Current solid propellant research and development in Indonesia and its future direction

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Abstract. This paper contains a study on the development of propellant research in Indonesia to support the mastery of rocket technology. The objective of this study is to formulate the direction of the propellant research that must be done by Indonesia. For such purpose, 31 relevant literatures are reviewed and discussed. The discussions include the development of propellant technology in the world, and the position of propellant research in Indonesia, which mean to support the development of sounding rocket and satellite orbiter. This study identified the challenges that must be addressed by propellant researchers in Indonesia, in order to pursue the mastery of up to date propellant technology as in the developed countries.

1. Introduction
The development of rocket technology in Indonesia is directed to civilian and defense interests [1]. The National Institute for Aeronautics and Space (LAPAN) aims to develop a rocket to launch its own satellite in 2040 [2], while the Research and Development Agency under Indonesian Ministry of Defense developed a rocket to support national defense. Mastery of rocket technology in Indonesia faces the difficulty in obtaining the transfer of technology and international references because rocket technology has characteristic of dual-use (can be used for civil and military purposes). The countries which are developing rocket incorporated in the MTCR (Missile Technology Control Regime) restrict the transfer of rocket technology, while Indonesia politically decided not to join MTCR. Therefore, mastery of rocket technology must be done independently. The mastery of long-range satellite rocket spacecraft is done through the development of Rocket RX-320, RX-420, and RX-550. This pattern of development is similar with the development model of a Japanese satellite orbiter rocket that developed solid rockets of 310 and 520 mm diameters for a height of 400 km [2].

Rocket is a high-speed launch vehicle, consists of rocket bodies, propulsion motors, and payloads. The rocket motor as a source of rocket propulsion consists of a motor tube with its nozzle and propellant as fuel [3]. The propellant is a rocket fuel that generates enormous thrust energy to drive a rocket. Propellant technology is one of the key mastery of rocket technology. The development of propellant for defense begins with the construction of a nitroglycerine plant by DAHANA Co. Ltd. in 2016 in cooperation with Indonesian Ministry of Reseach and Tehnology and Ministry of Defense. The double base propellant plant for munitions and defense rockets is being pioneered and targeted for completion by 2020. The development of composite propellants for sounding rockets and satellite launchers is carried out by LAPAN [2].
The direction of rocket propellant research in the world today is the application of energetic and insensitive material, longer viscoelasticity, reusability, propellant, and green propellant [4]. New developments in terms of propellant formulations and process technology have been explored. The development of composite propellant research in the world and Indonesia is presented in this paper. The purpose of this paper is to study the direction of propellant research in Indonesia in order to master the propellant technology independently and catch up with developed countries. The study was done by reviewing 31 relevant literatures.

2. Development of Solid Propellant Research for Rocket

2.1. Role of propellant in rocket technology

The rocket as a launch vehicle comprises a rocket body in which there is a propulsion and charge motor, as shown in figure 1 [5]. The propulsion motor comprises a motor tube, nozzle as the exit of combustion gas, and propellant as the main fuel. Propellant consists of oxidizing agent as a source of oxygen and fuel as well as binder. The propellant combustion reaction produces converted combustion energy resulting in a rocket thrust force [5].

![Rocket components](image)

Figure 1. Rocket components.

The characteristic of the propellant is the specific impulse (Isp) which denotes the propellant energy, the burning rate representing the ballistic property, the pot life value (the time range required of a polymer blend reaching the effective viscosity) expressing the propellant viscoelasticity, tensile strength and hardness which express mechanical properties, as well as homogeneity, cracking, and porosity that express physical properties.

The technology development is divided into three groups, namely countries that developed early rocket technology (USA, USSR, and Germany), countries that have acquired technology from the developed countries and have been independent in rocket technology (UK, China, India, Korea South, Iran, Brazil, South Africa, Turkey), and developing countries that currently acquiring the technology like Indonesia. Developed countries in the field of rockets have propellant production facilities and raw materials supporting industries in their countries. The third layer rocket developers generally have propellant manufacturing facilities, but some components are supplied by large countries such as China and Korea [6][7].
2.2. **Propellant formulation**

