**Journal of Materials Science and Applied Energy**

Journal home page: jmsae.snru.ac.th

# Effect of Curing and Sodium Silicate to Sodium Hydroxide Ratio on Physical Properties of Bagasse ash Based-Geopolymer Material

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**Received** 3 April 2020; **Revised** 3 April 2020; **Accepted** 18 August 2020

## Abstract

For this research, bagasse ash from landfills was used as a raw material in producing geopolymer mortar to decrease negative environmental to dispose of waste material. The paper reports a study of the compressive strength and porosity of geopolymer mortar containing ground bagasse ash (GBGA). GBGA based-geopolymer mortar with sodium hydroxide (NaOH) of 15 M, constant liquid to GBGA ratio, and similar flow were used for the tests. Extra water was used to improve the workability of geopolymer mortar GBGA. Sodium silicate ($Na_2SiO_3$) and sodium hydroxide (NaOH) ratio were used as alkali activator solutions. The effects of the temperature of curing and alkali activator solutions on compressive strength and porosity were investigated. Test results indicate that extra water was needed for all mixes. The geopolymer mortars GBGA with good strengths were obtained with the alkali activator solutions ratio by weight of 2.50. At curing of 75 °C, the reasonable compressive strengths of 21 MPa were obtained. At curing of 75 °C, the reasonable compressive strengths of 6 – 21 MPa and porosity of 10 – 24 % were obtained.

*Keywords:* Bagasse ash; Compressive strength; Geopolymer material; Mortar; Waste material



## Introduction

Waste ashes or biomass ash from landfill such as rice husk ash, fly ash and bottom ash is popular for use in concrete or mortar work. These materials are pozzolanic material for using as cementitious for producing concrete or mortar [1 – 8]. There was some study research about pozzolanic materials used in concrete and mortar work. This is due to those pozzolanic materials are the material that has the main chemical composition of silica ($SiO_2$) or silica ($SiO_2$) and alumina ($Al_2O_3$) ($SiO_2$+$Al_2O_3$), or amorphous silica and alumina ($SiO_2$/$Al_2O_3$) contained in the materials [9, 10].

When combining a Portland cement with water, the hydration reaction will occur, which this reaction results in the cement paste coagulation and adhesion of Portland cement as the cementitious materials [10]. The products that come from the hydration reaction are calcium hydroxide. In addition, if the mix of cement has pozzolanic material substance combined such as bottom ash and rice husk ash, that is silica oxide ($SiO_2$) and alumina oxide ($Al_2O_3$), which the pozzolanic material substance will react with the base that is calcium hydroxide ($Ca(OH)_2$). Therefore, this is the improvement of a concrete or mortar property in the durability aspect [1− 8, 10].

The geopolymer materials are cementitious that has a chemical structure in according to the structure of polysialate that have silica oxide ($SiO_2$) and alumina oxide ($Al_2O_3$) to create aluminosilicate (Si − O − Al − O) [5, 9, 11− 16] as new smart materials, which have good physical property. The atomic of $SiO_2$ to the $Al_2O_3$ ratio will indicate the property of the material and using the category of those materials.

Bagasse ash is a biomass material from sugar mills in Thailand. Bagasse ash is waste material from landfills which not to utilize in anything and affecting the environment (approximately 15 − 16 megatons a year [1, 17]). Bagasse ash is waste materials that have the main chemical composition of silica ($SiO_2$) and alumina ($Al_2O_3$) contained in the material [1, 6, 16]. The aim of this research is to utilization the bagasse ash as a based-geopolymer material in producing mortar without Portland cement. Using bagasse ash in concrete or mortar not only has the potential to save cost and reduce the greenhouse gas emission but also improves the mechanical properties of the cement matrix.

## Materials and Methods

### *Materials*

The materials used in this study indicated as following:

#### *Bagasse Ash*

In this work, the raw material is ground bagasse ash (GBGA) for making geopolymer mortar without Portland cement. Bagasse ash (GBGA) was ground with ball mill for decrease particle size. The fineness and particle size of this material of 10 − 18 µm was defined by sieve standard No. 325.

#### *Natural Sand (Fine Aggregate)*

For fine aggregate, the natural sand was used in this research. The density and modulus of the fineness of natural sand are 2.40 and 2.54, respectively.

