DESIGN OF UPVC THIN CORRUGATED ROOFING SHEET FOR INDONESIAN MARKET

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ABSTRACT

Corrugated roofing sheet from Unplasticized Polyvinyl Chloride (UPVC) material has good prospects in Indonesia. The advantage of UPVC material is corrosion resistant, lightweight, not easily broken and economic. This paper describes the design of thin corrugated roofing sheet from UPVC material. The design includes determining the shape of the roof profile and its strength as a roof structure. Flammability properties, tensile strength and modulus of elasticity of roofing material are obtained from flammability and tensile tests of the roof sample. Roof production is carried out using an extrusion injection molding machine in a manufacturing plant at Tangerang, Indonesia. The result of the design is a corrugated thin roofing sheet from UPVC material with an effective roof width of 750 mm which has five crests and four valleys.

KEYWORDS: UPVC, Corrugated Roof, Roof Design, Sheet

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INTRODUCTION

Corrugated roofing sheets, commonly used throughout the world for industrial, commercial and other buildings are made of metals. Metal materials that are widely used for roofing sheets are steel and aluminum. The steel sheet material for the roof is usually coated with zinc and aluminum alloys (55% Al-Zn) for corrosion protection layer. The disadvantage of this type of roof in the application for factory and warehouse buildings on the coastal and other corrosive areas such as fertilizer factory is the degradation of the material due to corrosion [1-3]. In Indonesia, metal roofing sheets are available in various types of profiles and price, depending on the thickness of the roof and the protective layer.

Corrugated roofing sheets that are more economical than metal roofs are made of fiber reinforced mortar composites [4]. The reinforcing fibers commonly used are asbestos, glass fiber, and natural fiber [5, 6]. The main weakness of the mortar roof is its extra weight, brittleness due to its impact, hazard potential, and relatively short durability. On the other hand, it has the advantage of resistance to corrosion [7-11].

In order to reduce the weaknesses of metal and mortar roofing sheets, they are filled with polymeric material. The advantage of the polymeric materials are light weight, not easily broken, sound absorption, and resistant to corrosion [12-14].

In Indonesia, polymeric roofing sheet materials, particularly Glass Fiber Reinforced Polymer (GFRP), have been widely used in factories and warehouse buildings located in corrosive areas since 2008 [15]. The main

drawback of the GFRP roof are low resistance to fire and relative expensive. This deficiency can be mitigated by using Rigid Polyvinyl Chloride or Unplasticized Polyvinyl Chloride (UPVC). The UPVC provides benefit in terms of lower price and higher resistance to fire than GFRP materials [16].

In Indonesian market, hollow corrugated roofing sheets from UPVC material are available for more than five years. The hollow roofing sheets price is still more expensive than the price of metal roofing sheets and hence marketing is still limited [17]. These deficiencies can be filled by corrugated roofing sheets from UPVC solid material which is lighter and provides more economical value than hollow roofing sheets.

The advantages of the roofing sheets from UPVC material are corrosion resistant, fire retardant, noise insulation, lightweight, durable and reasonably price competitive. Furthermore, selection of grey color similar to the color of metal roofing sheet will result in cooler roof temperature since it has higher ability to reflect sunlight. This is supported by research studies on reducing the heat gains of corrugated roofing sheets made of aluminum and galvanized steel conducted by Kic and Müller [18]; and a study of highly reflective roofing sheets by Yuan et al [19] and Uemoto et al [20]. The selection of fillers and additives in a mixture of PVC resin in the right amount will provide sufficient strength and rigidity as a roof structure against loads from wind and rain. The study of the strength of corrugated roofing sheets when receiving static and dynamic wind force, whether thrust or lift and cyclone wind forces have been carried out by Koshy and Arul Jayachandran [21] and Narayan and Mathews [22-24]. These studies can be used as a reference for designing solid roofing sheets from UPVC material that will be aimed at increasing market opportunities in Indonesia. This paper describes the design of thin corrugated roofing sheets from UPVC material.

