</sup> で、ドーパミン神経系との関与が示されたことから、ヒスピジュリン（10 mg/kg）投与前にドーパミン D<sub>1</sub> 受容体拮抗薬（SCH-23390; 0.02 mg/kg）を処置したところ、ヒスピジュリンの作用は有意に抑制された。さらにヒ

スピジュリン (10 mg/kg) には前頭皮質における細胞外ドーパミン量を有意に増加する作用があることも見出している。したがって、ヒスピジュリンは、PCP 連続投与誘発統合失調症陰性症状モデルマウスにおける前頭皮質のドーパミンレベルを上昇させ、ドーパミン D<sub>1</sub> 受容体の機能を高めることによって、引きこもり行動を緩解した可能性が示唆された。

## 5. まとめ

ヒスピジュリンは、統合失調症における陰性症状 (引きこもり行動) の治療に有効であるかもしれない。今後も邱麗珠教授や李欣蓉研究員との共同研究を通じ、台湾の研究者との文化交流も進めていきたい。さらに中国、韓国、インドネシアの研究仲間たちとも持続的な共同研究を進め、次世代につなげ発展させていきたい。

## 謝辞

本研究は、国立台湾大学・脳與心智科学研究所 邱麗珠教授、藤田医科大学 鍋島俊隆 特任教授、毛利彰宏 准教授との 10 年以上にわたる共同研究の成果の一部である。また、実施するにあたり、文部科学省の科学研究費補助金 (基盤研究 (C) 15K08218) および 2020 年度 名城大学アジア研究センターアジア研究公募型プロジェクト研究助成を受けた。ここに深く感謝いたします。研究成果の一部は、Mouri A., Lee HJ., Mamiya T., et al. (2020) "Hispidulin attenuates the social withdrawal in isolated disrupted-in-schizophrenia-1 mutant and chronic phencyclidine-treated mice", *Br. J. Pharmacol.*, **177**, 3210-3224. に報告した。

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## Effects of hispidulin, extracted from *Clerodendrum inerme* (L.) Gaertn, on social withdrawal model in mice.

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### Abstract

*Clerodendrum inerme* (CI) is a shrub distributed in estuaries of southern China and Taiwan. Hispidulin is a flavonoid isolated from CI. Previously, we found that hispidulin attenuates hyperlocomotion and the disrupted prepulse inhibition induced by two phenotypes of schizophrenia resembling positive symptoms. Hispidulin can inhibit catechol-O-methyltransferase (COMT), a dopamine-metabolizing enzyme in the prefrontal cortex that is important for social interaction.

In the present study, we investigated effects of hispidulin on the impairments of social interaction, as an index of negative symptom of schizophrenia in mice using pharmacological and neurochemical techniques. Male ddY strain mice were treated with phencyclidine (PCP; 10 mg/kg, s.c.) for 14 days and then a 4-day withdrawal in order to induce social withdrawal. Hispidulin (10 mg/kg, i.p.) was administered 15 min before the social interaction test. Hispidulin significantly ameliorated PCP-induced social withdrawal, which inhibited by dopamine D<sub>1</sub> receptor antagonists (*R*(+)-SCH-23390). Hispidulin (10 mg/kg) significantly increased extracellular dopamine levels in the prefrontal cortex.

These and our preliminary results suggest that hispidulin may alleviate social withdrawal by indirectly activating dopamine D<sub>1</sub> receptors through elevation of dopamine levels in the frontal cortex by COMT inhibition. Hispidulin may be effective in treating the negative symptoms of schizophrenia.

**Key words** : *Clerodendrum inerme* (CI), hispidulin, social withdrawal, schizophrenia, negative symptoms



# Competency-based Education and Problems of Teacher Training in Vietnam

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## Abstract

This paper refers to the issue that Vietnam is implementing the renovation of education towards the formation and development of the learners' dispositions and competencies. In order to improve the quality of education, the core competences for both Vietnamese teachers and students have to develop accordingly. The article provides the requirements for the initial teacher training program to meet the demand for educating young generation with the new curriculum.

**Key words** :education renovation, core competencies, initial teacher training, teacher standards

## 1. Introduction

The world of knowledge is expanding rapidly in the age of science and technology. Teaching as a form of knowledge transfer is out of date when the volume of knowledge is growing significantly. In the digital age, faster career shift requires each person to be able to adapt to changes.