#### *Sodium Hydroxide (NaOH)*

The concentration of sodium hydroxide (NaOH) of 15 M was prepared by mixing sodium hydroxide pellet with RO water then kept in the chamber control temperature for 24 hrs before used as the liquid for alkali activator solutions.

#### *Sodium silicate ($Na_2SiO_3$)*

Sodium silicate ($Na_2SiO_3$) was used as liquid for alkali activator solutions ($Na_2O$ = 15.32 %, $SiO_2$ = 32.87 % and $H_2O$ = 51.81 % by mass). In addition, the $Na_2SiO_3$ to NaOH ratio was used as the liquid for alkali activator solutions. This work controls the quality of solutions to be the same.

*Sodium Silicate ($Na_2SiO_3$) to Sodium Hydroxide (NaOH)*

In this research, the ratio of $Na_2SiO_3$ to NaOH by GBGA of 0.50, 1.50, and 2.50 were used as alkali activator solutions.

*Physical Properties and Chemical Compositions*

Physical properties and chemical compositions of ground bagasse ash (GBGA) were determined by using Particle size distribution, Blaine fineness, Sieve standard No. 325, X − ray fluorescence (XRF) and X − ray diffraction (XRD), respectively.

*Testing*

*Mix Design and Curing*

Materials of geopolymer were producing with ground bagasse ash (GBGA) to sand ratio 2.75. The concentration of sodium hydroxide (NaOH) of 15 M (Molar) and the $Na_2SiO_3$ to NaOH ratio by GBGA of 0.50, 1.50, and 2.50 were defined in this research. The ratio of $Na_2SiO_3$ mixed with NaOH to GBA of 0.67 was used at constant. The production of mortar was mixed in the laboratory at temperature 25 °C for quality control. For the workability test, the flow standard in accordance with ASTM C230 was considered in this work [18]. For mixing mortars, the geopolymer mortar GBGA was compacted by a table vibration machine. For preventing moisture in specimens, geopolymer mortars GBGA wrapped with vinyl sheet were used to protect moisture loss in the specimens. After a wrapped, the geopolymer mortars GBGA were then put in the chamber for control temperature. The sample kept in the chamber for control temperature at 45, 75, and 90 °C for 1 day until the test. In Table 1, shows the mixes of geopolymer mortars GBGA.

**Table 1** Mix proportions of geopolymer mortar GBGA.

| **Samples** | **Ratio of $Na_2SiO_3$ to NaOH** | **Molar of NaOH** | **Flow (%), accordance with ASTM C230 [14]** |
|---|---|---|---|
| 15M-0.50Si/Na | 0.50 | 15 | 110 ± 5 |
| 15M-1.50Si/Na | 1.50 | 15 | 110 ± 5 |
| 15M-2.50Si/Na | 2.50 | 15 | 110 ± 5 |

*Compressive Strength and Porosity Test*

The mortar GBGA of the dimensions of 50 × 50 × 50 $mm^3$ cube molds was used in the standard of ASTM C109 [19]. At of the age of 7 days of mortar, GBGA was defined for considered compressive strength. The porosity test was applied to instructive vacuum pump testing, in which there have some researches that used this method [2, 16]. Preparing the dimensions of 50 × 50 × 50 $mm^3$ cube molds by following the ASTM C109 standard were used [19]. After curing mortar for 24 hrs (in the oven), the process will have replication in cool down in the air, and then test the porosity at ages 7 days. Taking the sample of mortar in desiccators under vacuum pump for three hours to render the porosity become air space and fill the distilled water, then measure the quantity of porosity unit as a percentage (%) by the porosity quantity would be calculated by equation (1);

$$p = \frac{(W_a - W_d)}{(W_a - W_w)} \times 100 \quad (1)$$

When determine $p$ is the porosity of the example by vacuum saturated to be the percentage, $W_a$ is the weight of the sample that saturated with water as the gram unit (g), $W_d$ is the weight of dried sample in control oven after 24 hrs at 100 ± 5 °C as gram unit (g), $W_W$ is the sample in the water as the gram (g)

*Symbol of Specimens*

The symbols of the specimens are given in Table 2 (as the description below).