METHOD

The design process is illustrated in Figure 1. The Product Design Specification (PDS) of the solid thin corrugated roofing sheets from UPVC material contains technical requirements of the roof designer. In parallel, flammability and tensile tests of the UPVC material samples are carried out to get flammability properties, tensile strength and modulus of elasticity based on UL 94 and ASTM D638 standards. The specimen and equipment for tensile and flammability tests are shown in Figure 2.

Figure 1: Design Process of the UPVC Thin Corrugated Roofing Sheet.

Figure 2: Tensile and Flammability Test Specimens and Equipment: (a) Tensile Test Specimens, (b) Universal Machine, (c) Flammability Test Specimens, (d) Flammability Test Equipment.

Considering the product design specification and material flammability, the conceptual design of the roof is drafted. The embodiment and detail designs of the roof are then determined by utilizing the mechanical properties of the test results. The last step involves trial production of the solid thin corrugated roofing sheets from UPVC material using the extrusion injection machine in a manufacturing plant at Tangerang, Indonesia.

DESIGN OF THE UPVC THIN CORRUGATED ROOFING SHEET

The main formula of the roofing sheets material consists of 100% wt. PVC resin, 50% wt. Calcium Carbonate (CaCO_3) filler combined with some small parts of additives and pigment. Tensile and flammability properties of the UPVC sample are summarized in Table 1.

Table 1: Tensile and Flammability Tests of the UPVC Sample

No.	Properties	Value
1	Flammability (UL 94)	V_0
2	Tensile strength (σ_b) and elongation at break (ϵ)	$27.3 \pm 2.5 \text{ MPa}$ and 20%
3	Modulus of elasticity	$2,960 \pm 160 \text{ MPa}$

The PDS of a UPVC thin corrugated roofing sheet is described as below:

- The corrugated roofing sheets must not transmit sunlight.
- Ability to reflect most of the sunlight.
- The material must be fire retardant and more economical than the GFRP composite material and also corrosion resistant.
- Able to accommodate very high rainfall 350 mm/h and can be installed up to the roof slope of 5 degrees.
- Able to withstand an installer-man, wind lift force, and a combination of wind and rain loads at the same time between 1.2 m purlins distance.

The conceptual design of the UPVC thin corrugated roofing sheet is arranged based on a combination of all sub-functions listed in Table 2. The results of the combination of all sub-functions will form an overall function that meets the PDS. There will be many variants of solution, so priorities need to be ranked based on technical and economic considerations. The first ranked option is considered as the first priority which will lead to the chosen conceptual design.

Table 2: Sub-Functions of the UPVC Thin Corrugated Roofing Sheet

No.	Sub-Function	Solution Alternatives		
		1 st Solution	2 nd Solution	3 rd Solution
1	No transmission of the sunlight	Solid roofing sheet	Hollow roofing sheet	-
2	Reflects most of the sunlight	Light grey color	Dark grey color	White color
3	Better fire retardant and more economical than GFRP and also corrosion resistant	UPVC material	CPVC material	Mortar composite
4	Ability to flow heavy rainwater at a low slope roof	Trimdek corrugation	Integrity corrugation	-

There are many variants of conceptual design that are a combination of the first to fourth sub-function solutions. These variants include,

- 1st conceptual design: 1.1 - 2.1 -3.1 - 4.1.
- 2nd conceptual design: 1.1 - 2.2 -3.1 - 4.1.
- 3rd conceptual design: 1.1 - 2.1 -3.2 - 4.1.
- 4th conceptual design: 1.1 - 2.1 -3.1 - 4.2.
- 5th conceptual design: 1.2 - 2.1 -3.1 - 4.1, and so on.