The Vietnamese general education program has so far followed a heavy way of transmitting knowledge. The form of examination in Vietnam in particular and Asia in general is still very problematic. Being aware of the demands of the new age, the Government of Vietnam is implementing education renovation towards the formation and development of learners' dispositions and competencies.

The renovation has made progress initially, however, it also poses a very urgent problem that current teachers need to update training (and retraining), and that future teachers need a new training program. These issues need to be resolved promptly and only this can lead to successful innovation.

## 2. Current Situation of Teacher Training in Vietnam

### 2.1. Education system of Vietnam

The system of education in Vietnam is split up into pre-primary, primary, secondary (lower-secondary, upper-secondary and secondary technical and vocational education), and tertiary (university/college) education

(Figure 1).

At the age of 6 students enter the elementary (primary) school which comprises grades 1-5. After completion of primary school, students can go for lower secondary education that lasts for 4 years (grades 6-9), followed by 3 years of upper secondary school studies (grades 10-12).

Secondary vocational education schools provide students with technical skills and knowledge of the intermediate level. Upon graduation, students receive a diploma. After completion of secondary school, students must appear for a general education graduation examination. This exam is managed and supervised by the Ministry of Education and Training (MOET). Passing this exam allows admittance into the higher (university/college) education sector. Those who want will then sit for a university entrance examination in order to gain admittance into universities in Vietnam.