**Table 2** Symbols of the specimens.

| Samples | Description |
|---|---|
| 15M − 0.50Si/Na | NaOH = 15M − ratio of $Na_2SiO_3$ and NaOH = 0.50 |
| 15M − 1.50Si/Na | NaOH = 15M − ratio of $Na_2SiO_3$ and NaOH = 1.50 |
| 15M − 2.50Si/Na | NaOH = 15M − ratio of $Na_2SiO_3$ and NaOH = 2.50 |
| 15 M | Concentration of NaOH = 15 Molar |
| $Na_2SiO_3$ | Sodium silicate ($Na_2SiO_3$) |
| NaOH | Sodium hydroxide (NaOH) |

## Results and Discussion

*Characteristics and Chemical Composition of GBGA*

The physical properties of GBGA are shown in Table 3. This works shown that the fineness and density of GBGA were $1.25 \times 10^4$ $cm^2$ $gm^{-1}$ and 2.24, respectively. The particle size distribution of GBGA is given in Fig. 1. It was found that the median particle size of GBGA is 18 µm. The main composition of GBGA was 65 % of $SiO_2$, 5 % of $Al_2O_3$, 3.20 % of $Fe_2O_3$, 9 % of CaO, and loss on ignition (LOI) of 18 %, respectively. The results indicated that the GBAGA is pozzolanic material due to the sum of the main composition was slightly higher than 70 % [9]. Fig. 2 is the pattern of XRD of GBGA. The pattern of XRD confirmed that GBGA is mainly amorphous silica (Quartz at 26 of 2Theta). SEM photograph (see Fig. 3) shows the photography of GBGA, where it has the polygon shape with a different size in the range of 1 − 50 µm. This work similar finding was also reported by some researchers [1 − 3].

**Table 3** Physical properties of ground bagasse ash (GBGA).

| Physical properties | Ground bagasse ash |
|---|---|
| Median particle size (µm), $d_{50}$ | 18 |
| Sieve standard No. 325 (%) | 3 − 5 |
| Density | 2.24 |
| Fineness of Blaine ($cm^2$ $gm^{-1}$) | $1.25 \times 10^4$ |

**Table 4** Chemical components of ground bagasse ash (GBGA).

| **Compositions** | **Ground bagasse ash** |
|---|---|
| $SiO_2$ | 65.00 |
| $Al_2O_3$ | 5.00 |
| $Fe_2O_3$ | 3.20 |
| CaO | 9.00 |
| $K_2O$ | 2.00 |
| $SO_3$ | 0.90 |
| LOI | 18.00 |
| $SiO_2 + Al_2O_3 + Fe_2O_3$ | 73.20 |