Conceptual design is determined by assessing each alternative solution based on technical and economic considerations. The first conceptual design variant was chosen. Solid roofing sheet is preferred over hollow roofing sheet because the roof production is easier and the amount of mass is lighter, so it is more economical [17]. Light grey roof color is preferred than dark grey because it reflects more sunlight [18-20]. Meanwhile, if the selected white color will cause the possibility of light transmission. This condition is undesirable. The material properties for blocking sunlight can be fulfilled by adding more white pigment. This will cause the cost of raw materials to be less economical. CPVC material was not chosen because it is more expensive than UPVC. Also, mortar was not chosen because it can be easily broken and heavy [4-6]. UPVC material was chosen because it is sufficient to provide physical-mechanical properties as a roof structure, as shown from the result of tensile test and the price is quite economical [16, 17]. Also, UL 94 test result shows that the flammability of UPVC (V₀ class) is better than GFRP (HB class). Trimdek and Integrity profiles, both have a large capacity to accommodate rainwater with a low roof slope [25]. Trimdek's profile was chosen because it has five crests instead of than four in Integrity profile. The fasteners of Trimdek's profile is more regular than Integrity profile where it is on the left and right sides and in the middle of the crests. Based on this description, the selected conceptual design should be the solid roofing sheet from UPVC material with color of light grey and the corrugated profile is Trimdek. The thickness chosen is 1.5 mm.

The embodiment design of the cross section of the UPVC thin corrugated roofing sheet is shown in Figure 2. The profile contains five crests and four valleys. The effective width is 765 mm, the crest height is 29 mm and the roof thickness is 1.5 mm. According to Lysaght [25] this Trimdek profile is able to flow heavy rainwater up to 400 mm/ h with a low slope of up to 5 degrees.

- Maximum bending moment at the both fixed support,
- $M_{\max} = (PL/8) + (w_1 L^2 / 12) = (736 \times 1.2 / 8) + (20 \times 1.22 / 12) = 112.8 \text{ Nm}$.
- Normal stress at the both fixed support,
- $\sigma = (M_{\max} c / I) = (112.8 \times 0.01921 / 0.161114 \times 10^{-6}) = 13.5 \times 10^6 \text{ N/m}^2 = 13.5 \text{ MPa}$
- $< \sigma_b = 25 \text{ MPa} \rightarrow \text{ok}$ (the safety factor, $sf = 1.9$).
- (2) The normal stress from the combination of rainwater and wind force,
- Maximum bending moment at the both fixed support, $M_{\max} = w_2 L^2 / 12 = (690 \times 1.22 / 12) = 82.8 \text{ Nm}$.
- Normal stress at the both fixed support,
- $\sigma = (M_{\max} c / I) = (82.8 \times 0.01921 / 0.161114 \times 10^{-6}) = 9.9 \times 10^6 \text{ N/m}^2 = 9.9 \text{ MPa}$
- $< \sigma_b = 25 \text{ MPa} \rightarrow \text{ok}$ (the safety factor, $sf = 2.5$).
- (3) The punch shear stress from the wind uplift,
- Area of the one roofing sheet on the 1.2 m between two purlins support, $A = 0.765 \times 1.2 = 0.918 \text{ m}^2$
- Wind uplift force, $F_w = W_w \times A = 679.83 \times 0.918 = 624 \text{ N}$.
- There are six screws fastener, but only four screws that are assumed fixed the roof from wind forced uplift. The punch shear stress,
- $\tau_s = F_w / A_s l = (F_w) / (4\pi D t) = \{(624) / [(4\pi) (0.015) (0.0015)]\} = 2.24 \times 10^6 \text{ N/m}^2 < \tau_s = 15 \times 10^6 \text{ N/m}^2 \rightarrow \text{ok}$ (the safety factor, $sf = 6.7$).