Solid rocket propellants are divided into composite propellants, double base propellants, and combination of both (composite modified double base). The double base propellant has a very fast burnout rate and reduced smoke, so it is widely used for rocket boosters and shortly defense rockets. Composite propellants have enormous energy so are widely used for long-range rocket launchers and defense sustainer rockets. The main components of composite propellants are oxidizing, binder, solid fuel, modifier, plasticizer, and other additive compounds. The oxidizing agent is a decomposed high oxygen-containing compound producing enormous energy, the binder is a composite matrix-forming resin as well as a propellant fuel, a solid fuel as a material for increasing combustion temperatures, a modifier is a compound used to regulate combustion rate, a plasticizer is a compound to regulate viscoelasticity, and additive compounds to improve the physical properties of propellants [5][6][7]. The most commonly used oxidizing agent is Ammonium Perchlorate (AP). The main material of the binder is a polybutadiene compound such as hydroxyl terminated polybutadiene (HTPB) and carboxy terminated polybutadiene (CTPB). The main materials of solid fuel are metals such as aluminum (Al) and magnesium (Mg). Most of the current composite propellants are developed based on AP/HTPB/Al. The main components of double base propellant are nitrocellulose and nitroglycerine. Both materials have a function as oxidizer as well as fuel. Some materials are added to increase the energy (high energetic material) and to improve its mechanical properties (modifier).

The direction of solid rocket propellant research in the world today is directed to higher energetic, reusable, and green propellant [4][8][9][10]. To increase the burning energy, several new energetic materials have been developed to substitute the oxidizer, binder, and other additives. High-energy oxidizers have been developed based on insensitive organic compounds such as ammonium perchlorate (AP), ammonium dinitramide (AND), hydrazinium nitroformate (HNF), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) octahydro1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and hexanitrohexaazaisowurtizitane (CL-20). The compound has a very high combustion heat as shown in table 1 [4].

### Table 1. Characteristic of composite propellant oxidizer [4].

| Oxidizer | Heat of formation (kJ/mole) | Oxygen balance (%) | Density (g/cm³) |
|----------|----------------------------|--------------------|----------------|
| AP       | -298                       | 35                 | 1.9            |
| ADN      | -151                       | 26                 | 1.8            |
| HNF      | -71                        | 13                 | 1.9            |
| RDX      | 63                         | -22                | 1.8            |
| HMX      | 76                         | -22                | 1.9            |
| CL-20    | 454                        | -11                | 2.1            |

Modifiers for regulating propellant burning rate (ballistic properties) have been developed to replace copper cordhits commonly used for double base propellants. Currently, the development of many modifiers switches to a more stable ferosene (Fe₂O₃) and can increase the burning rate with stability up to 8 percent [4][5][11]. HTPB-TDI polymer resin is the dominant propellant binder used because it has good mechanical properties. HTPB is a non energetic compound that has low energy. Efforts to raise the combustion energy have been carried out by substitution of high-energy binder materials from azido-type polymers such as glycidyl azide polymer (GAP) and poly-azidomethyl oxetane (P-BAMO), poly azidomethyl methyl oxetane (PAMMO) as well as nitrate polymers, polyglycidyl nitrate (PGN) and nitratomethyl methyl oxetane (NIMMO). The polymer has a very high energy as shown in table 2 [4].

### Table 2. The characterized energetic binder for composite propellant [4].

| Energetic binder | Heat of formation (kJ/mole) | Density (g/cm³) | Oxygen balance (%) | Glass transition temperature (°C) |
|-----------------|----------------------------|----------------|--------------------|----------------------------------|
| GAP             | +117                       | 1.30           | -121               | -45                              |
The development of energetic binders with their relatively good mechanical properties contributes to the increase of the HTPB energy by the nitration process resulting in N-HTPB. N-HTPB compounds have advantages of having mechanical properties similar to HTPB. This compound has good mechanical properties, higher energy, and is less harmful (stable). Some propellant with N-HTPB 10% nitro content can increase the 8% propellant energy without decreasing its mechanical properties, as shown in table 3 [4]. Another advantage is that it does not require special treatment for N-HTPB in the propellant process.

Table 3. Effect of N-HTPB to calor value of propellant [4].

| % N-HTPB | Average calorific value, J/g |
|----------|-----------------------------|
| 0        | 6417                        |
| 1        | 6605                        |
| 2        | 6630                        |
| 2.5      | 6772                        |

N-HTPB rubber content influences the character of linear burning rate changes corresponding to pressure for three distinctive pressure ranges for propellants. The use of rubber N-HTPB improved the ballistic properties of the composite solid propellants. The addition of a small amount of rubber N-HTPB about 2% can affect the energy and the ballistic properties of the composite solid propellants.

