Inventions of Acoustic Biopanel made from Palm Fiber and Coconut Fiber Waste for Passive Fire Protection

Eka Diana Mahira[1*], Ida Bagus Gde Primayatna[2], Anak Agung Ayu Oka Saraswati[3] and I Wayan Yuda Manik[4]

[1, 2, 3, 4] Bachelor of Architecture, Faculty of Engineering, Udayana University, Badung 80361, Indonesia
ekamahira@unud.ac.id

Abstract. Coconut and palm trees (palmyra palm) are an important part of the life of the Hindu community in Bali. On the other hand, the utilization process of both materials leaves waste that has not been optimally processed. Innovations in processing waste from both coconut (coir) fiber and palmyra fiber into products of economic value have been carried out to preserve the environment. However, products made from both wastes are flammable. This research aims to develop acoustic bio-panels using palmyra fiber and coconut (coir) fiber raw materials with a passive fire protection system by SNI no. 03-1736-2000. Each acoustic bio-panel was treated with a chemical compound solution, in the form of ammonium sulfate salt, etc. This research was limited to testing the material's durability against fire using the same subject design (treatment by subject design). The findings show that applying chemical compound solutions on bio-panel material increases the passive fire protection capacity while maintaining optimal acoustic performance. This research contributes to the creation of waste-based building materials with fire resistance.

Keywords: Acoustic Bio-Panel, Coir Fiber, Palmyra Fiber, Passive Protection, Ceremonial Waste.

1 Introduction

The utilization of traditional materials such as coconut and palm trees for building materials has been done for a long time. Palm leaves have been used as literacy media since the 9th century. It is known that Bali is nicknamed as the island of a thousand temples (*pura*). Bali is nicknamed the island of a thousand temples. This can be understood from the many temples from the smallest environmental unit to the environment on a macro scale. In the construction of temples, palmyra fiber obtained from palm trees is often chosen as a natural roofing material (see Figure 1). The choice of this material is due to its durability of up to 40 years of use. The fiber has the properties of non-perishability, environmental friendliness, and economic value [1]. The palmyra fiber used for roofing has gone through a process of selection and sorting, to obtain the best quality palmyra fiber.

S. Murtiyoso et al. (eds.), *Proceedings of the International Conference on Religious Architecture (ICRA 2024)*,
Advances in Social Science, Education and Humanities Research 923,
https://doi.org/10.2991/978-2-38476-420-4_23

Fig. 1. The palm fiber for temple roofing materials.

The same is true for coconut. Coconut is a versatile fruit that symbolizes the layers of life (*mahatala*) and living water (*pawitra*), so it is always present in every religious ceremony (*yadnya*) of Balinese Hindus [2]. Therefore, coconuts are an important part of ceremonial activities in every Hindu religion (*yadnya*) in Bali, from the leaves to the fruit (see Fig. 2).

Fig. 2. Api *Takep* and *Canang* by the part of the coconut tree that is used as a means of Hindu ceremonies.

For example, coconut (coir) is used as a means of *api takep* in traditional rituals in Bali, symbolizes the introduction of rituals and neutralizes any negative energy. *Api takep* is a fire made from two coir fibers that are crossed over each other to form a *tapak dara* (+) [3][2]. The part of the coconut fruit that has been removed is used as coconut daksina as a symbol of the strata of life and is also used as an ingredient in the tabuh rah performed before Hindu ritual ceremonies reach their peak. Then, there are also coconut leaves that are always used in every ceremony with canang decorated with flowers, leaves, and other materials. It is a symbol of prosperity, peace, purity, and fun in a performance. Coconuts are also used in Hindu wedding ceremonies as part of the *metanjung sambuk* ritual which represents the letting go of the ego [4].

The many uses of coconut in the lives of Hindu communities in Bali, as well as the use of palmyra fiber (palmyra fiber), produce waste that is reused by the community. Palmyra fiber waste is currently used by the community as a filter layer in infiltration sources, while some coconut waste is used as craft material. But even then it has not been optimally utilized, where some are burned (see Fig. 3).