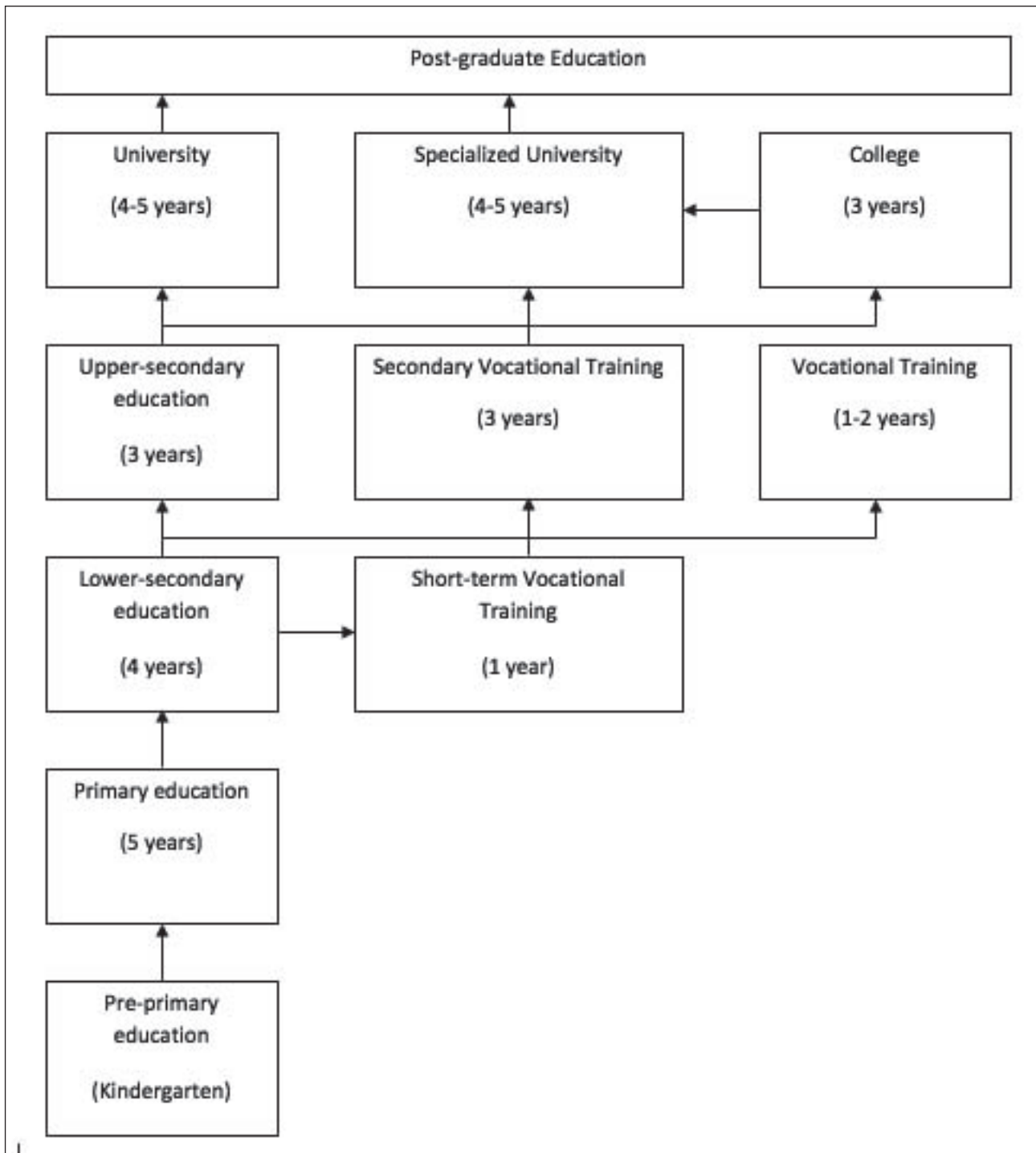


Figure 1. Education system of Vietnam<sup>1</sup>

**2.2. Teacher training system in Vietnam**

The requirements for teachers in Vietnam depend on the level of education ( 1). Pre-school and elementary (primary) school teachers must have a two-year program to get a diploma in teaching (Bằng Tốt nghiệp Trung học Sư phạm), usually awarded by the colleges of education. Lower-secondary school teachers commonly hold a diploma of a three-year program from a pedagogical junior

college (Cao đẳng Sư phạm), whereas upper-secondary teachers must have a bachelor degree in education from a university of education (Trường Đại học Sư phạm). Holders of bachelor degrees in other disciplines can obtain a teaching qualification by earning a supplementary one-semester teacher training certificate (Chứng chỉ Sư phạm). Like other parts of Vietnam’s education system, teacher education is changing. MOET seeks to strengthen teacher training while simultaneously trying to respond to teacher shortages.

Table 1. Network of National Teacher Training Institutions<sup>2</sup>

<i>Level of education</i>	<i>Number</i>	<i>Provision of Teachers for</i>	<i>Qualifications</i>
University of Education (Đại học Sư phạm)	14	- Upper secondary schools, - Pre-schools and primary schools	Bachelor's degree in education
Junior College of Education (Cao đẳng Sư phạm)	33	- Lower secondary schools, - Pre-schools and primary schools	Associate degree in education
Professional secondary school (Trung học Sư phạm)	2	- Pre-schools and primary schools	Professional secondary school diploma in teaching
Universities and Colleges offering teacher training certificates (Chứng chỉ Sư phạm)	100	- All kinds of schools	Teacher training certificates

### 2.3. Teacher training programs in Vietnam

The teacher-training programs have been redesigned with the competence-based approach and have a close correlation with national learning teacher outcomes, school teachers' professional standards as well as the new national curriculum<sup>3</sup>. Upon the most updated guidelines of curriculum development for the universities of education (UE), a four-year bachelor program comprises of from 120 to 135 credits with up to 45 modules. In addition to these modules, all teacher students have to complete 8 credits of national defense education and 5 credits of physical education.

The framework of each teacher education curriculum encompasses three components as follows.

(1) Common modules for students in all majors such as Introduction of Psychology, Psychology of Child Development and Educational Psychology, Introduction of

Education, Basic Education, Educational Assessment, Curriculum Development, Communication in Education Context. Among those modules, Educational Assessment and Curriculum Development have just launched as obligatory modules.

(2) Subject matter modules: provide subject-related knowledge for school teachers (STs) to prepare to teach subjects in school. These modules are specifically designed to suit STs in each major. For example, Mathematics Education STs have to study several subjects related to algebra, and geometry.

(3) Professional education modules: allow students to develop their teaching competencies including university-based modules and practicum blocks in school (8 credits). This component occupies a quarter of the total number of credits in each program and the modules vary depending on the requirements of each major. For instance, STs in Early Years Education have to study some

Table 2. Overall results of survey on current teacher competencies<sup>5</sup>

<i>Item to survey: Please check the statements that correspond to the competencies that a teacher should possess to be considered competent.</i>	
<i>Statements</i>	<i>Percentage (%)</i>
Satisfactory	75.3
Not satisfactory	16.6
Difficult to evaluate	8.0

dancing, singing, drawing modules which are categorized as essential professional modules for them.