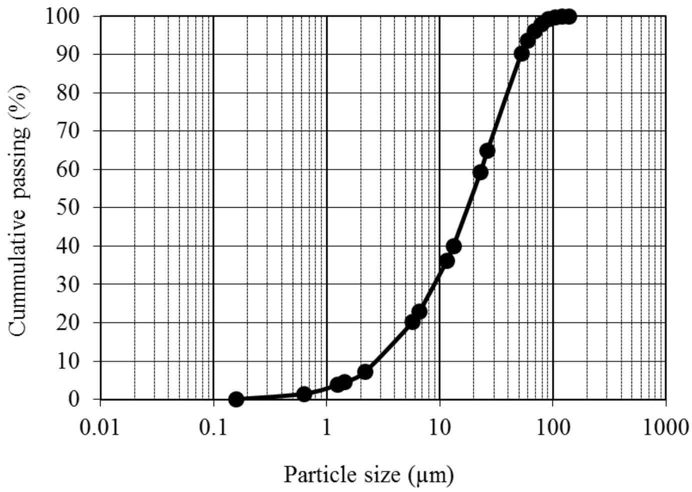


**Fig. 1** Particle size distribution of ground bagasse ash (GBGA).

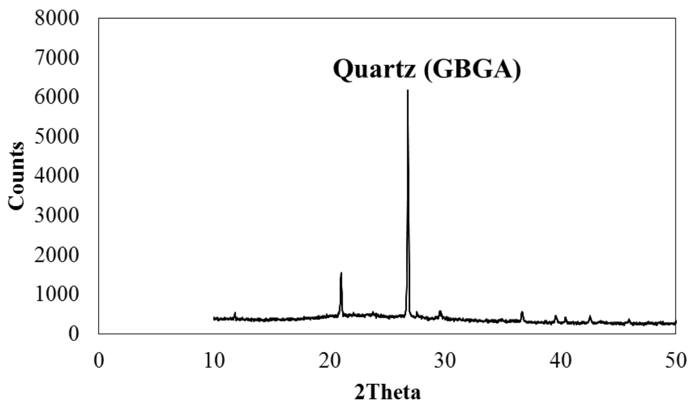


**Fig. 2** Pattern of XRD for ground bagasse ash (GBGA).

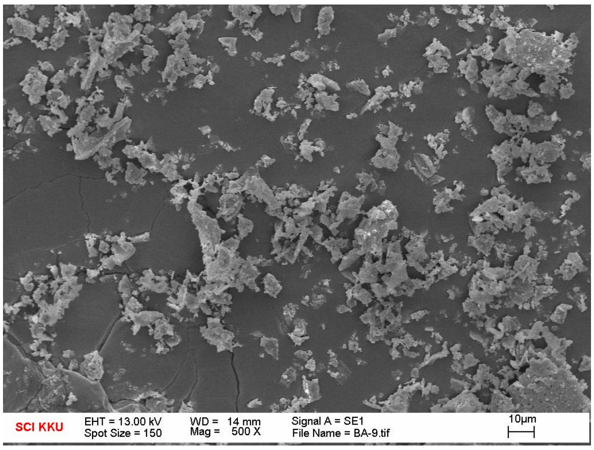


**Fig. 3** SEM photograph of ground bagasse ash (GBGA).

*Workability of Geopolymer Mortar GBGA*

In Table 5, shows the workability of the geopolymer mortar GBGA with 15M of NaOH and ratio of $Na_2SiO_3$ to NaOH of 0.50, 1.50 and 2.50. This results found that the flow of geopolymer mortar GBGA to decreases when an increase in ratio of $Na_2SiO_3$ to NaOH. However, extra water is to be increased. That is means that in order to obtain the 113, 109 and 108 % of flow, extra water of 3.80, 4.20 and 4.60 % by weight of GBGA was needed. This work similar finding was also reported by some researchers [11, 14 – 16]. An increase in the ratio of $Na_2SiO_3$ to NaOH resulting in decreases the workability of the mixes [11, 16]. This is due to the alkali activator solutions from $Na_2SiO_3$ have viscosity is very high resulting in difficult workability of geopolymer mortar GBGA [11, 16].

**Table 5** Workability of the geopolymer mortar GBGA.

| Ratio of $Na_2SiO_3$ to NaOH | Molar of NaOH | Workability of Flow (%) | Extra water (% of GBGA) |
|---|---|---|---|
| 0.50 | 15 | 113 | 3.80 |
| 1.50 | 15 | 109 | 4.20 |
| 2.50 | 15 | 108 | 4.60 |

*Effects of $Na_2SiO_3$ to NaOH Ratio on Compressive Strength and Porosity*

The compressive strength results of geopolymer mortar GBGA with various ratio of $Na_2SiO_3$ to NaOH at a curing with chamber control of 45, 75 and 90 °C are shown in Fig. 4. The results indicated that the compressive strength of geopolymer mortar GBGA with ratio of $Na_2SiO_3$ to NaOH at 2.50 was higher than those with ratio of $Na_2SiO_3$ to NaOH of 1.50 and 0.50, respectively. The compressive strength of geopolymer mortar GBGA is good with increase in $Na_2SiO_3$ to NaOH ratio to 2.50. This is due to the increase in ratio $Na_2SiO_3$ to NaOH also results in the increase Na ions content of the mixture [5, 12 – 16]. These results found that the effect of alkali activator solutions from $Na_2SiO_3$ and NaOH on the compressive strength of mortars is therefore very significant [11 – 16]. The alkaline liquids that consist of silicate solution will increase reactive ratio when compared with the alkaline liquids with only hydroxide [5, 12 – 16]. The increased concentration of NaOH results in decreased Na ions in the system which was important for the geopolymerization as Na ions were used balanced the charges and formed the alumino-silicate networks [5, 12 − 16]. This work similar finding was also reported by some researchers [5, 12, 16].