Fig. 3. Suboptimal processing of palm fiber and coconut waste.

There are many breakthroughs in processing these two wastes as acoustic bio-panels. The characteristics of both materials exhibit excellent acoustic absorption, are readily available from nature, and are biodegradable and odorless. Based on experimental test results, coir fiber was shown to have good acoustic properties at low and high frequencies and to be an environmentally friendly product as an alternative to synthetic-based commercial products [5]. Coir fiber (coconut fiber) in particular has the characteristics of lightness and strength due to its high lignocellulose content. On the other hand, both materials have very poor resistance to fire, making them highly flammable. Several acoustic bio-panel recreations made from waste materials with fire protection have also been carried out, but generally focus on active fire protection systems [6][7]. Other studies related to the fire resistance of plywood have shown differences in the weight of combustion residues left behind by ammonium sulfate impregnation interventions [8].

Fire is the most alarming and most frequent hazard compared to other major hazards [9]. Fire accidents can occur in all types of buildings, such as housing, industry, hospitals, and other buildings and structures [10]. The causes of fires include low public awareness of fire risks, public reluctance to face and overcome fire risks, the lack of a fire protection management system, and the infrastructure of fire protection systems in buildings.

Fire is the leading cause of injury and death in the United States [11]. In New York, a fire broke out at the Triangle Shirtwaist Company, killing 146 employees due to inadequate occupational safety protection [12]. The number of fire disasters is increasing every year. Even in hot weather conditions and strong winds such as those that have hit since the beginning of 2024 have caused many fire incidents, especially in Bali. In fact, from January 2024 to June 2024 there have been 89 fire cases in Denpasar

City, Bali [13]. The number of fire incidents shows that fire is a serious problem for human life [14].

For this reason, a fire protection system is needed which is a system of building protection systems from fires used in materials, equipment and building security systems. The fire protection system aims to detect and extinguish fires as early as possible using equipment that is driven manually or automatically. Generally, the fire protection system used is active in the form of a fire protection system implemented by using equipment that can work automatically or manually, used by occupants or firefighters in carrying out blackout operations. In addition, this system is used in carrying out initial fire prevention.

Another fire protection system is a passive fire protection system. A passive fire protection system is a fire protection system that is formed or built through the regulation of the use of building materials and structural components, compartmentalization or separation of buildings based on the level of fire resistance, and protection of openings. Some parts of the building that use passive fire protection systems, including walls that act to limit the spread of fire in a room when a fire occurs, floors, roofs, ducting used for air distribution and electrical systems, beams and columns, piping systems, and control holes in buildings [15].

Creative efforts to use building materials to increase Passive Fire Protection power are carried out by using various materials that function as fire extinguishers or limit the flames. Fire extinguishing materials in terms of their form can be divided into 3 types including solid types: sand, soil, fire blankets, and chemical powder (dry chemical). Liquid types are water, foam, and volatile liquids. Gas types are Charcoal acid gas (CO2), limp gas (N2), argon gas, and other inert gases [16]. Some of these materials can dissolve in water and are not harmful to the environment, such as extinguishing agents in the form of dry chemical powder [17]. Dry chemical powder is a combination of Mono-ammonium phosphate and ammonium sulfate. Characteristics of dry chemical powder fire extinguishing media, including is a versatile fire extinguishing media, safe and widely used because it can extinguish class A, B, and C fires; can withstand heat radiation with fog (powder) particles; does not conduct electricity (nonconductive); dry chemistry is non-toxic (nontoxic) so it is not harmful to plants, animals, especially humans [18].

This research aims to create a waste-based building material that has a passive fire protection system (self-defense), through the creation of acoustic bio-panels made from palmyra fiber and coir fiber waste that is given a chemical compound solution. The use of these two wastes certainly provides economic value as well as for the ecological sustainability of the environment. This study will examine the effect of chemical compound coating composition on the level of resistance of the same test subject to fire.