Deflection Analysis of the Roof Structure

- The limit ratio between the maximum deflection and the span length is determined from the allowable strain $\epsilon_{\max}$ of 1%, and so $\sigma = (M_{\max}) (c) / (I) = E \epsilon_{\max}$
- $(w_2 L^2 / 12) (0.01921) = EI \times 1 \times 10^{-2}$
- $w_2 = (12 \times 1 \times 10^{-2} \times EI) / (0.01921 L^2) = 6.24675 EI / L^2$
- $\delta = (w_2 L^4 / 384 EI) = \{(6.24675 EI L^2) / (384 EI)\} = 0.0162676 L^2$
- $\delta/L = 0.0162676 L = 0.0162676 \times 1.2 = 0.01952 = 1/51$
- The maximum deflection at the middle span from the rainwater and the wind forces,
- $\delta = (w_2 L^4 / 384 EI) = \{(690 \times 1.24) / (384 \times 2,800 \times 10^6 \times 0.161114 \times 10^{-6})\} = 8.26 \times 10^{-3} \text{ m} = 8.26 \text{ mm}$.
- The ratio between the maximum deflection and the span length is,
- $\delta/L = 8.26 \times 10^{-3} \text{ m} / 1.2 \text{ m} = 1/121 < (1/51) \rightarrow \text{ok}$
- The maximum deflection, $\delta = 8.26 \text{ mm} < \text{crest height of } 29 \text{ mm} \rightarrow \text{safe against the possibility of overflowing rainwater}$.

The final design chosen is in the form of solid thin corrugated roofing sheet from UPVC material with Trimdek profile that clearly meets all PDS requirements. No light transmission and a good reflection of sunlight are fulfilled by the selection of the grey light color of UPVC material. This UPVC material is not only corrosion resistant, but also has better fire resistant and is cheaper than GFRP material. Its ability to discharge rainwater with high rainfall rate of 400 mm/h at a low slope of 5 degree is fulfilled by Trimdek's profile. The cross section of Trimdek corrugated roof has an effective width of 765 mm, peak height of 29 mm and thickness of 1.5 mm with five peaks and four valleys. The detailed design of the roof structure with the purlins distance of 1.2 m shows that the roof structure is able to withstand an installer-man, the combined force of rain and wind, and the exerting lift force from the wind. The designed roof has met the technical requirements equivalent to metal roofing sheet, but has the advantage of corrosion resistant and economic value. Thus, it has an excellent opportunity to fill the market needs in Indonesia.

TRIAL PRODUCTION OF THE UPVC THIN CORRUGATED ROOFING SHEET

The last step is the trial production of the solid thin corrugated roofing sheets from UPVC material using the extrusion injection machine in a manufacturing plant at Tangerang, Indonesia. Preparation of the production trial begins with preparing a mixture of raw materials which are mixed homogeneously. The chosen formula of the UPVC material consists of 100% wt. of PVC resin, 50% wt. of CaCO_3 filler, and some small parts of additives and pigment. The homogeneous powder mixture of raw material is placed in a hopper. From the hopper, the raw material enters the heated barrel cylinder. The heat produces a temperature of around 218-225 degrees celsius which transform the raw material into a liquid phase. Inside the heated barrel cylinder, there is an extruder screw that serves to push the liquid material toward the injection nozzle. Liquid material is injected into the mould to produce a continuous plate sheet. The temperature of the slabs decreases with the additional distance travelled. Furthermore, the plate sheet which was still hot enough about 205 degrees celsius was formed by a set of Trimdek profile forming rollers. The profile sheet that is formed will continue to cool by a water chiller and solidify so that it forms a thin solid corrugated roofing sheet of Trimdek profile. The trial production of the UPVC thin corrugated roofing sheet is shown in Figure 3.

Figure 3: Trial Production of the UPVC Thin Corrugated Roofing Sheet.

CONCLUSIONS

This paper describes the design of thin corrugated solid roofing sheets from UPVC material. The roof is designed for carrying loads of a man roof installer, a combination of wind and rain loads and wind uplift. The distance between the two roof support of purlins is designed at a distance of up to 1.2 m.

The resulting design is a solid roofing sheet from UPVC material with light grey color. The roof will have Trimdek corrugated profile with five crests and four valleys with effective width of 765 mm, crest height of 29 mm and thickness of 1.5 mm. The Trimdek profile with a low slope of up to 5 degree is chosen since it is able to flow heavy rainfall with a rate of up to 400 mm/h.

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