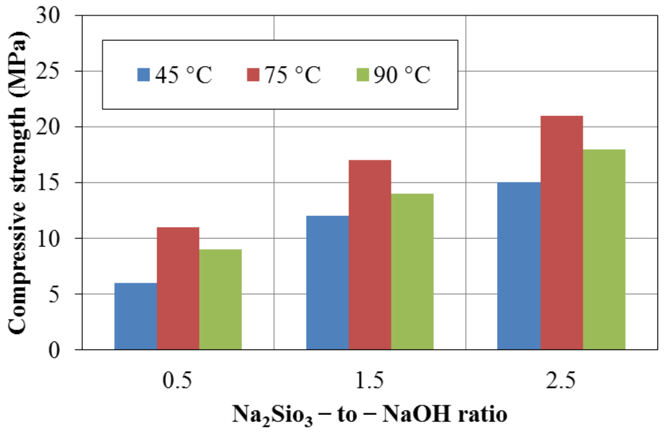


**Fig. 4** Compressive strength of geopolymer mortar GBGA with various $Na_2SiO_3$ to NaOH ratio at the age of 7 days.

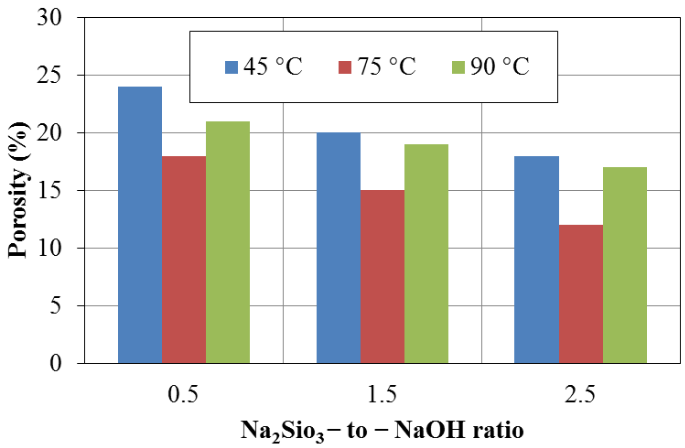


**Fig. 5** Porosity of geopolymer mortar GBGA with various $Na_2SiO_3$ to NaOH ratio at the age of 7 days.

The results of porosity by various ratio of $Na_2SiO_3$ to NaOH are shown in Fig. 5. It was found that the porosity of geopolymer mortar GBGA of ratio $Na_2SiO_3$ to NaOH at 2.50 was low while the porosity of geopolymer mortar GBGA of ratio of 1.50 and 0.50 was high. This is due to the GBGA have silica oxide content is high which contained in material. These results found that the effect of $Na_2SiO_3$ to NaOH ratio is main factor of porosity [16].

*Effects of Curing on Compressive Strength and Porosity*

Compressive strength of geopolymer mortar GBGA with the various ratios of $Na_2SiO_3$ to NaOH at curing with chamber control of 45, 75, and 90 °C are shown in Fig. 6. Test results indicated that the compressive strength of geopolymer GBGA increases with the uses in curing at 75 °C for the oven. In addition, test results found that the compressive strength of geopolymer mortar GBGA decreases with the use in curing at 90 °C for the oven. This is due to when the temperature was high at 90 °C resulting in the loss of moisture in mortars [11, 16]. Therefore, it should prevent moisture loss of mortars is therefore very significant. This work found that the maximum compressive strength of 21 MPa was improved with maximum temperature at 75 °C for oven [11, 16].