2 Research Method

This research uses an experimental method to determine the effect of independent variables (treatment) on dependent variables (results) under controlled conditions so that the cause-and-effect relationship can be known quantitatively. Palmyra fiber, coir fiber, and coconut shell were the main raw materials in the study. The materials were chopped and formed into panels with an organic adhesive (tapioca) and pressed using a hydraulic press with a capacity of 10 tonnes by the same pressure so that they have the same density. The use of tapioca adhesive has the advantage of low cost, dry adhesion, and relatively little ash [19]. Seven test samples were made with the same size of (l x p x t) 20 cm x 50 cm x 5 cm. The measuring instrument used is a digital scale that has a precision level of 0.1 grams. (see Fig. 4)

The matrix used is a solution of fire-fighting chemical compounds based on Ammonium Phosphate, Ammonium Sulfate, and other ingredients from special concentrates dissolved in water. This chemical compound solution is the most effective extinguishing agent in reducing fire intensity and is environmentally friendly because it leaves no residue [20]. To determine the level of difference to the test sample, seven measurements of the sample were carried out with different treatments resulting in differences in residual combustion and the average of the measured data is presented here.

Fig. 4. Test subject and measuring tool.

2.1 Procedure and testing of passive fire protection system.

Palmyra fiber, coir fiber, and coconut husk are chopped and then added to the adhesive solution of tapioca starch and mixed evenly. The fiber was then moulded with a press and after drying it was divided into four parts with the same weight. Four parts of the test material were intervened by giving different chemical compound solution application treatments, ranging from one layer to three layers, and one test material did not receive chemical compound solution intervention as a control material. This experimental design uses a same-subject design (treatmen by subject design) with seven repetitions for each of the same treatments.

Furthermore, the four test materials were burned by the same fire size and the same time of 5 minutes. The independent variables of this study are the layers of chemical compound fire extinguishing solution (one layer, two layers and three layers in the field of experimental test objects). While the dependent variables are the level of passive fire protection ability, which is measured from the physical changes of the combustion process and the weight of the remaining combustion of the test object. The research design is depicted in Fig. 5.