Plasticizer added to the binder to improve mechanical properties and easy to process. Usually used is from the class of phthalate such as dioctyl adipate (DOA) and isodecyl pelargonate (IDP). Several high-energy plasticizer compounds have been developed compounds containing nitro, azido, nitrate group are emerging as potential plasticizer candidates such as triethylene glycol dinitrate (TEGDN), 1,2,4 butane triol trinitrate (BTTN), etriol trinitrate (TMETN), nitroethyl nitramine (NENA), 2,2 dinitro propyl formal bus (BDPF), bis 2.2 dinitro propyl acetel (BDPA), diethylene glycol bis (azido acetate) (DEGBAA), trimethyl nitromethane triazido acetate (TMNMTAA), pentacyrthritol tetraakis azido acetate (PETAA ), 1,2-diazido-3 fluoro dinitro ethoxy propane (DAFP), 1,3-diazido isopropyl fluoro dinitroethyl formal (AFFO), and Triphenyl Bismuth (TPB) as shown in table 4 [4][12].

Table 4. Characteristic of energetic plasticizer.

| Name     | m.p. (°C) | Density (g/cm3) | dHf (kcal/mole) | Energy of comb (cal/mole) | Oxygen balance (%) |
|----------|-----------|-----------------|-----------------|--------------------------|-------------------|
| TEGDN    | -23       | 1.5             | -149            | 823                      | -67               |
| BTTN     | -6        | 1.49            | -99             | 523                      | -17               |
| TMETN    | 182       | 1.3             | -99.6           | 674                      | -34.5             |
| Ethyl NENA | 5         | 1.3             | -34             | 3549                     | -67               |
| Propyl NENA | -        | -               | -37             | 4132                     | -87               |
| BuNENA   | -9        | 1.2             | -40             | 4630                     | -                 |
| BDPF     | -18       | 1.39            | +484            | -                        | -51               |
DEGBAA  -  1  -329  -  -100
TMNMTAA  -  1.4  -230  -  -72
PETAA  -  1.4  -215  -  -89
DAFP  -  1.4  +57  -  -
AFFO  -  -  +23  -  -

Propellant with the new composition of the Ukrainian Yuzhnoye company has a specific impulse (Isp) reaching 280 seconds. The propellant used for rockets made by Brazilian Avibras and Hanwa Korea companies has a specific impulse reaching 249 seconds [13]. This data can be shown in table 5. LAPAN has not been able to adopt the use of new energetic materials due to the limited condition of its processing equipments. Propellant formulas with some new materials have been explored and can be obtained by propellant with Isp reaching 224 seconds [13]. The addition of plasticizer is used to prolong the pot life so that the propellant becomes homogeneous [13]. The propellant used for S-310 and S-510 rockets (Japanese rocket) has a pot life of 7 days; Hanwa Korea's propellant production company has a pot life of more than 7 hours. The LAPAN propellant formula, which originally had a 2-hour pot life, has been upgraded to 4-hours one using DOA, DOS, and TPB materials [13]. In order to improve the quality of propellant, the use of alternative materials has been explored. Some alternative binder materials that have been explored as HTPB's substitutes such as rubber, asphalt, Crude Palm Oil (CPO), and castor oil, as well as materials of other oxidizers for substitution of AP such as ammonium nitrate [23][24][25]. The results show that natural rubber, asphalt, and CPO are not good enough for propellant binder. Castorized castor oil has the potential to be developed into a propellant binder with the addition of dialcohol [14].