### 3. Requirements of Teachers

#### 3.1. The current situation

The teacher is regarded as the decisive factor in the education quality and as the key element of any education reform. No matter what age, without teachers being good at both professional competencies and virtue, it is hard to achieve quality education. However, the requirement of educational innovation is a big challenge to the existing competency of secondary teachers. The most recent research<sup>4</sup> shows that about 25% of secondary school teachers do not meet the teaching and education requirements under the current program (Table 2). Some of them have quite good expertise, however, their mission is mainly to transfer knowledge to learners. They are facing challenges in implementing new curriculum with their traditional way of transferring knowledge content. They find it difficult to get to know other teaching approaches like developing learners' dispositions and competencies by integrating teaching, teaching differentiation, and creative experience.

There has never been a time for the renewal of teacher training curriculum and review of teacher training programs in universities of education, which has become such an urgent matter in the current period. The current program is heavily academic, the pedagogical training program still reveals many shortcomings. According to researchers<sup>6</sup>, the total time provided for pedagogical knowledge is only 33-36 credits, accounting for 16-18%. In particular, pedagogical practice only accounts for 10 units/ 210 units. General knowledge accounts for 38% of the total time. This current heavily academic program is less practical, and fails to direct students to knowledge and skills applications.

Because the examination forms have not changed, the teacher motivation is to make students have good knowledge in order to gain high results for exams. In Vietnam, the transfer exams, the entrance exams into the selected or specialized classes, and the college and university entrance examinations are often stressful<sup>7</sup>. For high school education, the race and examinations take place right from the time when children prepare to go

to the first grade. With higher levels of education, fierce competition is passed between candidates, between schools, between public and non-public schools. This competition leads to private tutoring and extra-learning. Even many scholars have discussed seriously about giving up exams for reasons such as examinations create too much pressure, a single exam does not evaluate all the learning process, or the exam questions do not comprehensively assess the learner's competencies and knowledge after a long learning process, and so forth.

MOET has produced schoolteacher standards as a base to assess teachers' performance in the whole system<sup>1</sup>. This policy affects the teacher education curricula in institutions of education because the training programs have to assure that they equip prospective teachers with all knowledge, skills, and attitudes to meet those national requirements. Furthermore, the current education reform requires institutions of education to innovate their training programs<sup>8</sup>. The new national curriculum focuses on competency-based education, a student-centered approach to develop students' multidisciplinary knowledge, creativity, and self-directed lifelong learning skills<sup>1</sup>. To succeed in the national education reform, the government emphasizes the role of teachers and affirms it is imperative to deploy innovation in institutions of teacher training.

The Circular No. 20/2018/TT-BGDĐT dated August 22, 2018 of the Minister of Education and Training has been prescribing professional standards of general education teachers<sup>2</sup>. As a rule, Vietnamese teachers' competences are grouped into 5 strands, 15 standard criteria as follows.

Standard 1. The dispositions of teachers, including two criteria: 1) Teacher ethics to preserve the quality, honor and prestige; 2) Teachers have exemplary style, scientific nature of work;

Standard 2. Professional development, including five criteria: 3) Professional development; 4) Develop teaching and education plans in the direction of developing students' dispositions and competencies; 5) Using teaching methods and education towards developing students' dispositions and competencies; 6) Checking and evaluating towards developing students' dispositions and competencies; 7) Counseling and student support;

Standard 3. Building an educational environment, including three criteria: 8) Building school culture; 9) Implement grassroots democracy in schools; 10) Implement and build safe schools, prevent school violence;

Standard 4. Developing the relationship between school, family and society, including three criteria: 11) Creating a cooperative relationship with parents or guardians of students and stakeholders; 12) Coordination between schools, families and society to implement teaching activities for students; 13) Coordination between schools, families and society to implement moral education and lifestyle for students;

Standard 5. Using foreign languages or ethnic languages, applying information technology, exploiting and using technological equipment in teaching and education, including two criteria: 14) Using foreign languages or Ethnic languages; 15) Application of information technology, exploitation and use of technological equipment in teaching and education.

### 3.2. Training teachers in pedagogical schools - a key factor to ensure the quality of education

Teacher education in Vietnam with developing learners' competencies orientation is to provide better quality schooling that fosters higher-order cognitive and behavioral skills (such as creative and critical thinking) for more young people. Accordingly, the Ministry of Education and Training (MOET) is working with K-12 educators on an ambitious reform to design coherent, focused, high-quality curricular standards that optimize learning and promote the competencies needed to master content and apply knowledge.