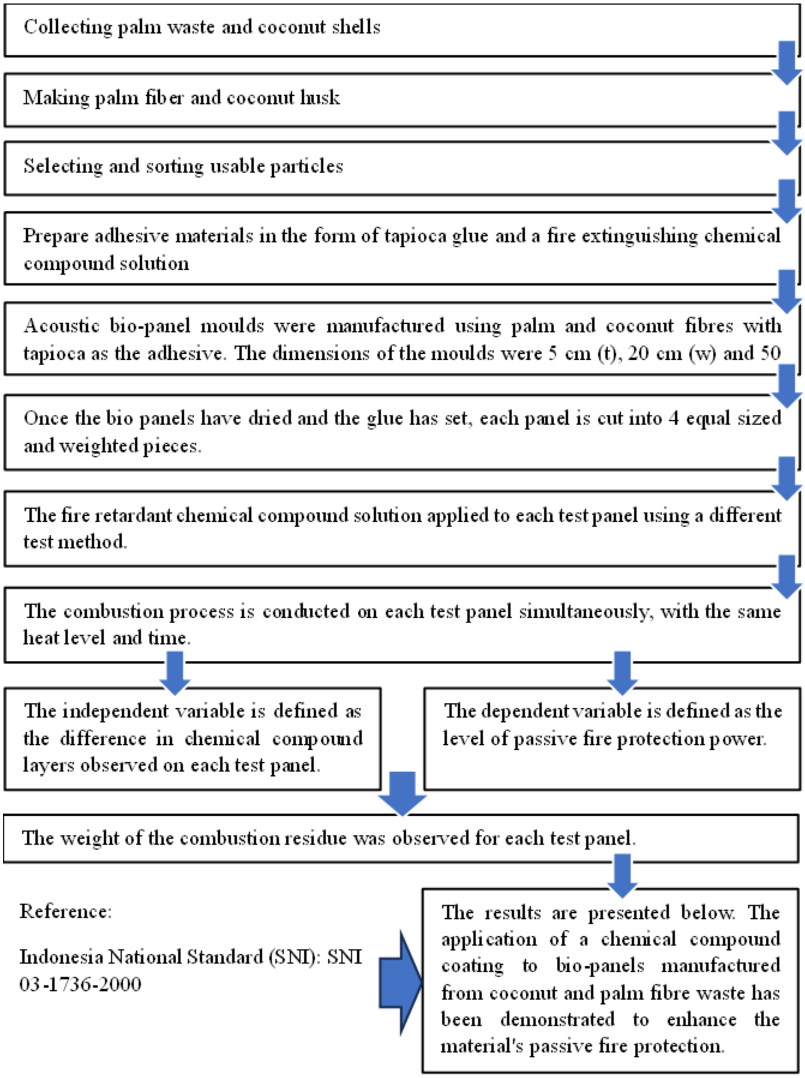

Fig. 5. Research design.

This biopanel testing standard uses SNI 03 - 1736 - 2000 on Planning Procedures for Passive Protection Systems for Fire Hazard Prevention in Buildings. Building materials used for building elements must meet the requirements of the combustibility test and the nature of the spread of fire on the surface (surface test) by applicable provisions on building materials. (Decree of the Minister of Public Works No.10/KPTS/2000 Year

2000). Building materials that are formed into building components (walls, columns, and beams) must fulfill the requirements for testing fire resistance properties expressed in terms of (30, 60, 120, 180, 240) minutes

The following building materials are classified as follows: non-combustible materials (grade I), non-combustible materials (grade II), fire retardant materials (grade III), semi-fire retardant materials (grade IV), and combustible materials (grade V). These requirements are ultimately linked to the material's level of resistance to thermal stresses (fire scenarios) that could cause the item to be exposed to fire. Such tests make it possible to evaluate fire propagation, and fire ignition resistance, and generate classification levels based on the results obtained from the tested items. The test conditions used in the scope of this study are detailed in Table 1.

Table 1. Test condition applied

Test Method	**Test Condition**			
	M4	**M3**	**M2**	**M1**
Testing configuration	3 layers of chemical compound solution	2 layers of chemical compound solution	1 layer of chemical compound solution	Without a chemical compound solution
Test time	5 minutes	5 minutes	5 minutes	5 minutes
Combustion chamber	Ambient air, open space	Ambient air, open space	Ambient air, open space	Ambient air, open space
Measured parameters	Final volume of combustion residue	Final volume of combustion residue	Final volume of combustion residue	Final volume of combustion residue
Tools	Stoves with the first flame level	Stoves with the first flame level	Stoves with the first flame level	Stoves with the first flame level

3 Result and Discussion

The four test configurations are shown in Table 1. Each configuration was tested 7 times using the same weight of 64.2 grams of test material. Each test material was burned for 5 minutes with the same flame size (see Fig. 6). The average weight of residual combustion produced in each configuration is in the range of 14.54 grams - 52.01 grams. The lowest average residual weight in the test specimen with test condition 1 (M1) was 14.54 grams. While the highest average residual weight with test condition 4 (M4) is 52.01 grams. The condition of the test specimen with the M1 method (1st configuration) has the smallest residual combustion volume which is in the range of 11.60 - 17.10 grams, with a burn percentage of 77.35% (22.65% percentage of resistance to fire). This condition is caused because each test object in the 1st configuration (M1) does not get the intervention of chemical compound solutions. Different conditions occur in the 2nd - 4th configurations (M2, M3, and M4), which get chemical compound interventions with different coating levels (M2: 1 layer - M3: 2 layers - M4: 3 layers).