Table 5. Performance of propellant LAPAN.

| Item             | LAPAN     | Others        |
|------------------|-----------|---------------|
| Isp, sec         | 224       | 249-280       |
| Pot life, hrs    | 4         | 8-20          |
| Material         | AP/HTPB/Al| More than 12 component |
| Mass gravity, g/cm³ | 1.60-1.67 | 1.70-1.75     |
| Homogeneity, %   | 75% (calculated) | 95%           |

2.3. Composite technology
Composite propellants consist of oxidized solids granules and solid fuel placed in an organic polymer matrix. Composite propellant research strives to reach a maximum solid content with high density. High-density propellants will produce more oxidizing and solid fuel content, so their performance will increase significantly. The development of composite propellants is now using three-trimodal oxidizing compositions, i.e., 100, 200, and 400 mesh sizes to obtain more solids in a composite matrix. Based on free volume theory it is shown that trimodal propellant can increase the solid content of 7 percent of bimodal propellant use. Composite propellants for satellite orbiting rockets typically have a density above 1.7 g/mL [15][16]. The development of nanotechnology over the last 20 years has been adopted in propellant technology with the use of oxidizer and aluminium in nano size to enhance the solid content of composite propellants. The use of nanoscale oxidizers in propellant composition can increase 6% of solid content, so the propellant performance increases by 5% [17][18]. The nano technology of aluminium on composite propellant is the new concern of composite propellant research in the last ten years and may be can be applied in several next years. The shape and size of the oxidizing powder has an effect on the total time of the oxidizer. The irregular shape will give the powder a smaller position than the spherical shape. The ideal grain shape is a spherical shape with low porosity. New studies show that oxidators are shaft and coated with silant that have low energy.

Composite propellants with slurry ingredients are sometimes difficult to be stirred perfectly, meanwhile solid particles can be distributed evenly (homogeny). One of them is the paraglastic nature
of the metal that is easily agglomerated because of its very small size. Currently the focus of the research is the use of oxidized coated with aluminum, so that the aluminium can be distributed evenly. The development of polymer resins is also evolved in the presence of many plasticizers that can maintain the polymerization process in order to have a long enough time so that all the grains are perfectly distributed. Plasticizer of phthalate compounds has been combined with the azide and silant which have long thickened time but has a higher combustion energy [4][19][20]. The propellant developed in LAPAN has already begun to adopt a composition with trimodal AP and conventional plasticizers (DOA, DOS, and TPB). Impeccable propellant performance is indicated by a low density of propellant (1.6 g/mL) [21].

2.4. Propellant process technology
Based on the propellant process technology, it is differentiated into a free standing and case bonded process. Preparation of propellant with a free standing system is done by pouring propellant separately from the rocket motor tube. The making of propellant with case bonded system is done by pouring the propellant directly inside the rocket motor tube. The process of making propellant with case bonded is applied to the mass production of propellant. The process of pouring propellant with free standing is still widely used for the purposes of research formulations [10]. The case bonded process of pouring propellant has many advantages because the resulting propellant has high reproducibility and homogeneity. The rocket developing countries have a proprietary pouring facility with free standing for research purposes of propellant formulation and case bonded pouring for mass production. LAPAN has built a production line based on case bonded propellant with capacity of 400 units per year by 2015 and started to be used to meet the rocket requirement in 2017 [13][14].

3. The Challenge of Mastery of Propellant Technology in Indonesia
Based on the development of propellant technology and its formulation in the world and in Indonesia, it turns out that Indonesia is running slowly compared to other countries that also develop rockets. The new, effective and efficient propellant formulation program must be built by LAPAN researchers because of the limitations of reference sources and technology transfer from other countries. The national need for rocket prototypes with increasing numbers and variants requires an effective and efficient formulation. The problems in propellant research in Indonesia are: a) limited exploration of new materials, b) limited data base of propellant materials; c) limitations of the propellant supporting (raw materials) industry; and d) limited production equipment to support new propellant formulations.

The development of propellant technology is very rapid, starting from AP/HTPB/Al propellant then added energetic material to improve energetic and ballistic propellant. The addition of energetic materials can significantly increase the rocket’s reach. For example, Roxel’s 122 mm diameter rocket can be increased in range from 38 km to 50 km by changing its raw material composition [21].

The rapid development of propellant formulations with the use of new, high-energy, reusable, and environmentally friendly materials should be adopted to keep pace with propellant technology. There are two lines of propellant development, i.e. AP/HTPB/Al based and new energetic based materials. It is necessary to accelerate the existing capability so that it is be able to equal the propellant research development in other countries. Propellant raw materials are strategic chemicals, however, are still imported from China and Korea. The import process is limited by the producing countries. The availability of raw materials is not only influenced by the inventory of the producers, but also the policies of the producing countries. Some providers do not provide complete specification data for propellant formulations. Technological manufacturing of HTPB and AP that have been mastered need to be developed into bigger scale to fulfill requirement of rocket R & D. AP production equipment capacity of 100 kg per week can be increased to 20 tons per year, to meet R & D propellant demand in LAPAN. Similarly, HTPB manufacturing technology needs to be scaled up from the laboratory scale to 2 tons per year [22].