More recently, issues such as the formation of teacher identity in initial teacher education (ITE) and the role of research in connecting theory and practice and curriculum integration in ITE have been advocated. The initial teacher training which grants the right to teach in primary, middle, high schools, colleges and higher education institution is provided by university-level programs. As "21st century learners require 21st century teachers" initial teacher training programs should be developed around the desired outcomes for initial training along with the core values (dispositions).

The dispositions a learner of the 21st century is expected to have include patriotism, kindness, diligence, honesty and responsibility. The competencies include self-control, independent learning, communication and collaboration, problem-solving and creativity, as also core competencies in languages, mathematics, social sciences and natural sciences research, technology, computer science, aesthetics and physical capacity<sup>9</sup>.

Considering different aspects such as the philosophy of teacher education, the orientation model forms the dispositions and competencies for teachers so that they can respond flexibly and creatively with the responsibility of teaching and education in their school. The initial teacher training program aims to develop a professional teacher personality, requiring future teachers to have the competencies to revive, explore, innovate, collaborate, work with the community, in which attitude, values and whole-heartedness to the profession are more emphasized than pedagogical and professional competence.

### 3.3. The core values (dispositions) of the initial teachers

(1) The values toward learners (love for children, the belief that every child can learn, be committed to nurturing the potential of each child and value the diversity of children);

(2) The values of teachers (professionalism, towards developing competencies to meet high standards, eager to learn, perfect constantly, love career, ethics, adaptation and patience); and

(3) The values of serving the profession and community (collaborating with colleagues, having social responsibility and integration, having the spirit of learning and helping colleagues, having management skills).

## 4. Conclusion

Globalization and deep integration with the rapid development of science and technology are trends that have been taking place in all aspects of social life in every country, including Vietnam. This requires learners today to acquire the necessary competencies to meet the demands of 21st century human resources. In this context, the occupational characteristics of teachers must

have certain adjustments. The contingent of teachers is one of the factors that is crucial to the successful implementation of educational reforms. In the current situation of teacher training in Vietnam, improving the quality of teacher training to meet the requirements of educational innovation in the stage of international integration and industrial revolution 4.0 is urgently needed.

#### Address and Thanks

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書評

Book Review



## China A History Volume 2: From the Great Qing Empire through The People's Republic of China, (1644 - 2009)

Harold M. Tanner  
Hackett  
ISBN: 978-1603842051  
Hardback, 289 pages  
Published: 2010

The 21<sup>st</sup> century promises to belong to China. This huge nation of over a billion people is on track to overtake the United States to become the world's leading economic and military power. As such, students and educators need to know more about this complex country to understand the policies and guiding principles that the Chinese leaders are likely to follow over the next few decades as the power and influence of the People's Republic looks set to increase. In fact, as the book points out, China has always been one of the most, if not the most powerful and unified nation on earth, except for the crises of the Qing Dynasty in the late 19<sup>th</sup> century and the struggles of the early republic and the Guomindang in the first half of the 20<sup>th</sup> century. For this brief period, in historical terms, China saw parts of its territory invaded, and in some instances annexed, first by technologically-superior Western imperial powers and later by a Japanese government and military determined to expand their influence over their near neighbor.

Harold M. Tanner's book *China A History Volume 2: From the Great Qing Empire through The People's Republic of China, (1644 - 2009)* continues his history of China from the first volume *China A History Volume 1: From Neolithic Cultures to the Great Qing Empire*. Though published over a decade ago in 2010 before the outbreak of Covid-19 first reported in Wuhan, the passage of the new Hong Kong Security Law and China's increased assertiveness vis-a-vis Taiwan, the book still has much of relevance to inform its readers.

China's rise to a position of both regional and possibly world dominance began slowly after the chaos of Mao's Cultural Revolution and the death of the Great Helmsman in 1976. When the Communist Party first came to power the author explains how the CCP had a vision to "transform the lives of the Chinese people" to realize the dreams of Chinese reformers and revolutionaries since the late Qing dynasty. This vision was to transform China into "a wealthy, militarily powerful nation-state that could stand proud and defend its territory in the modern

world." By 2021 this vision has largely been achieved. How this remarkably change has come about after the chaos of almost constant war and revolution from the mid-19<sup>th</sup> century until 1976 is the main theme of Tanner's book.