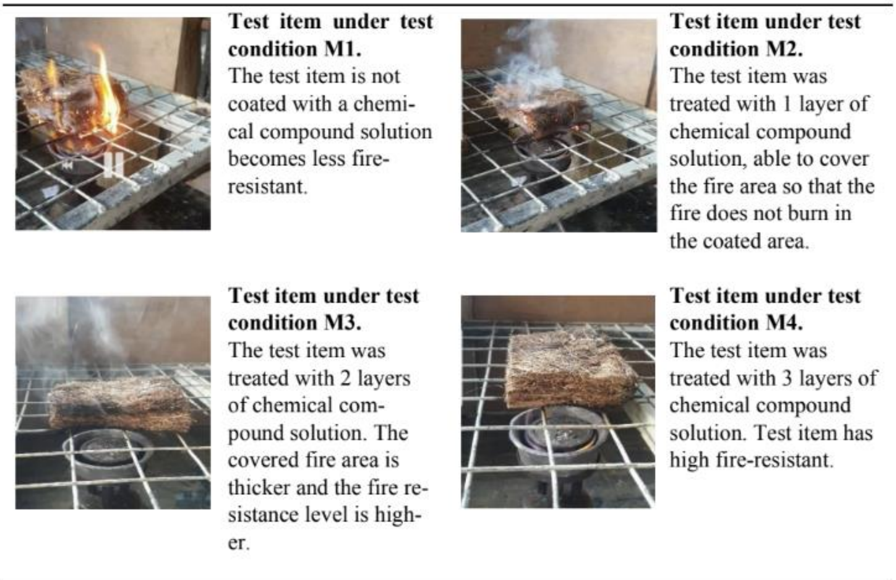

Fig. 6. The combustion conditions at four different treatments.

The experimental test data as shown in Table 2 shows the percentage of fire resistance level that varies for each configuration, which is indicated by the ratio between the weight of the test specimen after burning (the final residue of combustion) and the initial volume of the test specimen. The test specimen in configuration 1 (M1) has only 22.65% passive fire protection capability, while the test specimen in configuration 4 (M4) has 81.02% passive fire protection capability. This condition is seen from the residual weight (final weight) of each test specimen after the combustion process. In test condition M4, the residual combustion produced in seven trials had a weight range of 48.90 grams - 55.7 grams. In test condition 3 (M3), the resulting combustion residue weighs 40.60 grams - 46.40 grams. In test condition 2 (M2), the resulting combustion residue weighs 26.30 grams - 34.60 grams. While the test object that is not given a layer of chemical compound solution, has a residual combustion weight of 11.60 grams - 17.10 grams. The difference in final weight in each configuration can be caused by several things that become confounding variables, and in this study, these variables are ignored (see Fig. 7).

Table 2. Experimental results of passive fire protection ability of test items with chemical compound solution intervention

Test configuration	M4	M3	M2	M1
Initial wight of the test item (gram)	64,20	64,20	64,20	64,20
Final weight of the test item (combustion residue) (gram)				
Test -1 (BP-1)	55,70	41,20	34,60	13,40
Test -2 (BP-2)	54,20	46,40	30,30	17,10
Test -3 (BP-3)	51,10	42,10	27,40	14,90
Test -4 (BP-4)	53,80	47,30	33,10	15,60
Test -5 (BP-5)	50,70	44,50	31,50	12,90
Test -6 (BP-6)	49,70	40,60	29,70	11,60
Test -7 (BP-7)	48,90	43,30	26,30	16,30
Total weight	364,10	305,40	212,90	101,80
Average weight	52,01	43,63	30,41	14,54
Percentage of passive fire protection capability	81,02%	67,96%	47,37%	22,65%

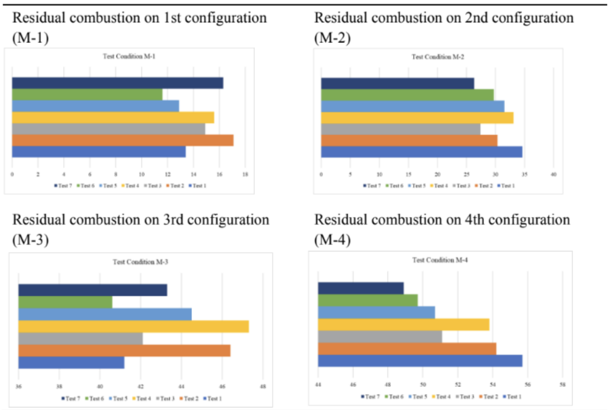

Fig. 7. Residual combustion variance at each test condition.