Standardization of propellant products for R & D rockets is the basic needs to improve the quality of research results and produce products with industrial standard. The standardization efforts of
propellant products have been done with the construction of propellant production line in LAPAN. Another challenge is the need to establish a process control system and a strong quality of propellant feedstock. Propellant raw materials are easily damaged and degraded over time. Therefore, the quality control for imported propellant raw materials from various providers needs to be carried out periodically to ensure compliance with the requirements.

4. Direction of Propellant Research in Indonesia

Propellant research in Indonesia, especially composite propellants, is directed to sounding rockets and satellite orbiter. Composite propellant research aims to increase the propellant's energy with long pot life, the availability of propellant feedstock, and the upgrading of propellant-making equipment that meets the standard qualifications.

4.1. Increasing the propellant performance

The increased of propellant energy is carried out in two steps, namely the use of energetic materials and refinement of process technology. Development of propellants is done on the basis of AP oxidizers adjusting existing equipment. High-energy oxidizers such as TN AZ, RDX, and HMX require special equipment and handling. Energetic materials that are developed are stable materials. The study of the use of energetic binders should be directed to a relatively stable use of N-HTPB, which has good mechanical properties, rather than other energetic binder compounds. The GAP and PGN compounds are less stable than N-HTPB with equivalent combustion energy values. The use of N-HTPB binders does not require special propellant process equipment. Ferosen modifiers have been explored to regulate the propellant's fuel rate and are quite stable [23][24][25][26]. Materials plasticizer that has been explored is DOA, DOS, and TPB. The combination of conventional plasticizer material can increase the pot life of propellant stirring up to 4 hours. Development of the stable and relatively easy-to-handle plasticizers, which are TEGDN and TMETN, is commonly used to improve the plasticity of propellant double base. These compounds are considered the most stable compared to other energetic plasticizers such as BTTN [23][31].

Completion of process technology has been done using AP trimodal oxidator to get solid content’s maximum reach of 82.5%, and the propellant density can be boost from 1.5 to 1.6 gr/mL. To improve the solid content and density of propellant, it is necessary to develop the AP size of nano so that it can improve the solid content, to apply the high density ammonium perchlorate, and to apply trimodal ammonium perchlorate composition. The standard propellant used usually has a density of 1.7-1.8 gr/mL. The use of a high density AP type is required to increase the overall propellant density. The selection of round-shaped AP type with low porosity will increase the propellant density. The best AP has a maximum porosity of 5% [4][22].

Current propellant formulation research in Indonesia still focuses on increasing solid content through the use of trimodal AP and propellant reformulation with the characteristic of imported propellant raw materials. The propellant results still have relatively low specific impulses. Limitations of the characteristics of imported propellant raw materials are one of the main obstacles. Importable AP ingredients are low-medium grade (low purify, high porosity and low density). Imported HTPB material is medium grade with maximum solid loading content of 85%, the HTPB RB45 (special for propellant application) has solid loading content of 92% [1][10]. To overcome these problems, several steps are needed, namely pretreatment technology of AP and HTPB materials for improving quality, improved AP shape and size in order to obtain a high solid mass fraction, and the addition of energetic material to improve the specific impulse. Some suitable materials added are AND for oxidizing and N-HTPB for low sensitivity binders, compatible with HTPB binders, which are easily processed and safe, and have a good stability.

4.2. Independence of propellant raw materials program

The mastery of manufacturing technology of laboratory scale with 100 kg capacity is needed to fulfill requirement of propellant research. The AP has been used for LOCON self-contained rocket and successfully tested in 2007 in Pamengpeuk, Garut [27]. Similarly, the mastery of laboratory-scale HTPB technology has been tested for propellant binders with good results, having an Isp of up to 214
Material for standard manufacture of HTPB has been available in Indonesia. The mastery of propellant feedstock production needs to be developed into an industrial scale to ensure the supply of the propellant feedstock. Thus, the quality assurance of propellant feedstock can be obtained.