A factional power struggle ensued after Mao's death mainly between Mao's widow Jiang Qing, who wished to continue her late husband's revolutionary line of "class struggle" and a group of CCP elders and PLA generals headed by Deng Xiaoping, who had had quite enough of revolution and wished instead to achieve the so-called "Four Modernizations" in agriculture, industry, science/technology and national defence. Deng's faction won out. The Chinese people in the main were also tired of revolution, especially the young, many of whom had been sent down to the countryside during the Cultural Revolution and were now returning to the cities. One of these young men is now China's leader, Xi Jinping, who in total spent 7 years exiled in the Chinese countryside as part of Mao's Down to the Countryside Movement.

Deng Xiaoping came to power promising to change tack from class struggle to economic revitalization. This was the beginning of the so-called "Building Socialism with Chinese Characteristics" period from 1978-1989. Major economic reforms included restoring markets and loosening government control of the economy as well as encouraging foreign trade and investment as well as tourism. Farmers began to cultivate some of their land for these new free markets, and related village industries also sprang up. In the cities, new economic reforms from the mid-1980s enabled people to set up their own businesses, among these new entrepreneurs were a substantial number of women. Huawei, now a massive global communications and electronics manufacturer, began as a small business in 1987, for example. Deng's policy of "opening to the outside" also spurred the phenomenal growth of such cities as Shenzhen and Zhuhai in Guangdong Province and Xiamen in Fujian Province that became Special Economic Zones (SEZs) open to foreign



investment and trade. In the SEZs, Chinese firms could produce export goods in joint partnerships with foreign firms. This has become the model for much of China's incredible often double-digit economic growth of the 21<sup>st</sup> century in particular. Reforms were also carried out in the fields of law and politics but not with the aim of creating a Western-style multi-party democracy but to "preserve and enhance the stability of the single-party state." A more lenient policy in the fields of art and culture saw a flowering of new Chinese art, music and literature. Ai Wei Wei, the Chinese artist, now living in exile in the West, has a similar story to so many men of his generation. His father had been exiled for supposed political faults and Ai Wei Wei and his family were not able to return to Beijing until the death of Mao. Deng's political reforms allowed him to leave China to study and live in the USA until 1993. He prospered on his return to China under the new freedoms granted to artists until running foul of the CCP in 2011.

The new economic forces unleashed by Deng's reforms also increased social tensions in the major cities. Corruption on the part of CCP cadres and their children, who as a group seemed to be gaining the most personal reward from the new reforms, increased the anger of many students, professionals and workers. This anger came to a head in the Beijing Tiananmen Square protests of 1989. These were violently crushed and for a time more conservative elements in the CCP held sway until Deng's "Southern Tour" of 1992, when the now ailing leader took a tour of the SEZs, Shanghai and other coastal cities that had prospered due to his policies.

Deng's death in 1997 did not stall economic reform in China. By the end of the century the country as a whole had changed dramatically, though not all areas or sectors of the population had seen equal improvement. There was by now a growing gap between rich and poor.

Tanner's book describes the changes not only on the Chinese economy but also in the architecture of its cities and the lifestyles of its people. In the late 1980's Shanghai had only one building over 20 floors, by 1999, just a decade later, this had risen to a staggering 1,350. A huge construction boom was underway. In China's major urban centres, bicycles and Mao suits gave way to motor vehicles and Western and Japanese fashions. China has now become a huge market for both Western and Japanese brands and services.

However, the burgeoning middle classes and the CCP were not interested in "extending freedoms to speech, action or news" that might undermine the position of the

Communist Party and its territorial integrity. As a result, the author notes that opposition in Tibet, among the Uighurs in Xinjiang or reformers in Hong Kong are met with the "upmost severity."

The book ends with an analysis of China's new position in the world. China's economic miracle of the last 50 years means its economy is intricately linked with that of the outside world. To maintain growth China needs access to foreign raw materials and new markets and to assert its global political and economic interests a modern military has been prioritized by the leadership. China's relationship with the USA is the most complex of its foreign relations. On the one hand it needs access to American markets but on the other hand it seeks to avoid American criticism of its human rights record. The issue of Taiwan is a source of potential tension between the two superpowers. The book concludes with a series of questions about China's future direction. What is certain is that nothing is certain but China's future direction now matters to us all.

**「名城アジア研究」  
投稿規則**

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● **名城大学アジア研究センター**

発行日 / 2022年3月31日  
編集・発行 / 名城大学アジア研究センター

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Date of issue / March 31, 2022  
Edit / Meijo Asian Research Center

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MEIJO  
ASIAN  
RESEARCH  
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2022.03

VOL.11 NO.1

名城大学