The use of gas stoves creates several confounding variables, such as uneven stove flames caused by dirty burner brass or clogged with combustion residue, and uneven gas flow supply. Wind is also one of the variables that can cause flame instability and affect the combustion residue. The test conditions are in an open space, so the influence of wind and ambient air cannot be avoided. This causes the fire in the furnace to move and hit areas that are not covered by the chemical compound solution. Another factor is the difference in the level of homogeneity of the mixture and the density of the test specimen. The material selection process, mixing process, and molding process of the specimens were done conventionally, so the specimens did not have the same density and were less homogeneous. Test specimens with a denser waste material mixture component have a heavier combustion residue than specimens with a lower density. Several previous studies have shown that the density of acoustic biopanels made from palmyra or coir fiber waste affects the acoustic properties of the material. Therefore, further research is needed to see the correlation between the level of fire resistance and the acoustic properties of biopanel.

4 Conclusions and Suggestion

This study shows the success rate of passive fire protection on acoustic biopanels made from coir fiber and palmyra fiber treated with a layer of anti-fire propagation chemical compound solution in accordance with SNI 03 - 1736 - 2000. It was found that the increase in passive fire protection percentage is equivalent to the thickness of the chemical solution layer on the biopanel. The percentage of passive fire protection power in each test condition is as follows 81.02% in M4 (test specimen receiving 3 layers of chemical compound solution), 67.96% in M3 (receiving 2 layers of chemical compound solution), 47.37% in M2 (receiving 1 layer of chemical compound solution), and 22.65% in M1 (no intervention). Fire resistance is optimised in test specimens that receive more layers of anti-fire propagation chemical compounds.

Although the acoustic properties of palmyra fiber and coir fiber were not observed in this study, previous studies have shown that both materials have good acoustic properties at low and high frequencies and can be used as alternatives to synthetic-based commercial products. Providing a coating of anti-fire propagation chemical compounds can be the basis for the development of material technologies that are ecological and inexpensive, yet have passive fire protection capabilities. Therefore, it is suggested that further research is needed to prove the durability of biopanels through experimental tests to see the combustion time and heat value that can be retained. The research can also be extended with the effect of chemical compound coating with adhesive solution and the resulting acoustic ability.