Increased propellant homogeneity is also necessary because so far propellants have low homogeneity. Low homogeneity is suspected due to the rapid propellant ripening process. Increased homogeneity has been attempted by using a double stirring system but not yet satisfactory. Increased homogeneity needs to be improved by developing plasticizer that has a long pot life, and then by adding accelerator compaction when needed. Combination of stirring and maturation arrangement is required.

The mastery of propellant technology is usually supported by the raw material industry. The main raw materials for composite propellants are AP and HTPB; the main raw material of double base propellant is nitroglycerin and nitrocellulose. These materials are strategic materials because they are produced only for propellant and munition products. Rocket developing countries usually build propellant feedstock industries such as AP, HTPB, and NG with government assistance because the users are the government itself. The existence of propellant feedstock industry can guarantee the support of continuous propellant feedstock with guaranteed quality. Indonesia has not yet had the industrial support for AP and HTPB material, the procurement of imported raw materials still involves some providers [15]. The limitation of obtaining raw materials and technical specifications makes it difficult in propellant formulations. Technology transfer of raw material AP, HTPB, nitrocellulose and nitroglycerin does not exist until now [29]. The impact is that the process of propellant formulation takes a long time and needs expensive costs [12]. The efforts to use new materials in Indonesia continue to be cultivated by LAPAN in order to reach the independence of propellant raw materials supply such as the use of asphalt and Castor oil for propellant binder [30][31].

Indonesia has developed prototypes of AP-making and pilot-scale HTPB. The propellant with AP and HTPB material has been tested for small size rocket (LOCON70 program) with good results in 2007. The development of AP and HTPB material independence needs to be increased to a large capacity so that in the future LAPAN will be able to use the AP and HTPB of its own production. The independence of raw materials production becomes important to ensure the continuity of the quality of raw materials, and to produce the standard results. Cooperation needs to be built by offering industry in building the propellant raw materials industry with the help of the government.

4.3. Improved equipment

The efforts to modernize propellant making techniques have been done with the use of propellant molding systems with case-based techniques. The use of a controlled agitation system has also been done to reduce stirring errors such as voids and so on. The use of production line systems for research has also been done to provide propellant with a high reproducibility.

The manufacture of propellant for ballistic rockets is almost entirely using case-bonded method, wherein the propellant is molded directly in the tube so that the propellant's homogeneity is better than the conventional method. The processing technology in Indonesia is still using conventional (free standing) methods for all propellant processes [1][10]. The propellant production line has already begun to be applied to small size propellants, and is still in the test phase. In the future, propellant development should use case-based method entirely to ensure better propellant homogeneity. In the case bonded technology, mixed propellant is poured to coated tube directly where the tube is rotated continuously. This technology can increase the homogeneity of the propellant significantly. In the conventional technology (free standing), mixed propellant is poured into the casting tube and then is released after curing process. The propellant is lined with heat isolator and inserted into rocket tube. This process needs a lot of steps and low homogeneity.
5. Conclusion
In developing the propellant technology in Indonesia, it is necessary to conduct a structured and systematic propellant research to be able to be in line with the industrial support and R & D policy. The problem that must be solved is how to obtain propellant that has high energy and homogeneity independently. To solve this problem, research and development of propellant formulations with energetic materials, process technology improvements, propellant material independence, and modernization of propellant process equipment are needed. To solve these problems, several steps are needed, namely pretreatment technology of AP and HTPB materials for improving quality, improvement of AP shape and size in order to obtain a high solid mass fraction, and the addition of energetic material to improve specific impulse. Some suitable materials added are AND for oxidizing and N-HTPB. The effort needs to be done is to research the using of energetic materials both for binder and plasticizer based on ammonium perchlorate oxidizer. Development of the process technology with trimodal AP and nano-sized aluminum usages is required to obtain the expected solid content and propellant density. The development of combined plasticizers and regulated mixing times can produce highly homogeneous propellants. With the use of propellant production line in propellant making research, propellant formulation can be improved so that in a few years the propellant development which is equivalent to the one of the developed countries can be obtained. The independence of raw materials becomes important to ensure the continuity of quality raw materials and research.

Acknowledgement
Special thanks addressed to Rocket Technology Center, LAPAN Indonesia through Sonda Rocket Program for financial support in doing this research with contract No. 082.01.06.3534.001.002.053A.524119.

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