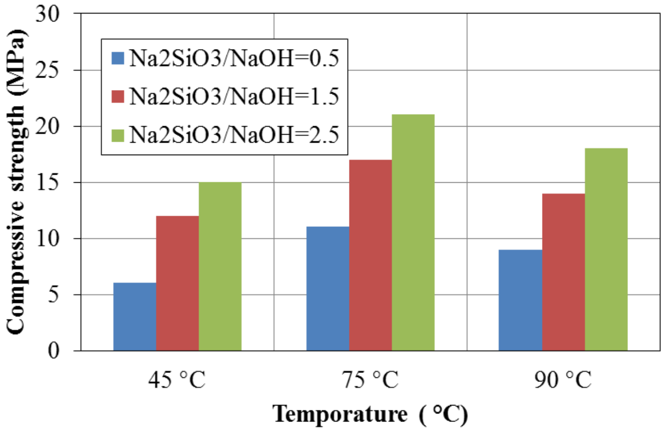


**Fig. 6** Compressive strength of geopolymer mortar GBGA with chamber control of 45, 75 and 90 °C at the age of 7 days.

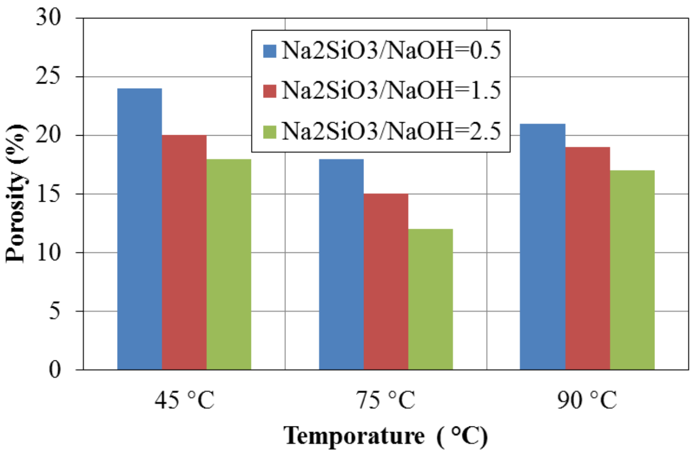


**Fig. 7** Porosity of geopolymer mortar GBGA with chamber control of 45, 75 and 90 °C at the age of 7 days.

The results of porosity by the different temperature of curing are shown in Fig. 7. It was found that the porosity of geopolymer mortar GBGA decreases with the uses in curing at 75 °C for the oven. At curing of 75 °C, results indicated that the reasonable compressive strengths of 6 – 21 MPa and porosity of 10 – 24 % were obtained (see Fig. 8). Therefore, the porosity is the main factor of compressive strength.

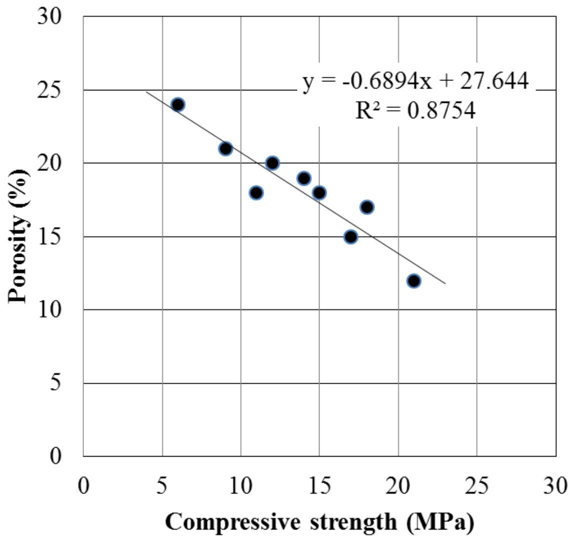


**Fig. 8** Compressive strength and porosity of geopolymer mortar GBGA.

## Conclusion

Based on the obtained data, it is possible to get medium – strength geopolymer mortar with the use of the ground bagasse ash (GBGA) with high fineness. Curing temperatures and the ratio of $Na_2SiO_3$ to NaOH also have an effect on compressive strength and porosity of geopolymers mortar GBGA. A strong geopolymer mortar GBGA with low porosity and high compressive strength can be produced at a curing temperature of 75 °C. High ratio of $Na_2SiO_3$ to NaOH at 2.50 produces a geopolymer with a good compressive strength comparing to that with a ratio of $Na_2SiO_3$ to NaOH of 0.50 and 1.50. The ground bagasse ash (GBGA) could be used as the geopolymer materials because there are chemical compositions such as silica or silica and alumina are the main chemical composition. Some of the previous work studied about the use of blended Portland cement mortar containing bagasse ash in producing concrete. On the other hand, this work found that the ground bagasse ash (GBGA) could be used as the materials in repairing concrete structure without Portland cement. The knowledge, in orders of repair and durability of concrete, will be beneficial for applying this material in the future.

## Acknowledgement

This work was financially supported by Rajamangala University of Technology Rattanakosin (RMUTR). Lab of Department of Civil Engineering, Faculty of Engineering, RMUTR, the Sustainable Infrastructure Research and Development Center (Khon Kaen University), Thailand and Toray Science Foundation (TTSF).

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