Acknowledgments. This research was conducted with funding from the superior research fund of the Udayana University study programme in Fiscal Year 2024. The research team came from the Bachelor of Architecture Study Programme of Udayana University, Bali. All researchers declare that there is no potential conflict of interest. Not applicable as this article did not involve human participants. This article does not contain any studies with human participants performed by any of the authors.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Zulfian, Sajidin, M: Kajian Tentang Kemungkinan Pemanfaatan Bahan Serat Ijuk sebagai Bahan Penyerap Suara Ramah Lingkungan. Rekayasa Kimia & Lingkungan **7**(2), 94–98 (2009)
2. Putri, N.K.A.K., Agustina I. A. S, Dewi N.L.S.: Makna Filosofi Buah Kelapa dalam Upakara Yadnya. Majalah Ilmiah Untab **19**(2), 221 – 225 (2022)
3. Adiputra, N., Wardi I.N.:Kelapa dalam Budaya Bali serta Upaya Pelestariannya. Jurnal Bumi Lestari **15**(1), 87–91 (2015)
4. Salendra I.W.: Fungsi dan Makna Api serta Air dalam Upacara Ritual Yajnya (Perspektif Agama Hindu). J Widya Katambung **7**(2), 1–12 (2016)
5. Zulkarnain R.Z., Nor M.J.M.: Noise Control Using Coconut Coir Fiber Sound Absorber with Porous Layer Backing and Perforated Panel. Am J Appl Sci 7, 260–264 (2010)
6. Ratnayanti, K.R., Hajati, N.L., Trianisa, Y..: Evaluasi Sistem Proteksi Aktif dan Pasif sebagai Upaya Penanggulangan Bahaya Kebakaran pada Gedung Sekolah X Bandung. Rekayasa Hijau **3**(3), 179–192 (2019)
7. Harianja E, Toruan M, Hasibuan A.: Analisis Penerapan Sistem Proteksi Aktif Dalam Upaya Pencegahan dan Penanggulangan Bahaya Kebakaran di PTPN IV Unit PKS Pabatu, Serdang Bedagai. J Healthc Technol Med **6**(2), 134–146 (2020)
8. Nur R., Irmis S.: Studi Daya Tahan Kebakaran Kayu Lapis Struktural dengan Pelaburan Amonium Sulfat Berkosentrasi 10%, 35% dan 60%. Menara J Tek Sipil 1, 144–160 (2006)
9. Lestari, R.A., Oginawati K.: Analisis Potensi Ledakan dan Kebakaran Primary Reformer sebagai Unit Proses Produksi Amonia di PT. X. Jurnal Rekayasa Kimia dan Lingkungan **11**(2),72-81 (2016)
10. Kowara R, Martiana: Analisis Sistem Proteksi Kebakaran Sebagai Upaya Pencegahan dan Penanggulangan Kebakaran. J Manaj Kesehat 3, 69–84 (2017)
11. Ta, V.M., Frattaroli, S., Bergen, G., Gielen, A.C.: Evaluated community fire safety interventions in the United States: A review of current literature. J Community Health 31, 176–197 (2006)
12. Campbell, R., Levenstein, C.: Fire and Worker Health and Safety: An Introduction to the Special Issue. NEW Solut A J Environ Occup Heal Policy 24, 457–468 (2015)
13. Supartika P.: 89 Kasus Kebakaran Terjadi Sejak Januari 2024 di Denpasar, Kebakaran Gudang Paling Banyak. In: Bali.tribunnews.com. https://bali.tribunnews.com/2024/07/21/89-kasus-kebakaran-terjadi-sejak-januari-2024-di-denpasar-kebakaran-gudang-paling-banyak#google_vignette, last accessed 2024/07/11
14. Supriyanto, Nugraha, R, Ginanjar R Kajian Sistem Proteksi dan Penanggulangan Kebakaran di Stasiun Pengisian Bahan Bakar Umum (SPBU) di Jalan Kedunghalang Raya, Kota Bogor Utara tahun 2018. J Mhs Kesehat Masy 1, 130–139 (2018)
15. Badan Standarisasi Nasional SNI 03-1736-2000, Tata Cara Perencanaan Sistem Proteksi Pasif untuk Pencegahan Bahaya Kebakaran pada Bangunan Rumah dan Gedung. Jakarta (2000)
16. Ramli, S.: Petunjuk Praktis Manajemen Kebakaran (Fire Management). Dian Rakyat, Jakarta (2010)
17. Su, C., Chen, C., Liaw, H., Wang, S.: The Assessment of Fire Suppression Capability for the Ammonium Dihydrogen Phosphate Dry Powder of Commercial Fire Extinguishers. In: “2014 ISSST”, 2014 Int. Symp. Saf. Sci. Technol. Procedia Engineering, pp 485–490 (2014)
18. Mróz, K., Hager, .I, Korniejenko, K.: Material solutions for passive fire protection of buildings and structures and their performances testing. In: Int. Conf. Ecol. new Build. Mater. Prod. ICEBMP 2016. Procedia Engineering, pp 284–291 (2016)

19. Susilawati N, Rahmaniar: Pengaruh Penggunaan Tepung Tapioka Dalam Pembuatan Lem Tegel Karet. J Din Penelit Ind 29, 84–91 (2018)
20. Chanpirak, A.: The Effect of Ammonium Sulphate on Fire Retardancy and Thermal Decomposition Mechanism of Rubberwood. Naresuan Univ Eng J 13, 1–9 (2018)